AOVET North America

Principles in Equine Fracture Management Course

LECTURE ABSTRACTS

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Principles in Equine Fracture Management Course

THURSDAY LECTURE ABSTRACTS
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Bone Structure, Vascularity and Function

Kenneth A Johnson, MVSc PhD FACVSc Diplomate ACVS Diplomate ECVS
Bone Structure, Vascularity and Function
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Learner Objectives:

• Describe how the gross and microscopic structure of bone facilitates the load carrying capacity of normal long bones
• Explain how the blood supply of bone can be compromised by fracture or open reduction and internal fixation
• Describe one clinically relevant example of how Wolff's Law applies to bones in animals or humans
Bone Structure

The skeletal system provides support and protection for all the other body organs. It also acts as a reservoir for minerals, fat and haematopoiesis, and as levers and fulcrums for the musculature. The entire canine skeleton consists of about 319 bones that can be classified according to their shape as being long (limb), cuboidal (carpus and tarsus), flat (head and ribs), irregular (vertebrae and pelvis) and sesamoid bones. The shape of individual bones is largely under genetic control, but bone shape is also modified by loading. On a structural basis, bone is either cortical (compact) or cancellous (trabecular) and the mechanical and biological differences between these two have important implications for the holding power of orthopaedic implants and the rate at which fractures progress to union. Cortical bone is mainly found in the diaphysis and flat bones, but it also contributes a thin shell around the cuboidal and irregular bones such as the vertebrae. Cancellous bone is mainly found in the epiphyses and metaphyses of long bones and within the cuboidal bones. The internal three dimensional lattice 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, are 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][1]

![Medullary and Periosteal Supply][2]
The flow of blood to cortical bone is about 2-7 ml/minute/gram of bone, and to cancellous bone is 10-30 ml/minute/gram of bone tissue. At the local level, flow is controlled by vasoactive substances. When systemic blood pressure falls below 80 mmHg, then flow of blood to cortical bone is temporarily shut down. The haematocrit of blood flowing through bone is not the same as in the central circulation. It can be in the range of 50 -75%, and tends to be lower in regions of higher flow rates.

**Function**

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

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

**References:**

Fracture Classification and Biomechanics

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

- Accurately describe a fracture
- Explain Unger's classification and the reason for its development
- Recognize the different forces acting on a fracture and have a basic understanding of the different fracture patterns generated by those forces
- List the different forces acting on a fracture and be able to select a fixation method that addresses those forces
- Explain the concept of viscoelasticity and anisotropy
- Recognize high and low energy fractures and explain the biomechanical and biological consequences associated with each
There are two types of forces that 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”:

*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:

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<th>Rotation</th>
<th>Bending</th>
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Reference:
Bone Healing Under Stable and Unstable Conditions

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

- Define the different types of bone healing
- Discuss how rigid internal fixation versus biological fixation affects bone healing and describe other factors that may lead to complications
- Apply direct and indirect bone healing to clinical case examples and case outcomes
Bone Healing under Stable and Unstable Conditions
Amy S. Kapatkin, DVM, MS, Dip ACVS
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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.

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 (> 200µm but < 1mm) bone healing:

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

Mark D. Markel, DVM, PhD, Diplomate ACVS
BMP, Growth Factors and Bone Substitutes
Mark D. Markel, DVM, PhD, Diplomate ACVS

Learner Objectives:

- List the principal functions of bone substitutes
- Describe the most important bone graft substitutes available to orthopedic surgeons and their optimal uses
- Explain the functions of BMP
- Describe the pathways through which BMP exerts its action
- Recognize the important BMP’s currently in use clinically
ENHANCED BONE REGENERATION

It should be noted that the use of bone substitutes and BMP’s is mainly derived from experimental animal models, which are geared to provide data to support human use. The actual number of case reports for treatment in animals and any objective studies in clinical settings is extremely low, as most published studies regard experiential data.

Methods to improve fracture healing are an ongoing research area both as it applies to human beings and to various animal species. Clearly, enhancement of fracture healing for rapid restoration of skeletal function could greatly benefit the equine patient. Both biological and mechanical methods to accelerate fracture healing have been described. Long standing methods have included the use of autogenous cancellous or cortical bone grafts applied to the fracture site to enhance healing, although both autogenous and allogeneic demineralized bone matrix had been used to facilitate bone repair (Figure 1). A significant number of bone substitutes have been developed over the past 10 years, with many available on the commercial market. Figures 2 and 3 outline the optimal characteristics of bone substitutes and the properties of the most common substitutes available on the market. A number of growth-promoting substances that are part of the fracture repair process have been identified and are generally categorized into 2 groups: one (growth factors) and two (immunomodulatory cytokines). Although these factors have not been investigated to any great extent for equine fracture repair applications they have been extensively evaluated in various animal models, which will be reported here.

BONE SUBSTITUTES

Demineralized bone matrix (DBM), which has been shown to have an osteoconductive and osteoinductive potential provides no structural strength, and its primary use is in a structurally stable environment. DBM also revascularizes quickly and acts as suitable carrier for autologous bone marrow. It does not evoke any appreciable local foreign body immunogenic reaction as antigenic surface structure of bone is destroyed during demineralization. The biologic activity of demineralized bone matrix is presumably attributable to proteins and various growth factors present in the extracellular matrix and made available to the host environment by the demineralization process. The osteoinductive capacity of demineralized bone matrix can be affected by storage, processing, and sterilization methods and can vary from donor to donor. Possible limitation of demineralized bone matrix is that different batches may have different potencies because of the wide variety of donors used to supply the graft.

Collagen as an osteoinductive material is due to its osteoconductive property and when it is used in combination with osteoconductive carriers like hydroxyapatite or tricalcium phosphate. These composites are mixed with autologous bone marrow, which subsequently provides osteoprogenitor cells and other growth factors.
CERAMIC-BASED BONE GRAFT SUBSTITUTES

Hydroxyapatite is a biocompatible ceramic produced through a high-temperature reaction and is highly crystalline form of calcium phosphate. The nominal composition of this mixture is \( \text{Ca}_{10} (\text{PO}_4)_6 (\text{OH})_2 \) with a calcium-to-phosphate atomic ratio of 1.67. The most unique property of this material is chemical similarity with the mineralized phase of bone; this similarity accounts for their osteoconductive potential and excellent biocompatibility.

The ideal pore size for a bioceramic should be similar to that of spongy bone. It has been demonstrated that microporosity (pore size <10 μm) allows body fluid circulation whereas macroporosity (pore size >50 μm) provides scaffold (Pore size-100-200 μm and porosity-60-65%) for bone-cell colonization. An ideal pore size diameter of 565 μm is reported as the ideal macropore size for bone ingrowth compared to a smaller size (300 μm). However, in another study by Kuhne et al, the optimal size of the pores was found to be 500 μm. In an experimental study in goats with porous calcium phosphate ceramics, Toth et al found that the ceramic when mixed with autograft in the ratio of 70 (ceramic): 30 (autograft) were effective for anterior cervical interbody fusion, Johnson et al found that hydroxyapatite alone gave poor results.

The nominal composition of TCP is \( \text{Ca} (\text{PO})_3 \). It exists in either α or β-crystalline forms. The rate of biodegradation is higher when compared with HA. Degradability occurs by combined dissolution and osteoclastic resorption. Tricalcium phosphate implants have been used for two decades as synthetic bone void fillers in orthopaedic and dental applications in humans. The small particle size and interconnected sponge like microporosity are believed to improve osteoconductive properties and promote timely resorption concomitant with the process of remodeling. Zhang et al reported bone formation with bone marrow stromal cells (BMSCs) and β-tricalcium phosphate (β-TCP) as bone substitute implanted in rat dorsal muscles. Cutright et al found 95 per cent absorption of tricalcium phosphate ceramic implants in rat tibias 48 days postoperatively with extensive bone growth and marrow reformation. Cameron et al observed both the toxicity and the bone-ingrowth potential of TCP in canine model and reported no untoward tissue or systemic reaction when implanted in cancellous bone; it was rapidly infiltrated with bone and slowly resorbed. Recombinant human bone morphogenetic protein (rhBMP)-2 with beta-TCP is a promising composite having osteogenicity and efficient enough for repairing large bone defects.

Properties of the calcium phosphate cement with the surrounding milieu have been pointed out as a relevant parameter, among others. High microporosity in CPC is directly correlated with the exposed surface, and therefore an elevated dissolution in the pores where the level of stable critical level of free calcium ions and possibly free orthophosphate ions might trigger cell differentiation into osteogenic lineage. In addition, through a dissolution–precipitation process, the development of a bone-like mineral layer might initiate bone formation either by mimicry with the bone mineral structure or by the presence of osteogenic compounds (for example bone morphogenetic proteins) contained naturally in body fluids that might have concentrated at the newly formed mineral layer.

Calcium sulfate graft material with a patented crystalline structure described as an alphahemihydrate acts primarily as osteoconductive bone-void filler that completely resorbs as newly formed bone remolds and restores anatomic features and structural properties. It is biocompatible, bioactive and
resorbable after 12 weeks. Significant loss of its mechanical properties occurs upon its degradation; therefore, it is a questionable choice for load-bearing applications.

**BMPs**

- **Overview**
  - BMPs belong to the TGF-B superfamily
  - BMP 2, 4, 6, and 7 all exhibit osteoinductive activity
  - BMP 3 does not exhibit osteoinductive activity
- **Mechanism**
  - Osteoinductive, leads to bone formation
  - activates mesenchymal cells to transform into osteoblasts and produce bone
- **Signaling Pathways and Cellular Targets**
  - BMP targets undifferentiated perivascular mesenchymal cells
  - a transmembrane serine/threonine kinase receptor that leads to the activation of intracellular signaling molecules called SMADs.
  - SMADs are primary intracellular signaling mediator
  - currently eight known SMADs, and the activation of different SMADs within a cell leads to different cellular responses.
- **Clinical applications**
  - use to promote bone healing

Since the discovery of bone morphogenetic proteins (BMPs) as bone inductive proteins by Urist, many investigators have shown that BMPs induce stem and mesenchymal cell differentiation into osteogenic precursors. From a physical and chemical point of view, BMPs are proteins secreted by cells, which act as ligands for receptors present on the plasma membrane of different types of cells (autocrine and paracrine effects), thus establishing cell and tissue organization.

The general role of BMPs in the process of bone formation during the development and repair of fractures has been well established. BMPs are capable of inducing the formation of bone tissue in ectopic sites and in critical-sized bone defects in several animal models. The study of BMPs began in the 1960s, with the observation that demineralized bone matrix had the capacity to induce endochondral bone formation in subcutaneous and intramuscular pockets in rodents. This research group subsequently isolated a low-molecular weight glycoprotein from bone and demonstrated that it promoted bone formation when ectopically located. Induction of ectopic bone formation has been consistently demonstrated with the use of rabbit, canine, bovine, and native human xenogenic demineralized bone matrix implanted in mice.

Bone morphogenetic proteins belong to the transforming growth factor β (TGF-β) superfamily. It has been shown that the N-terminal region controls the stability of the processed mature protein and that the downstream sequence adjacent to the cleavage site determines the efficiency of cleavage. BMPs consist of dimers whose chains are connected by disulfide bonds, and this dimerization is a prerequisite for bone induction. More specifically, a BMP is a dimeric molecule with two polypeptide chains held together by a single disulfide bond, and a primary structure 50% similar to that of TGF-β. However, TGF-β are found in the bone matrix in higher amounts than BMPs, being classified as cytokines rather than morphogenes. Hence, while BMP-2 induces or enhance the expression of
alkaline phosphatase and osteocalcin, TGF-β1 dramatically inhibit the expression of osteocalcin and the activity of alkaline phosphatase.

Osteogenesis comprises a sequential cascade with three critical phases: migration and mitosis of mesenchymal cells, differentiation of mesenchymal cells into chondroblasts, cartilage formation and, finally, substitution of cartilage by bone. These sequential events are triggered by the binding of plasma fibronectin to the demineralized bone matrix, enhancing adhesion and proliferation of mesenchymal cells at 3 days after implantation. The sequence of morphogenetic events in response to the demineralized bone matrix mimics the initial events of skeletal morphogenesis in embryos and of bone repair in adults.

As a signaling molecule of the TGF-β superfamily, BMP-2 binds to a type II specific receptor present on the cell membrane and recruits a type I receptor, forming a complex. These receptors are transmembrane serine/threonine kinase proteins that self phosphorylate after the formation of the BMP-receptor II-receptor I complex and acquire the ability to phosphorylate Smad proteins, a family of TGF-β transducers.

Recent studies have identified specific BMP antagonists (i.e., noggin and chordin) and members of the DAN family (i.e., gremlin). Such antagonists bind to BMP with the same affinity as their specific receptors, blocking signal transduction and thus decreasing bone formation. The effects of BMPs on osteoblasts and periosteal cells have been thoroughly studied in order to obtain a better understanding of the action of BMPs at the cellular level. In general, there is an increase in DNA synthesis activity and in the transcription of genes involved in the synthesis of bone matrix proteins. rhBMP-2 blocks the differentiation of osteoblast precursor cells into myoblasts or adipocytes. Since many types of BMPs can induce endochondral ossification, chondroblasts should also be natural targets of these proteins. In fact, many BMPs have been shown to induce cell proliferation and synthesis and activity of alkaline phosphatase of chondroblasts and chondrocytes of the growth plate. The nature of the chondrocytes for in vitro culture has a significant role in the effect of BMPs, showing that the stimuli for these proteins are tissue-specific.

Two recombinant proteins are now commercially available in humans, rh-BMP-2 and rh-BMP-7. These products have been investigated as an alternative to bone autografting in a variety of clinical situations, including spinal fusions, internal fixation of fractures, treatment of bone defects, and reconstruction of maxillofacial conditions. Rh-BMPs are delivered to the bone-grafting site as part of a surgical procedure; a variety of carrier and delivery systems has been investigated. Carrier systems, which are absorbed over time, function to maintain the concentration of the rh-BMP at the treatment site, provide temporary scaffolding for osteogenesis, and prevent extraneous bone formation. Carrier systems have included inorganic material, synthetic polymer, natural polymers, and bone allograft. The rh-BMP and carrier may be inserted via a delivery system, which may also function to provide mechanical support. For interbody spinal fusion, delivery systems have included interbody fusion cages. The carrier and delivery system are important variables in the clinical use of rh-BMPs. For example, different clinical applications will require different dosages of rh-BMP with different carriers and delivery systems.

The InFUSE® system consists of rh-BMP-2 on an absorbable collagen sponge carrier. Through April 30, 2011, the FDA had received hundreds of reports of adverse events associated with INFUSE Bone Grafts, including severe back pain, leg pain, difficulty breathing and implant failure.
However, a number of studies released by Medtronic-sponsored doctors promoted several “off-label,” or unapproved, uses of the product. According to these studies, using INFUSE in ways not approved by the FDA produced good results with little or no side effects. Doctors guided by these Medtronic-sponsored studies used INFUSE in procedures not approved by the FDA, including upper-back spinal fusion surgery, jaw reconstruction and posterior lumbar interbody fusion (PILF) surgery, a surgical technique that accesses the spine through the back.

On July 1, 2008, the FDA issued a Public Health Notification to health care providers regarding life-threatening complications arising from off-label use of INFUSE in cervical (upper-back) spinal fusion. People who suffered these events needed respiratory support with intubation, medication or tracheotomy – a surgical procedure where a small incision is made in the neck and a tube is inserted into the opening to allow breathing.

However, all the clinical and experimental studies of BMP’s have demonstrated the potential capability of BMP and other carriers to act as osteoconductive scaffolds. Figure 4 describes the most promising osteoconductive scaffolds and their biologic properties with regard to the enhancement of fracture healing. In the coming years, it is highly likely that tremendous advances in enhancement of fracture healing will occur both from a mechanical and from a biologic perspective.

Future biosynthetic bone implants may obviate the need for autologous bone grafts. There is increasing interest in combining an osteoconductive protein in an osteoconductive carrier medium to facilitate timed-release delivery and/or to provide a material scaffold for bone formation. Further, advances in tissue engineering, “the integration of the biological, physical and engineering sciences” will generate new carrier constructs that repair, regenerate and restore tissue to its functional state. These constructs are likely to encompass additional families of growth factors, evolving biological scaffolds and incorporation of mesenchymal stem cells. Ultimately, the development of ex vivo bioreactors capable of bone manufacture with the appropriate biomechanical cues will provide tissue-engineered constructs for direct use in the skeletal system. Finally, as researchers continue to find new materials and biologic approaches to bone repair, the future of bone graft substitutes continues to be an expanding topic of interest.

References:


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**Figure 1.**

**Autograft/Allograft Characteristics**

<table>
<thead>
<tr>
<th>Bone graft</th>
<th>Structural Strength</th>
<th>Osteoconduction</th>
<th>Osteoinduction</th>
<th>Osteogenesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autograft</td>
<td>Na</td>
<td>++</td>
<td>+++</td>
<td>+++</td>
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<tr>
<td>Coralline</td>
<td></td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Cortical</td>
<td></td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Allograft</td>
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<td>++</td>
</tr>
<tr>
<td>Coralline</td>
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<td>++</td>
<td>+</td>
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<tr>
<td>Frozen</td>
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<tr>
<td>Preserved</td>
<td></td>
<td>++</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

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**Figure 2.**

**Bone Graft Substitutes**

- Osteoconductive
- Osteoinductive
- Biocompatible
- Bio-resorbable
- Structurally similar to bone
- Easy to use
- Cost-effective

---

**Figure 3.**

**Bone Graft Substitutes**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Grafs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osteoconduction</td>
<td>Calcium Sulphate</td>
</tr>
<tr>
<td></td>
<td>Calcium phosphate cements</td>
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<tr>
<td></td>
<td>Ceramics</td>
</tr>
<tr>
<td></td>
<td>Collagen</td>
</tr>
<tr>
<td></td>
<td>Synthetic polymers</td>
</tr>
<tr>
<td>Osteoinduction</td>
<td>DESM</td>
</tr>
<tr>
<td></td>
<td>BMP-2</td>
</tr>
<tr>
<td></td>
<td>Growth factors</td>
</tr>
<tr>
<td></td>
<td>Genetic therapy</td>
</tr>
<tr>
<td>Osteogenesis</td>
<td>Bone marrow aspirate (BMA)</td>
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<tr>
<td>Combined</td>
<td>Composite grafts</td>
</tr>
</tbody>
</table>

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**Figure 4.**

**Osteoconductive Scaffolds**

<table>
<thead>
<tr>
<th>Type</th>
<th>Grafs</th>
<th>Osteoconduction</th>
<th>Osteoinduction</th>
<th>Osteogenesis</th>
<th>Advantages</th>
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</thead>
<tbody>
<tr>
<td>Bone</td>
<td>Autograft</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>Availability in many forms</td>
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<tr>
<td></td>
<td>Allograft</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Bio-materials</td>
<td>DESM</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>Supplies osteoconductive BMPs, bone graft biomaterial ready for delivery system</td>
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<tr>
<td></td>
<td>Collagen</td>
<td>2</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Ceramics</td>
<td>TCP</td>
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<td>0</td>
<td>0</td>
<td>Bio-compatible</td>
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<tr>
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<td>Hydroxyapatite</td>
<td>1</td>
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<td>0</td>
<td>Bio-compatible</td>
</tr>
<tr>
<td></td>
<td>Calcium phosphate cement (CPC)</td>
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<td>0</td>
<td>0</td>
<td>Some initial structural support</td>
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<td>Composites</td>
<td>β-TCP/DESMA composite</td>
<td>3</td>
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<td>Ample supply</td>
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<tr>
<td></td>
<td>BM/membrane composite</td>
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<td>2</td>
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</table>

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Implants and Principles of Plate Application in the Horse

Prof. em. Dr. Dr. h. c. Joerg A. Auer, Dipl. ACVS, ECVS
Implants and Principles of Plate Application in the Horse
Prof. em. Dr. Dr. h. c. Joerg A. Auer, Dipl. ACVS, ECVS

Learner Objectives:

- Describe the different implants and the instruments used to apply the implants
- Appreciate the differences between the implants
- Explain the principles of the application of the implants
Implants and Principles of Plate Application in the Horse
Prof. em. Dr. Dr. h. c. J.A. Auer, Dipl. ACVS, ECVS
Past Chairman AOVET

The special instruments and implants that are discussed in this course and that you are using in practical exercises were developed by trauma surgeons together with instrument companies. The AO Foundation has a contract with Synthes and uses exclusively their implants and instruments, which represent a uniform functional system whose components are well coordinated and which can be expanded anytime, depending on the desires and the necessities of the surgeon. All the instruments were developed because of a specific need. Replacement of Synthes instruments by other similar instruments may not guarantee correct use and correct implantation of implants. Synthes will not take any responsibility for errors carried out because of substitution of implants or instruments with other possibly less expensive, but similar ones. Synthes implants are manufactured from high quality rust-free 316 L steel, containing chrome, nickel and molybdenum. A high standard in quality control by the affiliated producer assures manufacturing of top quality instruments and implants. These implants and instruments may be slightly higher in price than their competitors, which simply copy the Synthes system. But it is important for everybody to know that from every implant and instrument a certain percentage goes towards development and research of new improved systems and devices.

Most of the instruments and implants were developed for human use, but could be easily adapted to our veterinary purposes. Nevertheless, some implants such as the 3.5 mm cortex screw were primarily developed for the veterinary market (originally the DOG SCREW) and then adopted by the humans as well. Therefore, both profit from each other.

**Instruments:** The instruments used for screw implantation were discussed in detail in the previous lecture. Instruments needed for plate application include plate benders, the bending irons, and the tension device.

**Bending press:** For the large plates used in equine fracture treatment the bending press is favored over the bending pliers, which are used in small animal fracture treatment. The anvil and the support block for the plate to be bent have a complimentary contour to facilitate bending of the plate without creating damage to the plate (Fig. 1). Therefore the plate to be contoured is placed towards the bottom of the support block if a convex bend has to be created (Fig. 2) and towards the top if a concave bend has to be created (Fig. 3).

The support block can be adjusted closer or further away from the anvil to assure that bending is performed by applying vertical pressure on the horizontally positioned handle. This provides the greatest control over the amount of bending (Fig- 4). If the handle is oriented in an oblique upward direction (Fig. 5), a lot of force has to be exerted that frequently results in an over-bending all at one location (Fig. 6). It is important to apply as little force as possible and bend the plate over a larger area.
Bending irons: are used to apply rotational distortions to the plate to facilitate adaptation of the plate to the anatomical configuration of the bone to which the plate is to be applied. This type of contouring is more difficult physically and technically.

Tension device: The tension device was instrumental in applying axial compression to the original round-hole plates. With the development of the dynamic compression plate (DCP), it became partially obsolete. However, there are some indications where the tension device is still important, such as in fetlock arthrodeses.

The plate is first fixed to one fragment with several screws. Subsequently the device is hooked to the opposite end of the plate and attached proximal to the plate to the bone with a cortex screw. With the help of a wrench, the desired amount of axial compression can be applied. Once reached, cortex screws are inserted in neutral position and tightened to maintain the axial compression across the fracture.

Other instruments used for osteosynthesis are the general instruments used for the approach to the bone and the set of instruments such as periosteal elevator, osteotome, chisels, mallet, etc. used to prepare the surface of the bone.

Implants: The most frequently used implants for osteosynthesis are screws and plates. In addition to that, cerclage wires and occasionally Kirschner wires are used, sometimes in combination with other implants. The main emphasis in this presentation is given to the different plates and the instruments used to implant them properly.

Screws: Their “anatomy” and mode of action was discussed in the previous handout.
Recently the locking head screws were developed. These screws have a relatively thick shaft covered by thin and narrow threads. The screw head also contains threads that engage the threaded portion of the “combi-hole” of the Locking Compression Plates (LCP) (see below).

**Plates:** Plates are again distinguished according to the size of screw they accept. One distinguishes the 4.5, 3.5, 2.7, 2.0 and the 1.0 mm plates. Up to recently the most widely used plates were the DCP (Dynamic Compression Plates) which are manufactured for the 4.5 & 5.5 mm cortex screws in two sizes, the broad and the narrow, and the 3.5 mm plates as regular and re-enforced 3.5 mm plates respectively.

The LC-DCPs have a special design – at any cross-section of the plate, the same amount of metal is present - and contour much easier than the DCP (Figs. 7&8). To achieve this, the plates were undercut between the plate holes (Figs 7&8). The LC-DCP plate holes are of the “DCU”-type (DCU = Dynamic Compression Unit). These holes allow compression to be exerted from both sides, which means, that the plate doesn’t have center any more. Additionally the holes allow a greater extent of screw angulation along the long axis of the plate (± 45° compared to ± 25°, which the DCP allows). The plates can be purchased as stainless steel or titanium implants. The price for the stainless steel implants is the same as for the regular DCP’s. The only new instrument required for this implant system is either the universal drill guide or the plate double drill guide (neutral and load). A 3.5mm broad and a 5.5mm Equine LC-DCP has been developed for veterinary use. The latter was replaced by the 5.5mm LCP (see below).

![Fig. 7: 5.5mm LC-DCP used as fetlock arthrodesis plate for horses.](image1)

![Fig.8: Bone healing under a LC-DCP](image2)

Additional plate types are the T-plate, third tubular plate and reconstruction plate. Using special clamps, the plate may be placed onto a bone to allow its fixation to the bone by means of screws.

The Locking Compression Plate (LCP): The LCP concept includes a plate with special plate holes: the “combi-Holes” (Fig 8). The hole is oblong (figure 8 shape) and contains two portions: one side with the conventional DCU (Dynamic Compression Unit) hole – as in the LC-DCP – and the other side with a threaded round hole. The threads complement the threads on the screw head of the special locking screw, whereas regular screws can be inserted using routine technique through the DCU-side. The joining area of the two portions is open. The locking head screws can only be inserted perpendicular to the plate and they do not press the plate down onto the bone. The locking mechanism prevents any micro-movement of the screw head in the plate hole, which is a significant step forward. The LCP is also referred to as an internal fixator, as when it is applied with locking head screws only, a 2mm gap is maintained between the bone and the plate. Therefore the LCP does not make contact with the underlying bone. To achieve contact with the bone, which is important in equine fracture treatment, the first screws to be inserted through the plate have to be cortex screws, or the plate has to be pressed onto the bone with the push-pull-device.

The plate contains a beveled end at one end that allows plate insertion through a small incision and sliding of the plate along the periosteum of the fractured bone. The thin beveled end separates the soft tissues from the periosteum. The other end has a rounded appearance that allows locking head screw insertion closer to the bone. The screws may subsequently be implanted through minimal invasive stab incisions. At that end a stacked combi-hole is located that allows insertion of either a locking head screw or a conventional cortex or cancellous screw, the latter two with a slight angulation away from the joint if needed.
The plate has a center and the combi-holes are arranged with locking component pointing towards the center of the plate and the DCU component towards the ends of the plate (except the stacked combi-hole at the rounded end). The plate has undercuts as the LC-DCPs.

Fig. 8: Veterinary LCP with the stacked combi-hole on one end and a beveled end at the other end

Because of its qualities as a rigid internal fixator technique this plate can be applied in special situations, as well as in routine cases. This implant is presently in the process of replacing the other ones. Everything that can be done with the DCP and the LC_DCP can also be done with the LCP. Therefore this represents a “universal” plate and the newcomer to plating is encouraged to purchase this plate only. The price is slightly higher than the DCP and LC-DCP. The real difference in price are the screws. The LCP can be applied with only cortex screws, which mimic the DCP function. I can also be applied with only locking head screws, resulting in an expensive fixation. A third option is the “hybrid” application, where 2 locking head screws are applied to either side of the fracture and the remaining plate holes are filled with cortex screws. This how it is done usually.

Special instruments for LCP

Fig. 9: Threaded drill guide
Fig. 10: Push – pull device to press the plate onto the bone
Fig. 11: Torque-limiting device

Principles: The following principles for plate application in adult horses have been developed:

1. Plates are the strongest in tension
2. Usually 2 plates are applied at 90° relative to each other. Exceptions: to this rule are the ulna in adult horses and special fractures in foals
3. The plates should span the entire bone. To achieve this they can be staggered
4. All plate holes are filled with screws, except when there is a gap in the bone in this location
5. The screws are usually inserted perpendicular relative to the long axis of the bone
6. The plates are arranged such that the screws of one plate cross the bone between two screws of the other plate
7. Every screw crossing the fracture plane is inserted in lag fashion.

The sequence of steps during plate application is as follows:
1. Bone is approached such that fixation can be achieved through one incision
2. The fracture is (anatomically) reduced
3. The fracture is repaired with 1 or 2 lag screws (3.5mm or 4.5mm)
4. The first plate is contoured to the tension side of the bone
5. The first screw is inserted towards one end of the plate
6. The next screw is inserted towards the other end of the plate usually under axial compression
7. The second plate is contoured and applied with some screws
8. All screws crossing the fracture plane are inserted in lag fashion

The application of a LCP the initial 4 steps are identical. Contouring is concentrated between the plate holes and over the DCU parts of the holes to prevent distortion of the threaded portion of the combi-holes.

5’. The plate is applied to the bone with the help of the push-pull device inserted through the DCU part of the last hole on either end of the plate
6’. Cortex screws are inserted at strategic locations at both sides of the fracture plane and tightened. One or two may be inserted in the load position. The push-pull devices are removed.
7’. The second plate is contoured and applied as point 5’ and secured with some screws
8’. The desired number of locking head screws is applied to both plates (the last holes on both sides of the plates and one near the fracture plane). Additional locking head screws are optional.
9’. The remaining plate holes are filled with cortex screws, which may have to be angled because of the locking head screws that must be inserted perpendicular to the plate.

Literature:


Sites and Technique for Harvesting Bone Grafts in the Horse

Mark D. Markel, DVM, PhD, Diplomate ACVS
Sites and Technique for Harvesting Bone Grafts in the Horse
Mark D. Markel, DVM, PhD, Diplomate ACVS

Learner Objectives:

- Describe the principal indications for the use of bone grafts
- List four (4) common locations for harvesting bone grafts
- Identify the principle factors leading to successful bone graft survival and transplantation
Bone grafts have been used for augmentation of bone repair for more than 100 years in human surgery. They have been, and continue to be, used for correction of segmental bone loss secondary to tumor or trauma, for improvement of fracture repair, for treatment of osteomyelitis, and for revision of total joint arthroplasty. Bone grafts are replaced by host tissues via a process known as creep substitution. Autogenous bone has been shown to be superior to all other types of grafts, but because of limited supply and difficult in reconstructing large segmental defects of bone, allogeneic bone and bone substitutes have been developed for application in some circumstances. In horses, abundant sources of autogenous bone are found in the ilium, sternum, and proximal tibia; therefore, sources of bone augmentation beyond autogenous graft have been explored to only a limited degree. This presentation describes the biologic events and outcome related to the use of autografts in bone.

FUNCTIONS OF BONE GRAFTS

The three principal functions of bone grafts include osteogenesis, osteoinduction and osteoconduction. Osteogenesis is whereby the cellular elements with a donor graft survive transplantation and synthesize new bone at the recipient site. Osteoinduction is new bone realized from the active recruitment of host mesenchymal stem cells from the surrounding tissue, which differentiate into osteoblasts. This process is facilitated by the presence of growth factors within the graft, principally BMPs. Osteoconduction is the facilitation of blood vessel incursion and new bone formation in a defined passive trellis structure.

TYPES OF BONE GRAFTS

Cancellous Bone

Cancellous bone is the form of bone graft most commonly used in the horse, for two important reasons. First, abundant cancellous bone is available in the horse and little morbidity results from harvesting the bone. Second, cancellous bone has the greatest osteogenic ability of any of the bone grafts. It is also a potent osteoinductive agent. Because of its wide use, cancellous bone harvesting and grafting in the horse will be discussed in detail. However, other graft types to be aware of include cortical bone grafts (rarely used in horses) but also bone marrow aspirates, which largely comprise an osteogenic role.

Surgical Technique

To limit total surgery time, it is recommended that a second surgical team be used to harvest the graft. The graft should be harvested so it will be immediately available for application to the host bed. This ensures maximum cellular survival and osteogenic capabilities. If there is a lag time from the time of harvesting to the time of graft application, the graft
should be stored in blood soaked sponges, since exposure to air or saline-soaked sponges may cause increased cell death. In addition, the graft should not be directly treated with antibiotic solutions, since antimicrobial agents may also decrease cellular survival. When the host bed is ready for graft application, the bone graft should be embedded into the host bed and only lightly packed. If the graft is packed too vigorously, excessive pressure in the site may decrease cell survival and revascularization. During application of bone grafts, it is imperative that the fracture bed and graft be stable in order to allow for bone ingrowth.

**Harvesting Sites**

Three principal sites are used for bone graft harvesting in the horse: the sternum, the tuber coxae, and the proximal tibia (Fig. 1). All three are readily accessible, although a greater volume of graft can be harvested from the sternal and tuber coxae than from the proximal tibia. Although previous reports have indicated that the holes used to access the cancellous bone in the proximal tibia might create added stress that results in fracture, a recent report states that carefully placed drill holes can eliminate this potential complication.

**Sternebrae.** The sternum has many advantages as a source of cancellous bone for grafting. First, the site is easily accessed, particularly when the horse is in dorsal recumbency. Second, the sternum is dependent and hidden, so if infection or incisional dehiscence occurs, drainage is easily achieved and a scar is not visible. Third, the site can provide a large amount of high-quality bone graft. The one major disadvantage of the site is that if a horse is in lateral recumbency for the repair of a proximal forelimb fracture, two surgical teams may impede each other during the harvesting of the graft.

For the approach, a straight median incision is made over the sternum, beginning approximately 20 cm cranial to the xiphoid, and extending 10 cm caudally. The pectoral muscles on both sides of the hyaline cartilage of the sternum are elevated for 1 to 2 cm abaxial from the sternum with a periosteal elevator. Large rongeurs are used to remove a 2 cm long section of hyaline cartilage, until cancellous bone is seen. If cancellous bone is not discovered after removing a depth of 1 to 2 cm of hyaline cartilage, the procedure is repeated 1 to 2 cm cranial or caudal to this site. A large curette is used to remove as much cancellous bone as needed. If necessary, as many as six or seven sternebrae can be accessed for cancellous bone harvesting (Fig. 2). Care should be taken not to incorporate hyaline cartilage into the bone graft. The muscle, subcutaneous tissues, and skin are apposed routinely. The only complication that has been reported with the use of this donor site is dehiscence of the incision, although the wound will heal secondarily without difficulty.

**Tuber Coxae.** A straight to slightly curved skin incision is made over the tuber coxae through the subcutaneous tissue and fat pad to the bone. A 1 to 2 cm bone plug is removed from the tuber coxae to gain access to the cancellous bone within the tuber coxae (Fig. 3 and 4). Cancellous bone is harvested with a curette, carefully avoiding the thin inner cortex of the ilium so as not to fracture it. The cortical plug is replaced after cancellous bone harvesting, and the fat pad and subcutaneous tissues are closed routinely. The skin should be apposed with tension sutures, and a stent applied over the site to protect the incision.
from excessive trauma in recovery or after surgery. The only significant complication that can occur secondary to using this site is traumatic dehiscence of the wound after surgery. The wound can be difficult to manage, since drainage from this location is not easily achieved.

**Proximal Tibia.** A straight incision is made over the proximal medial tibia through the skin, subcutaneous tissue, and periosteum. The marrow cavity is accessed with a 4.5 or 5.5 mm drill bit, and bone marrow is removed with a curette. The deep tissues and skin are closed routinely, and a stent bandage is applied over the incision. The only significant complication that has been reported with this technique is fracture of the tibia secondary to stress concentration of the screw hole or holes. This complication can be minimized by limiting cortical holes to less than 5.5 mm.

![Figure 1.](image1)

![Figure 2.](image2)
Principles of Screw Application and Function in the Horse: Plate Screw, Position Screw and Lag Screw

Alan J. Ruggles, DVM Diplomate, ACVS
Principles of Screw Application and Function in the Horse:
Plate Screw, Position Screw and Lag Screw
Alan J. Ruggles, DVM Diplomate, ACVS

Learner Objectives:

- Describe the types and functions or orthopedic screws for internal fixation in the horse
- Integrate the principles of screw function in the clinical management of equine fractures
- List the proper technical aspects of the lag screw technique
Screw Type
There are many types of screws available. Screws are named by their design not their function. Because of this it is important to think of screws in both ways, essentially as a noun and a verb if you will. In general, cortex, cancellous and locking screws are used for the vast majority of orthopedic repair in veterinary medicine. Some additional types of screws are available which are used for specific repairs but will not be discussed in this lecture. In our laboratories you will be using cortex and locking screws.

Screw Function
The purpose of bone screws are to compress fracture fragments together (lag function), maintain the position of fragments relative to each other (position function), compress a plate to a bone (plate function) or maintain a fixed angle between the screw and the plate (locking function). On occasion screws can have more than one function based on the typed and manner used.

The lag screw principle to provide intra fragmentary compression across a fracture line is a basic technique in orthopedic procedures. By placing a screw in lag fashion we are able to compress bone fragment together to provide stability by counteracting shear forces (sliding relative to each other). While this technique is an essential part of orthopedic repair it by itself is no sufficient to protect a repair form other forces such as bending and torsion (rotation around an axis). The lag screw technique can be used on independent screws or those placed through plates. Cortex screws and cancellous screws can be used in lag fashion and locking screw does not provide intra fragmentary compression and cannot be used in lag fashion.

Both cortical and cancellous bone screws can be used in lag fashion. The type of screw chosen and diameter of the screw threads dictates the equipment necessary. The basic method of placing a 3.5 mm cortical screw in lag fashion is as follows. Remember the outside diameter of the threads of a 3.5 mm screw is 3.5 mm diameter and the shaft diameter of the screw is 2.5 mm.

Procedure for placing a cortex screw in lag fashion
1) Drill a 3.5 mm glide hole with a 3.5 mm drill through the 3.5 mm tap sleeve across the fracture portion of bone to or just past the fracture line.
2) Place the 2.5 mm drill insert (3.5 mm outer diameter) into the glide hole and drill the thread hole with a 2.5 mm (bronze) drill completely through the parent bone. The 2.5 mm drill insert will center the thread hole.
3) Use the countersink to provide a beveled on the surface of the fracture fragment so the screw head can complete contact the bone for maximal
compression and even distribution on the screw head.
4) Use the depth gauge to obtain the correct length of screw prior to tapping the thread hole.
5) Using the 3.5 mm tap and 3.5 mm tap sleeve (to protect soft tissues) cut the threads in the thread hole by turning the tap two times forward and one time back, to move the swath material up the tap and prevent tap breakage.
6) Select the proper length screw and tighten to provide intra fragmentary compression.

Procedure for placing a cancellous screw in lag fashion
1) Drill the thread hole the entire length of the bone 3.2 mm for a 6.5 mm screw or 2.5 mm for a 4.0 mm cancellous screw. (In hard bone a glide hole of the appropriate diameter may need to be drilled).
2) Use the countersink to provide a beveled on the surface of the fracture fragment so the screw head can complete contact the bone for maximal compression and even distribution on the screw head.
3) Use the depth gauge to obtain the correct length of screw prior to tapping the thread hole.
4) Using the 6.5 or 4.0 mm tap and appropriate tap sleeve (to protect soft tissues) cut the threads in the thread hole by turning the tap two times forward and one time back, to move the swath material up the tap and prevent tap breakage.
5) Select the proper length screw, with the appropriate thread length and tighten to provide intra fragmentary compression.

Procedure for placing a position screw or plate screw
1) Use appropriate drill guide to drill thread hole across bone while maintain reduction of bone to bone or plate to bone.
2) Use the depth gauge to obtain the correct length of screw prior to tapping the thread hole. (DO NOT USE COUNTERSINK)
3) Use appropriate tap through tap sleeve to cut the threads in the thread hole by turning the tap two times forward and one time back, to move the swath material up the tap and prevent tap breakage.
4) Select the proper length screw, with the appropriate thread length and tighten to maintain position of the fragments or compress the plate to the bone.

Procedure to place a locking screw
1) Place the centering threaded sleeve in the appropriate part of the LCP Combi-Hole.
2) Drill the thread hole with the appropriate size drill for the thread hole. Either 2.9 mm for the 3.5 mm systems or 4.3 mm for the 5.0 mm system.
3) No countersinking or tapping of the thread hole is required.
4) Use the depth gauge to obtain the correct length of screw
5) Select the proper length screw, with the appropriate thread length and tighten to the plate.
Do’s and Don’ts for Placement of Screws

Do:
Keep drill on forward during the entire drilling procedure. Backing up the drill will leave swath material in the drill hole.
Clean drill with moist 4X4 as swath material accumulates to reduce friction (heat) and prevent drill breakage.
Lubricate with saline as you drill to reduce friction and heat production.

***Use preoperative planning and intra-op radiographs to limit errors***

Don’t:
Use excessive bending force on drill that can lead to breakage
Use dull drills and taps
Forget to use depth gauge before tapping pilot hole.
Use excessive force while countersinking or tightening screws.

Cortex 5.5, 4.5, 3.5 mm
Cancellous 6.5 mm, FT, 16, 32mm

Cortex and Cancellous Screws

Locking screw

Cortex screw placed in lag fashion through a generic bone model. The screw threads glide through the near cortex and threads are cut in the far cortex.
Technique for placing a cortex screw in lag fashion across an oblique fracture.

2.2.5.2 Position Screw
If threads are tapped in both fragments it is not possible to compress the fracture gap by tightening the screw, but there are situations where a position screw is useful in maintaining fragment position. Placing a lag screw in such a fragment might draw it out of position into the marrow cavity (Fig. 60).

Fig. 60. The steps for inserting a position screw. The fragments are reduced and maintained in position. Both fragments are drilled with thread holes, measured and tapped. The inserted screw will avoid collapsing of the fragment

From Olmstead

Cortex screws through a plate as 3 cortex screws, 2 function as plate screws plate screws and used to compress the fracture and the center one as a lag screw
Cortex screws compression DCP

Locking screw engaging LCP there is no compression of the plate to the bone

Locking screw engaging threaded portion of combi-hole of the Locking Compression Plate (LCP)
How tight should you tighten a screw?

Screw should not be tightened to limits of strength, only about $\frac{2}{3}$, to allow additional functional loading.

Of the torque applied during tightening:
- 40% transformation into axial force
- 50% overcome friction at the screw head interface
- 10% overcome friction of the thread
Lag Screw Fixation of Carpal and Tarsal Fractures Using 3.5mm and 4.5mm Screws

Dean W. Richardson, DVM, DACVS
Lag Screw Fixation of Carpal and Tarsal Fractures Using 3.5mm and 4.5mm Screws
Dean W. Richardson, DVM, DACVS
University of Pennsylvania

Learner Objectives:

- Describe a detailed sequence of steps for accurate positioning of a screw for a dorsal (frontal) plane third carpal slab fracture
- Describe a detailed sequence of steps and the relevant anatomy for screw fixation of a sagittal third carpal slab fracture
- Identify the typical characteristics and basic repair strategies for 3rd tarsal and central tarsal slab fractures
Lag Screw Fixation of Carpal and Tarsal Fractures Using 3.5mm and 4.5mm Screws

Dean W. Richardson, DVM, DACVS
University of Pennsylvania

When doing surgery in athletic horses, we always have the optimal objective of returning it to athletic soundness. A return to athletic soundness can only occur if the joint is not too seriously damaged by the original injury OR by the surgeon. Surgical success is enhanced by paying attention to details and simple surgical principles. The surgical principles of the repair of articular fracture simply are (1) accurate reconstruction of the articular surfaces and (2) minimal surgical trauma to the joint structures. Clinical success is enhanced by: (1) recognizing the signs of concomitant damage that will preclude a successful outcome, (2) acceptable rehabilitative care and (3) working on horses with enough talent that a successful outcome is even possible. Obviously, slab fractures of the cuboidal bones of the carpus are fairly common injuries in racehorses but very unusual in horses performing other activities. The third carpal bone is the affected bone in more than 90% of carpal slab fractures although the radial, intermediate, ulnar and fourth carpal bones also can be affected.

Case Selection: Although it is possible for C3 slab fractures to heal with rest alone, it is usually advisable to repair any C3 slab fracture that is radiographically evident on a lateral or DLPMO projection. Radiolucent lines that are seen only on the tangential view may involve only the subchondral bone of the proximal joint surface and therefore may not require internal fixation. Prognostic considerations include comminution at the joint surface, marginal osteophytosis, loose fragments in the palmar-lateral joint space (an indication of comminution), size of the fragment and degree of displacement.

Fractures that confined within a single facet can be safely repaired with a single 3.5 mm lag screw. Simple fractures involving both facets should be repaired with 2 screws. If there is significant bone loss along the fracture line, 4.5 mm screws are preferred because interfragmentary frictional forces are lower and the screws more intensely loaded. If in any doubt at all, use the larger screw(s). Horses can break screws in this location. Smaller slab fragments that have extensive degenerative change or that cannot be accurately reduced may be best treated by removal.

Approach: Virtually every C3 slab can be repaired arthroscopically although the advantages are less if the surgeon is not an experienced arthroscopist. If an arthrotomy is elected, a straight 5-6 cm incision is made ~15 mm medial to the ECR tendon (for a radial facet fracture). The fracture line is debrided with small angled curettes and/or bone picks. It is easiest to debride the fracture with the limb in only partial flexion. Hard flexion closes the fracture line and tends to keep the fragment in reduction while the screw is placed. An Esmarch bandage is helpful if an arthrotomy is chosen and suction is very desirable. Tourniquets are not necessary for arthroscopy. Most surgeons today would consider arthroscopic guidance the technique of choice.

Arthroscopic technique follows basic principles. The scope is positioned between the ECR and CDE tendons when the fracture is in its typical location in the radial facet. If the fracture is in a frontal plane and extends into the intermediate facet, it is important not to position the scope too close to the distal row of carpal bones or it will be difficult to see the intermediate facet clearly. If the slab is off the dorsolateral corner of the intermediate
facet, the scope is inserted medial to the ECR. The latter tend to be smaller triangular fragments in which it may be difficult to centrally place a screw. Medial sagittal fractures are uniquely difficult because the screw must be positioned precisely along the edge of the second carpal bone. Because of this, the decision is sometimes made to perform an arthroscopic evaluation/debridement of the joint then made a small arthrotomy to allow exact positioning of the screw at the junction of C3 and C2.

Technique: With displaced slab fractures, an instrument portal is made on the opposite side of the joint. If possible, the instrument portal is made exactly at the margin of the fracture so that a curette can be inserted deeply to completely debride the fracture line. It is essential to remove all loose fragments in order to allow accurate reduction.

After debridement (with a displaced fracture) or after examining the joint (with a non-displaced fracture), a 3" 18g spinal needle is placed in the joint just above the proximal edge of the center of the slab fragment. If the position is not central, a second needle can be inserted. Additional 1" 22g needles are inserted at the medial and lateral margins of the fracture to verify the central positioning of the spinal needle. After the central needle is positioned correctly, a 22g needle is inserted into the carpometacarpal joint directly distal to it. A #10 scalpel is used to make a deep incision into the face of C3 measuring proximally from the CMC needle. It is usually possible to feel the dorsal ridge in the center of the face of C3 as the cut is made.

A 3.5 hole is drilled completely through the slab fragment. The direction of drilling is guided by the spinal needle. The needle's alignment in turn is checked arthroscopically. The surgeon should have the sense that he/she is drilling towards the center of the bone. An important error is to drill a radial facet fracture in a directly dorsopalmar direction because that angle will miss the palmar portion of C3 and damage the C2-C3 articulation. Another general alignment aid is to keep the bit perpendicular to the long axis of MC3. With displaced fractures it is easy to check arthroscopically that the glide hole has reached the fracture. With non-displaced fractures, careful measurements and intraoperative radiography/fluoroscopy are necessary. The centering insert is placed. A 2 mm pin placed through the centering insert can usually be seen entering the fracture plane if the carpus is extended and the scope directed in the fracture plane. With displaced fractures, the fragment can then be manipulated using the insert sleeve or a 3 mm pin in order to ascertain the position and completeness of the glide hole and to fully expose the fracture plane. Do not try to manipulate the fracture with a drill bit because the metal is much more brittle and may break.

The carpus is flexed, reduction is checked again arthroscopically and the thread hole is drilled. Usually, the thread hole is drilled only about 40 mm deep but it is not a major problem if the palmar cortex is penetrated. The hole is measured and tapped routinely. For most fractures, a 32 to 35 mm long 3.5 mm diameter cortical screw with fine thread is adequate. It is important to use a screw that is definitely shorter than the hole, especially if the palmar cortex is not penetrated. (The screw will fully tighten but the fracture will not be correctly compressed. If the fracture is large, i.e. involves both facets, 2 or sometimes 3, 3.5 mm screws are used. If there is a large comminuted fragment missing, 4.5 mm screws are preferred.

Four specific cautions: 1-Always keep a 2 mm K-wire in the hole while changing bits, guides and the tap. This makes it possible to never "lose" the hole until the screw is
actually inserted. 2- Remember there is (usually) a "bottom" to the hole and don't strip the threads or snap the tap by taking an extra turn. 3-Note that the hex socket of the 3.5 mm screw head is shallow and can be easily stripped if the screwdriver is not carefully inserted. 4-Remember that the arthroscope is often misleading in locating the center of the slab. The tendency will be for the surgeon to place the screws too close to the scope side. This tendency is minimized if the scope is kept as far distant from the slab as possible.

After the screw is inserted, the fracture line is probed and any remaining flaps are debrided. Occasionally, the slab fragment will rotate into slight malreduction when the first screw is fully tightened. If this occurs, the screw is loosened and the fracture reduced again. A second screw is inserted equidistant across the fracture and the screws alternately tightened. If there is a large fracture trough and a narrow remaining articular rim, the rim is debrided with heavy rongeurs or a motorized burr.

It is particularly difficult to accurately place a screw to compress a typical sagittal C3 slab fractures because the head must be placed precisely along the dorsal edge of the second carpal bone. In practice, it is often easiest to evaluate the joint, debride whatever is necessary and localize the dorsal junction of the second and third carpal bones with one or more needles. A small (~1.5-2 cm.) arthrotomy is made a few millimeters medial to the junction so that the screw can be placed exactly at the edge of C2. This allows the most perpendicular placement of the screw to the fracture line that is possible. The capsular tissue in this region is dense and a direct incision into the “slot” between C2 and C3 makes the surgery much easier.

**Closure and Post-Op Care:** Only skin sutures are used in the arthroscopic incisions and usually over the screw. If the screw incision is longer than 8-10 mm, a single subQ synthetic absorbable suture is used. A lightly padded bandage is used for recovery and to help minimize swelling in the postoperative period.

Time is essential. Although non-displaced fractures sometimes will be back to work in 3 to 4 months, 8-10 months is a more common convalescent time frame. Radiographs are taken at 2-3 month intervals.

**Prognosis** is not particularly good. Although the majority of horses will return to race, most drop in class. The prognosis is better if the horse has raced previously and better if there is minimal pre-existing degenerative joint disease. Size of the fracture does not appear to be the most important prognostic factor. Many larger slab fractures have less pre-existing degenerative disease than typical frontal plane radial facet fractures that seem to be the culmination of repetitive stresses. The prognosis is better for Standardbreds than Thoroughbreds.

**Key Points:**

**Fractures seen only on the skyline view may not require internal fixation. Arthroscopic debridement can be of value in such cases, however.**

**Fractures involving only a single facet can be treated with a single 3.5 mm screw.**

**Unstable fractures and those with more comminution should be treated with 4.5 mm screw(s),**
Arthroscopic guidance should be supplemented with fluoroscopic/radiographic imaging intraoperatively. It is surprisingly easy to misjudge the center of the fragment, especially if the scope is positioned close to its edge.

The prognosis is dependent on many things including the severity of the articular damage, degree of comminution and existing degenerative disease.

Arthroscopic view of a C3 radial facet slab fracture. Needles are placed at the edges of the fragment and its center to define its limits. A single needle is then placed in the CMC joint just distal to the central needle to complete the localization for screw insertion. Radiography/fluoroscopy should also be used to confirm accurate placement.
Even for “simple” C3 radial facet fractures, it is essential to obtain multiple views pre- and post-operatively.

Sagittal fractures of the third carpal bone are best repaired with 3.5 mm screws tucked in the crevice between C2 and C3 in order to optimize the vector of compression.

**Tarsal Slab Fractures:**

Third tarsal and central tarsal slab fractures are predominantly seen in racehorses but may be seen in any breed or activity. Third tarsal slabs usually occur on the dorsolateral aspect of the bone and central tarsal bones typically are more sagittal and positioned medially. They are easily identified with scintigraphy but multiple projections are sometimes required to see them on radiographs. Minimally displaced fractures can heal with rest alone but there is a strong argument to be made that properly inserted lag screws should improve healing and minimize osteoarthritis. The bones are narrow in their proximal-distal dimension and irregularly contoured, i.e. you cannot think of them as simple rectangular “blocks”, so meticulous radiographic control is essential. In my opinion, the optimal technique is to use pre/intra-operative CT combined with fluoroscopy. Although it is technically feasible to scope the distal intertarsal and
tarsometatarsal joints well enough to see the fracture margins, it probably isn’t worthwhile unless there are fragments to remove. These fractures are held in position well enough that lag screws will pull them reliably back into their anatomic alignment.

Because the bones are small, it is easier to “fit” 3.5 mm screws in the smaller tarsal bones, especially T3. Using CT guidance, 4.5 mm screws can be safely inserted. If possible, use two screws in larger fractures to provide additional stability. It cannot be overemphasized how careful the intraoperative imaging must be for these cases.

CT imaging allows very accurate placement of screws in tarsal slab fractures but the surgery can be done successfully with meticulous intraoperative fluoroscopic/radiographic control.
Treatment of Routine and Complex Fractures of the Metacarpal / Metatarsal Condyles

L.R. Bramlage, DVM, MS
Treatment of Routine and Complex Fractures of the Metacarpal / Metatarsal Condyles
L.R. Bramlage, DVM, MS

Learner Objectives:

- Assess a condylar fracture for potential repair strategies and prognosis
- Appropriately assess a condylar fracture and plan the fixation
- Approach and fix a condylar fracture using internal fixation methods
Condylar Fracture

Condylar fractures are para-sagittal fractures of the distal articular condyles of the metacarpal and metatarsal bones. They are one of the most frequent fractures in the racehorse. Condylar fractures are one of a complex of the distal cannon bone injuries that originate from the stress accumulation within the distal palmar/plantar articular condyles of the cannon bone that accompanies high-speed exercise. When the progressive accumulation of the stress of exercise begins to exceed the rate of repair, structural damage ensues. The condylar fracture originates on the palmar/plantar aspect of the bone in the area where the sesamoid bone articulates with the condyle. It is much more common in the lateral condyle than the medial condyle for reasons that are not readily apparent anatomically, because the medial condyle is larger than the lateral condyle and accepts more weight. Perhaps weight distribution plays a role in the creation of the fracture.

It is generally accepted that accumulation of stress and creation of micro-fractures is the initiating cause of the condylar fracture. The micro-fracture creation in the palmar/plantar condylar area progresses until enough coalescence occurs that a macro-fracture begins. The macro-fracture begins at the articular surface and progresses proximally in a sagittal plane. Condylar fractures are diagnosed in all degrees of propagation from very short fractures just being initiated at the articular surface to complete displaced fractures. This spectrum of fractures following generally the same plane, but in varying degrees of progression, is typical of stress fracture initiation and propagation.

Lateral fractures most often propagate abaxially from the site of initiation on the axial two thirds of the lateral condyle and exit the cortex 7-8 centimeters proximal to the fetlock joint, but they can occur more axial or abaxial and propagate axially or abaxially. Medial fractures more often propagate axially and can progress proximally as far as the proximal metaphysis of the bone. If the fractures propagate until they exit during exercise they will displace and set off a chain of events that de-stabilize the fetlock joint and may result in disarticulation. Fortunately most, but not all, condylar fractures show signs of lameness prior to completion and are diagnosed before the fetlock anatomy is destroyed.
The presence of articular comminution on the palmar/plantar condyle articular surface reduces the prognosis for a return to racing following surgical treatment of this injury. This comminution appears to be a hybrid of the palmar distal cannon bone semi-lunar fracture and the condylar fracture. The wedge-shaped articular comminution often occurs in areas of inflammation in the distal aspect of the cannon bone, at the same location the condylar fracture occurs. The fracture can start as a palmar articular fracture, eventually progressing to a condylar fracture.

Diagnosis in recent years has been greatly aided by a better understanding of the pathophysiology and anatomic configuration of this injury. This understanding has been facilitated by the digital radiographic and scintigraphic technology as well as three dimensional imaging with CT scans and MRI magnets that has better elucidated the pathology of this injury.

If the condylar fracture is discovered as a fine fissure fracture of only the palmar condyles, then the injury is stable and no surgical treatment is needed. If the injury progresses proximally, and certainly if it can be seen on the flexed dorsal palmar as well as standing dorsal palmar radiographs, the fracture benefits from surgical treatment by internal fixation in both the speed of healing and the quality of recovery. Condylar fractures that are non-displaced have historically been treated by the non-surgical means of confinement and exercise restriction. But experience has taught veterinarians and horsemen that the most rapid, most functional outcome occurs with compression and stabilization of the fracture via open reduction and internal fixation with lag screws. The prognosis is directly related to the severity of the injury. Displacement of the fracture adds to the severity of the injury and decreases the prognosis, as does the articular comminution. Articular comminution does not preclude

This radiograph demonstrates a complete displaced lateral McIII condylar fracture.
the successful repair if the articular comminution can be reduced and reconstructed with
the reconstruction of the primary fracture. But if a defect in the articular surface persists
the probability of a successful repair is greatly reduced. The goal of most condylar
fracture repairs is restoration of athletic activity, which is achievable with successful
internal fixation and anatomic reconstruction. Any residual articular defects or mal-
reduction of the condylar fracture greatly reduces or eliminates the chance of racing. The
margin for error is quite low in this heavily loaded joint surface.

The surgical repair is normally approached from the ipsilateral aspect of the injury and
non-displaced fractures can be stabilized without articular visualization for reduction.
Displaced fractures however, should be visualized arthroscopically to assure anatomic
reduction has been achieved. It is impossible to assure this with only radiographic
examination of the injury intra-operatively and therefore arthroscopic or open
visualization of the reduction of the fracture is indispensable to the successful repair in
displaced fractures.

Once the joint has been anatomically reduced and confirmed visually, the fixation is
technically similar in non-displaced and displaced fractures, with the placement of lag
screws across the fracture. Two screws are most commonly used. The distal lag screw
location is most important. It is should ideally be located in the palmar/plantar 2/3 of the
condyle of the distal cannon bone to provide compression on the palmar/plantar articular
surface.

Surgical treatment consisted of lag screw fixation with the horse in lateral recumbency
and the fractured condyle uppermost, or in dorsal recumbency. A 2cm incision or stab
incisions can be used as desired. If articular comminution is present, the fracture is
visualized through a dorsal arthrotomy in addition to the lateral incision or via
arthroscopic control. After reduction of displaced fractures, the fracture treatment
technique is identical in all horses. The fracture is maintained in reduction with a 2-mm
drill bit. The 2-mm drill bit is placed through the epicondyle regardless of the
displacement to act as a radiographic marker. Two radiographs are taken. Fluoroscopy,
if available, can be use rather than intra-op radiographs. Based upon the position of the
2-mm drill bit, two 4.5-mm or one 5.5-mm bone screw and one 4.5-mm bone screw are
used to reduce and stabilize the fracture. One can also use fluoroscopic imaging if

This arthroscopic picture shows the articular surface of the distal cannon bone after arthroscopic visualization and reduction of a displaced condylar fracture.
available to confirm screw location. Rarely are more than two screws used by the author of this paper.

Once the lag screws are in position and tightened, intra-operative radiographs are taken. When everything appears to be in good order, the horses are recovered without a cast. They are then given 60 days of stall rest and re-radiographed. Follow-up exercise is determined based upon those radiographs. Of the 135 horses with 145 fractures, one horse had fractures in three of the four cannon bones at the same incident. This lends credence to the concept that the fracture is not a single event occurrence, but rather is fatigue of the bone through repeated loading.

Location of the screws is more difficult than one might anticipate, especially when swelling of the injury distorts the anatomy. Some surgeons repair these fractures standing, but since the location of the screws in the ideal position is important and a few millimeters can make the difference between success and failure, the method that assures the best possible repair in the situation should be used.

Lateral condylar fractures and medial condylar fractures that do not displace or spiral proximally require no external coaptation for recovery from anesthesia. Condylar fractures that spiral into the diaphysis of the bone in some instances propagate proximally as far as the proximal metaphysis have increased risk for failure both in recovery and in the postoperative period and addition of a neutralization plate to the diaphysis of the bone to protect the bone during the healing period is preferred.

Once repaired the normal aftercare requires approximately three months. The prognosis has been well documented and one can anticipate successful recovery with condylar fractures in most instances, including articular comminution if the fracture is anatomically reduced and stabilized.

Metacarpal and metatarsal condyles are a frequent fracture. In a study of 145 fractures in 135 horses, 30% were complete, non-displaced and 37% were incomplete and 30% were
complete and displaced. The right front metacarpus was more likely to sustain a complete and displaced fracture. The left forelimb was more likely to sustain an incomplete fracture. This is possibly due to the fact that horses show clinical signs earlier on the left lead racing in the turns and have less chance to displace the fracture. Forelimbs were affected 81% of the time and the lateral condyles were 85% of the fractures. The fracture tended to involve the middle portion of the condyle with 59% entering the joint at the middle third; 15% of the 135 fractures had definitive articular comminution; 95% of those with articular comminution were complete fractures indicating that there may have been comminution in other fractures had they displaced. When the fractures entered the middle third of the condyle, 23% had comminution whereas only 2% of the fractures that entered the axial aspect of the condyle had comminution; 8 of the 135 fractures spiraled proximal toward the carpal joint. All of the spiraling fractures were in forelimbs.

Sixty-five percent of the 135 horses started a race post-injury in spite of the fact that some of the horses were repaired with the express purpose of saving them for broodmare or stallion duties and never trained. The mean time to start was 9.7 months with a mean number of 13.7 races post-injury. Having raced pre-injury did not confer an advantage though non-starters pre-injury tended to take longer to return to racing than horses that had started a race. Sixty-six percent of the horses improved or maintained their class post-operatively and 64% decreased their earnings-per-start, as do most horses as they age.

Eighty-five percent of the horses received internal fixation for their fractures as this was a group with somewhat more severe fractures than average. Many horses were not presented for examination because rest alone was elected prior to presentation at the hospital. Seventy percent of the 145 fractures were complete fractures which is a higher number of complete fractures than are normally seen. Eighty-seven percent of the horses with incomplete non-displaced fractures that received rest alone raced after surgery. Incomplete non-displaced fractures that were treated surgically had 74% of the horses race. In complete non-displaced fractures, 58% raced and in complete displaced fractures 60% raced. Seventy-three percent of the males raced post-injury whereas 53% of the females raced. The 73% of the males probably represent the truer prognosis for all fractures as many of the females were immediately retired. Fifty-two percent of the horses with articular fragments were able to race post-injury which indicates that this injury is not career ending if treated appropriately. Horses were more likely to race if the two to four month radiographic appearance of the fracture was healed with little evidence of having had a previous fracture. The prognosis was affected by the severity of the injury to the joint, the presence of articular comminution, and the quality of surgical repair as assessed on post-operative radiographs.

Contrary to previous studies, displaced fractures are not hopeless surgical prognoses as had been described.
References:


Third Metacarpal Stress Fractures, Pathogenesis and Treatment

Alan J. Ruggles, DVM Diplomate, ACVS
Third Metacarpal Stress Fractures, Pathogenesis and Treatment
Alan J. Ruggles, DVM, Diplomate, ACVS

Learner Objectives:

- Describe the pathogenesis of stress injury in cortical bone in the horse
- Describe the principles of surgical management of third metacarpal stress fracture in the horse
- Describe the post-operative management of a third metacarpal stress
Bone is a dynamic tissue, which responds to forces to which it is subjected. Its ability to withstand loads is dependent upon its material and structural (geometric) properties. When stress is applied to bone it alters its geometric properties in a fashion as to best counteract those forces. This concept known as Wolff’s Law, states that bone is laid down where it is needed and resorbed where it is not needed. Macroscopically, bone is divided into two categories cortical bone (syn. compact, osteonal, Haversian bone) and cancellous bone (syn. trabecular, spongy bone). Mature long bones are organized microscopically by osteons, tubular structures of mineralized bone (Type I collagen, ground substance, mineral, and osteocytes) surrounding a central vessel called a Haversian canal. The osteons that are formed during appositional growth are called primary osteons. Secondary osteons are concentric sheets of lamellar bone that are formed during remodeling of bone. This process consists of the osteoclastic resorption of bone via a structure called a cutting cone and then the organized deposition of lamellar bone by osteoblasts. The processes of bone remodeling, reconstruction of the internal architecture, and modeling, changes in the bone shape by addition of bone to the endosteal and periosteal surfaces, are of paramount importance in the maintenance of the structural integrity and improvement in geometric properties to adapt the bone to the loads to which it is subjected.1

Failure of bone is obvious during a single event such as fracture of a long bone from a blow or fall. In such a circumstance, the load applied exceeded the yield point of the structure causing plastic deformation. Fatigue failure and response to cyclic stress occur when bone is subjected to repeated loads that are below its yield point that is within its elastic limit. These loads, according to Wolff’s Law, initiate the processes of modeling and remodeling. Since remodeling causes resorption of primary osteons before secondary osteons can be formed increased bony porosity occurs and reduced stiffness (resistance to bending) occurs. It is hypothesized that high-strain cyclic loading causing decreased bone stiffness leads to increases in inertial properties of the bone. When the loss of porosity is gradual, the bone is replaced with lamellar bone (secondary osteons). If the rate of loss of porosity exceeds this process then periosteal new bone is formed. In bucked shin complex, various amounts of periosteal bone are formed and is dependent on the rate of loss of bone porosity.2 In addition, bone modeling will be altered by the rate of bone loading, which is fast speed (high strain) activity will model bone differently from low strain work.3 Ideally, bone should be subjected to the type of strain it will be subjected to at maximal performance.

The result of successful modeling and remodeling of bone is the development of bone that is architecturally and structurally able to withstand the rigors of performance. Properly conditioned bone is able to withstand higher loads and higher frequency loading. An unfortunate consequence of this is when failure occurs at high speeds a large amount of energy, which was stored in the bone, is released causing more severe injury.
Stress fractures are a syndrome most commonly seen in horses used for racing. Thoroughbreds, Standardbreds and Quarterhorses have been reported with stress fractures.\(^4\) Stress fractures most commonly occur in the metacarpus, humerus and tibia. Stress fractures cause lameness and in some circumstances lead to catastrophic failure of the bone.\(^8\)

The syndrome of bucked shins has been well recognized as a disorder of young Thoroughbreds leading to periosteal pain, lameness and thickening of the dorsal cortex of the third metacarpal bone as a response to training stress. The uses of counterirritants, rest and controlled exercise have been used with various successes in the treatment of bucked shins. Horses which develop stress fractures of the dorsal cortex of the metacarpus as three and four-year olds usually have a history of bucked shins as a two-year old. The clinical signs of metacarpal stress fracture are similar to that seen in bucked shins. It is likely that stress fracture is a continued manifestation of the same problem. Diagnosis of dorsal cortical fracture is by physical examination and radiography. Most stress fractures occur on the dorsolateral aspect of the metacarpus. Bilateral fractures can occur. Treatment options include controlled exercise, screw placement of the dorsal cortex and/or unicortical holes drilled around the fracture line.

Historically, pin firing or application of intense counterirritants had been considered acceptable methods in the treatment of bucked shin complex and stress fractures. With our current understanding regarding the development of bucked shins and stress fractures there seems to be no reason to recommend these treatments in the management of such injuries. Cortical drilling is thought to improve vascularization and new bone formation at the fracture line.\(^9\) The placement of a screw probably does not cause interfragmentary compression but may have a local effect on bone modeling and remodeling. Advantages of cortical drilling versus screw fixation are that a second surgery is not necessary to remove the screw and that in some horses this procedure can be performed standing. A disadvantage of this technique is the risk of drill breakage in the standing horse. Clinical reports have indicated that the use of cortical drilling and screw placement has a lower rate of fracture recurrence than cortical drilling alone. The healing rate with these techniques was 85% and 97%, respectively.\(^{10-11}\) The author presently performs the combination of screw placement and cortical drilling.

**Surgical Procedure:** The horse is positioned in lateral recumbency with the affected limb up. Both limbs can be operated upon from the same recumbency. The periosteal new bone can be felt through the skin and a 6 - 8 cm vertical incision is made over the fracture usually between the common and lateral digital extensor tendons. If necessary needles or skin staples can identify the fracture site placed in the skin with radiographic control. The periosteum should not be elevated and a 2.5-mm drill is used to drill the thread hole for the 3.5-mm screw, perpendicular to the fracture line. Only the dorsal cortex is drilled. Care should be taken to avoid impacted the instruments on the palmar cortex through the medullary canal since instrument breakage may occur. The use of sharp drill bits is recommended to avoid instrument breakage. The countersink depression is made and the length of screw necessary is determined using the depth gauge. The thread hole is tapped and the screw placed. Usually a single screw is used but on occasion multiple screws may be used for long fractures. Cortical drilling with typically 5 -6 unicortical drill holes is made with a 2.5-mm drill bit in the region of the
fracture. Either during or after screw placement radiographic control is necessary to determine proper screw placement. The tendons and subcutaneous tissue are sutured and the skin closed. Some surgeons omit the screw placement and use cortical drilling alone to treat metacarpal stress fractures. Recovery from anesthesia is in a bandage.

If dorsal cortical drilling alone is performed standing under sedation and regional analgesia a 3.2 mm drill is used to decrease the risk of drill breakage if the horse moves during the procedure.

**Postoperative Treatment:** Four weeks of stall rest with handwalking followed by 4 weeks of small paddock turnout, continued handwalking or swimming is recommended. Screw removal occurs at 8 weeks based on fracture healing and is performed standing. Return to light jogging can occur 2 weeks after screw removal but more intense training should be at least 16 weeks after surgery and should be based on lack of clinical signs and radiographic signs of healing.

**Prognosis:** Prognosis is considered good with 85% to 97% of horse returning to racing in two reports.\(^{10-11}\) Recurrence of fracture can occur and occurs more commonly after cortical drilling alone compared to cortical drilling and screw placement combination. Catastrophic failure of the metacarpus has occurred after cortical drilling alone but not with the combination of screw placement and cortical drilling.\(^{10-11}\)

**Nonsurgical management of third metacarpal stress fractures**

Rest and controlled exercise can be successfully used in the management of third metacarpal stress fractures. The decision to use nonsurgical management can be based on economic factors or the degree of healing evident when the fracture is diagnosis. Horses which have third metacarpal stress fractures which radiographically exhibit marked endosteal or periosteal healing will often heal on their own without surgical intervention. Likewise severe fractures, which are in multiple locations or spiral around the bone, have a risk of catastrophic failure upon recovery from general anesthesia and are usually treated by nonsurgical methods (Figure 5). To the author’s knowledge there is no objectively evaluated method of nonsurgical management of dorsal cortical stress fractures. The general principles are to walk the horse and confine to a stall until the horse is sound at the trot. Afterwards, there is a gradual return to training with jogging and easy galloping allowed as comfort dictate. Based on previous work one should consider the intervention of frequent, short breezes to train the bone for racing rather the training.\(^2\) Soundness and radiographic appearance are used to assess healing. In the authors’ experience the outcome after nonsurgical management is less reliable and does not result in a reduction in training days missed when compared to surgical management. In the authors’ experience the recurrence rate (or non-healing rate) with nonsurgical is higher than that found with surgical management.

**References:**


AOVET North America

Principles in Equine Fracture Management Course

FRIDAY LECTURE ABSTRACTS
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Internal Fixation of Mid-Sesamoid Fractures with Lag Screws

L.R. Bramlage, DVM, MS
Learner Objectives:

- Assess a mid-sesamoid fracture for potential repair strategies and prognosis
- Appropriately plan the fixation for a mid-sesamoid fracture
- Approach and fix a mid-sesamoid fracture using internal fixation methods
INTERNAL FIXATION OF MID-SESAMOID FRACTURES
WITH LAG SCREWS
L.R. Bramlage, DVM MS
Rood and Riddle Equine Hospital

Apical and abaxial fractures of the sesamoids are normally removed arthroscopically. But when too much of the suspensory ligament insertion is involved to remove the fragment, it must be repaired.

Mid-sesamoid fractures in the mature horse are a difficult problem because they totally detach half of the suspensory apparatus from the distal sesamoidean ligaments. Removal of a fragment nearing half of the mass of the sesamoid bone simply assures no hope of reconnection between the components of the suspensory apparatus. Therefore the only potential salvage for athletic activity is to attempt fixation and achieve re-union of the halves of the sesamoid bone. Without fixation displaced mid-sesamoid fractures have little chance to heal once the horse is mature.

The horse can readily give up, up to 25% of the suspensory attachment to the abaxial aspect of the bone. Once greater than 25% to 30% of the suspensory is attached to the apex fragment removal no longer is readily tolerated. Re-attachment and healing must then be considered. Many techniques have been tried. The original technique was lag screw fixation. However, the prolonged healing period resulted in sesamoiditis. Bone grafting alone was tried, however elongated sesamoids often resulted and therefore, a functional suspensory apparatus could not be obtained. The combination of lag screw fixation with bone grafting has proven acceptable at creating rapid healing without excessive degeneration of the sesamoid bone/suspensory ligament attachment. If perfect adaptation and stability can be achieved a bone graft is not necessary, but if a defect remains a bone graft is useful in aiding healing.

The surgical technique involves an approach to the base of the sesamoid which starts half-way between the ergot and artery, vein, and nerve. The base of the sesamoid bone is approached just under the palmar annular ligament through the proximal aspect of the digital annular ligament. When the base of the sesamoid bone is identified the natural separation within the middle distal sesamoidean ligament allows access to the central portion of the base of the sesamoid bone. The approach can be linear or curved and can be extended proximally as needed to access the fetlock joint if desired. With difficult reductions or complicated fractures incisions into the tendon sheath can be useful in aiding reduction.

Arthroscopic or direct visualization of the sesamoid articular surface via the proximal palmar/plantar pouch of the fetlock joint can be used if needed of preferred to assure reduction of the articular surface.
The reasons for the occurrence of mid-sesamoid fracture have not been well elucidated. Certainly some fractures are accompanied by sesamoiditis, demineralization and loss of strength of the sesamoid bone, making it likely that the structural diminution and diminished strength predispose the bone to fracture. However, many sesamoid bone fractures have no apparent predisposition for their occurrence and the explanation for failure of a radiographically normal sesamoid bone is unclear. Post-mortem studies have shown that the fracture may be predisposed by subtle defects in the palmar/plantar aspect of the sesamoid bone, but these are nearly impossible to find clinically and are evident only on extensive post-mortem exam.

The treatment via internal fixation can be done in two principal ways: the use of screws or wires, one or multiple, to adapt the bone fragments and to reconnect the bone. In some instances a bone graft is added to the fixation to stimulate repair because of the poor biomechanics of sesamoid fracture healing. Lag screw fixation can take place from the apex, the base or from the abaxial surface, depending on the configuration of the fracture. The lag screws are inserted in normal A-O fashion and it is the author’s preference to coapt the sesamoid bone, insert the screw and then subsequently loosen the screw and insert the bone graft if needed; though it can be done in any order. If perfect adaptation can be obtained a bone graft is not needed.

The surgical procedure is technically challenging because of the inter-position of the foot into the surgical field, in the location where one would like to orient the drill to create the hole and because the fracture is best reduced in flexion, but the surgery is easiest with extension of the fetlock joint as it reduces the articular surface. The orientation of the fracture will dictate modification of the position of the limb for insertion of the implants to best compress the fractured bone.

The healing process is fraught with many potential difficulties. In addition to the limited bone to insert the fixation, the bone heals slowly and if the healing process is accompanied by significant sesamoiditis, as it usually is, even a perfect reduction and healing of the sesamoid bone may not result in a sound horse.

The prognosis for successful treatment of mid-sesamoid fractures is limited by the technical repair is normally attempted only in horses that have no use other than their athlete career. Though many horses can return to racing, it is difficult to keep them sound because of the sesamoiditis that is caused by the fracture and the healing process when the fracture passes through the attachment

This radiograph demonstrates a mid-sesamoid fracture.
of the suspensory ligament to the sesamoid bone.

A 2mm drill bit can be used to "pin" the sesamoid bone fragments together after they are reduced with an A-O reduction forceps if possible. Grasping the A-O reduction forceps and tilting the base of the sesamoid abaxially allows placement of the 2mm drill bit at the appropriate angle. Care is taken to place the 2mm bit palmar/plantar to the center of the bone to allow the bit to remain in place while the screw is placed centered in the bone. Intra-operative radiographs are taken to determine the ideal location of the screw, in relation to the 2mm drill bit. “C-arm” fluoroscopy can also be used instead of radiographs if available.

Routine lag screw technique using a 4.5mm cortical bone screw is then used to place the screw from the base of the sesamoid bone through the apex, palmar to the articular surface. Ideal placement would pass the screw through the proximal aspect of the bone at exactly the apex of the sesamoid, palmar/plantar to the joint surface but as far palmar or plantar in the quality bone as possible, to obtain the best possible purchase on the bone as close to the tension surface as possible.

If the configuration of the fracture fragment indicates, the screw direction can be reversed and can be placed from proximal to distal, though it is somewhat more difficult to position the instrumentation for this screw placement. In very small fragments one or two 3.5mm screws can be used.

In most instances healing of the sesamoid bone can be achieved with fixation. However, it is very difficult to avoid the sesamoiditis and damage to the suspensory ligament that accompanies the fracture and the inflammation of the healing process, so the prognosis for return to previous function is unfavorable, even though healing of the bone can often be achieved.
**References:**


Internal Fixation of Sesamoid Fractures with Arthroscopic Guidance, Wire Application for Sesamoid Fractures

Dean W. Richardson
Learner Objectives:

- List a logical sequence of steps combining arthroscopy and intraoperative imaging for the lag-screw repair of mid-body sesamoid fractures
- Describe the anatomic approach and surgical sequence for hemicerclage wire repair of a mid-body sesamoid
- Describe the expected outcome for mid-body sesamoid fractures treated with lag screws or wire fixation
Internal Fixation of Sesamoid Fractures with Arthroscopic Guidance,  
Wire Application for Sesamoid Fractures  
Dean W. Richardson  
New Bolton Center  
University of Pennsylvania  

Mid-body sesamoid fractures remain surgical challenges. Non-displaced fractures can be successfully managed by extended periods of rest, although nonunion and refracture are fairly common. Displaced fractures should be surgically repaired if an athletic career is desired. The most common techniques for repair are lag screw fixation +/- graft or tension band wiring +/- graft. In most fractures lag screw fixation is superior but wiring can also be successful and is a useful technique to have available if screw fixation proves impossible for some reason (rare).

Arthroscopically assisted lag screw fixation

I prefer to do these in lateral recumbency with the fractured sesamoid up. The foot should be carefully cleaned and the thinnest possible sterile adhesive materials used to drape the foot. Any bulky materials over the heel will further complicate the positioning of the screw. It is ESSENTIAL to have long drill bits and taps. It is highly desirable to have hex-head screw drivers of different lengths.

An 18 G 1.5" needle is placed through skin and distal sesamoidean ligaments as perpendicular as possible to the center of the base of the PSB palmar or plantar to the neurovascular bundle. Its position was checked fluoroscopically or radiographically in dorsopalmar/plantar and lateromedial planes. A #10 blade is used to make a 10-12 mm skin incision at the location of the needle at the base of the PSB. (Figure 1) A 4.5 mm drill guide is placed through the distal sesamoidean ligaments at the base of the PSB and its position verified with fluoroscopic or radiographic imaging in two planes. (Figure 2) A long 4.5 mm drill bit is used to drill through the distal fragment to the fracture plane using fluoroscopic or radiographic guidance. (Figure 3) It is best to do this in displaced fractures before making an attempt to reduce the fracture. A 3 mm pin is placed through the 4.5 mm drill guide to maintain the location of the hole, the drill guide removed and the 3.2 mm centering sleeve placed into the glide hole. (Figure 4) The fracture is approximately reduced with large pointed reduction clamps. A standard scope portal is created in the proximal aspect of the ipsilateral palmar or plantar pouch, the joint distended and the articular surfaces and fracture plane examined. After arthroscopic-guided insertion of an 18 G 1.5" needle, an instrument portal is created at the level of the fracture plane through the collateral sesamoidean ligament distal to the scope portal. The fracture plane is debrided in moderately displaced fractures and reduction achieved by manipulation of the 3 mm pin and insert sleeve. A pointed bone reduction forceps is placed on the apex and base of the PSB. The reduction is evaluated arthroscopically after which the arthroscope is removed from the joint. The thread hole (3.2 mm) is drilled through the apex of the PSB with care to avoid unnecessary damage to the suspensory ligament. The hole is tapped and a cortical screw placed and tightened under arthroscopic observation (Figure 5,6). Following debridement of any loose cartilage flaps or osteochondral fragments, the joint is lavaged and skin incisions closed with simple interrupted sutures. If the fracture is not displaced, the cortical screw is placed in lag fashion under fluoroscopic or radiographic guidance and arthroscopy is performed only after screw placement to evaluate reduction, to debride small cartilage fragments from the fracture line and to completely evaluate
the articular surfaces. In the non-displaced fractures, the anatomical landmarks are more readily identified and the positioning of the screw is easier before the arthroscope and associated fluid distention change the topography. Arthroscopic evaluation of the dorsal aspect of the fetlock joint is performed if any abnormalities were detected on pre-operative radiographs.

Lag screw fixation can be done in a distal to proximal direction or in a proximal to distal direction. I prefer the former unless the fracture plane is oblique in a proximal axial to distal abaxial plane. The surgical incision is similar to that described above except the tendon sheath is not entered. The fragments are aligned, holding the fetlock in flexion. A stab incision parallel with the suspensory fibers is made over the most proximal abaxial aspect of the apical fragment and standard 3.5 mm lag screw technique is used. It is critical that the alignment of the fragments be exact during drilling and tapping. The tip of the screw should be near the axial corner of the base of the PSB. Whenever possible, a second 3.5 mm screw is placed to prevent rotation of the fragment. A small bone graft is placed in the fracture line’s palmar aspect from the articular or abaxial aspects. If perfect reduction is achieved this might be unnecessary, but usually there is some minor gapping along the palmar margin. Closure is routine and a cast is kept in place in most horses for 4-5 weeks.
Sesamoid repair with hemicerclage wiring:

Tension band wiring is technically less complex than lag screw insertion in the PSB and is a more versatile technique, adaptable to various degrees of comminution and fracture obliquity. The approach involves a curved incision extending from the tip of the splint bone palmarly over the neurovascular bundle then distally over the proximal 1-2 cm of the proximal phalanx and the extensor branch of the suspensory. The subQ tissue is incised dorsal to the neurovascular bundle and is dissected with the overlying skin to expose the PSB and joint capsule. An incision is made into the joint through the collateral sesamoidean ligament to expose the articular surface of the PSB. The fracture alignment is checked and the fracture line is debrided from the articular surface. The neurovascular bundle and attached subQ tissues are dissected from the palmar aspect of the PSB and a 4-5 cm incision is made into the tendon sheath along the palmar aspect of the PSB. A 14G 2” needle is inserted under the base of the PSB from the abaxial articular margin into the tendon sheath, holding the fetlock in palmar flexion and retracting the tendon to avoid penetration by the needle. A 20-30 cm piece of 1.2 mm (16g) wire is inserted through the needle and its end is retrieved from the tendon sheath. A 2.5 mm bit is used to drill a hole through the apical fragment also in an abaxial-dorsal to axial-palmar direction (Figure A). The bit is removed and a 14g 2” needle is used to enter the tendon sheath. The bevel of the needle is turned towards the surgeon and the tip of the wire in the sheath is inserted into the needle. The wire is passed through the hole either through the needle or by pushing the needle out of the hole with the wire (Figure B). This is the most difficult part of the procedure. After both ends of the wire are out of their respective “holes”, they are passed again through needles to position them as close as possible to the surface of the bone (Figures C,D,E). Prior to tightening, a cancellous graft harvested from the tuber coxae is placed in the fracture line. Usually, I pack the graft from the articular surface, but it can also be inserted from the abaxial side through a small stab in the fracture plane. With severely displaced fractures, there may be enough disruption of the dorsal surface of the tendon sheath that the graft can be placed directly into the palmar fracture plane. The amount of bone required is usually small (3-5cc or less); the graft can be taken by making a 1 cm stab over the tuber coxae, drilling a hole in the outer cortex with a 5.5 mm bit and scooping out bone through the drill hole with a #2 curette. An adequate volume of bone can be obtained quickly with this simple technique. The wire is tightened with pliers, vise grips or wiretighteners (e.g. Fastite, Synthes) while checking articular reduction. Depending on the configuration of the fracture and the position of the wire, overtightening of the wire can lead to shifting of the fragments and articular malalignment. The incision is closed in layers with interrupted synthetic absorbable sutures in the tendon sheath and joint capsule, a continuous pattern subQ and routine skin sutures. A cast is placed for anesthetic recovery and up to a few weeks. The primary complication of the technique is that the wire sometimes fatigues and breaks. If this happens and there are referable clinical signs, the wire is removed. A rare complication (especially uncommon with 1.2 mm or larger wire) is fracture of the wire in the sheath with distal migration of a piece of the wire. The advantages of the wiring technique are that it is straightforward and versatile. Its primary disadvantage is that exact anatomic reduction of the fracture is difficult. It may be that some gapping of the fragments is not such a bad thing as long as a graft is used. The bone may heal in a “lengthened” position and lessen the stress at the fracture line when the suspensory apparatus is fully loaded. This is purely conjecture and the disadvantages of poor articular alignment probably outweigh this speculative benefit.
Both wire and lag screw techniques can be performed in conjunction with arthroscopy instead of arthrotomy. It is highly desirable to have fluoroscopy available. It also is useful to have an aiming device that can help precisely align the drill through small incisions. Although some horses can return to work sooner, most horses with repaired mid-body or large basilar PSB fractures are rested for nearly a year before returning to work. The prognosis is fair with approximately 50% returning to intended athletic function. Most racehorses will drop in class. Sesamoiditis seems to be the most common cause for clinical failure/inability to return to form.

Lag screw fixation can be done in a distal to proximal direction or in a proximal to distal direction. I prefer the former unless the fracture plane is oblique in a proximal axial to distal abaxial plane. The surgical incision is similar to that described above except the tendon sheath is not entered. The fragments are aligned, holding the fetlock in flexion. A stab incision parallel with the suspensory fibers is made over the most proximal abaxial aspect of the apical fragment and standard 3.5 mm lag screw technique is used. It is critical that the alignment of the fragments be exact during drilling and tapping. The tip of the screw should be near the axial corner of the base of the PSB. Whenever possible, a second 3.5 mm screw is placed to prevent rotation of the fragment. A small bone graft is placed in the fracture line’s palmar aspect from the articular or abaxial aspects. If perfect reduction is achieved this might be unnecessary, but usually there is some minor gapping along the palmar margin. Closure is routine and a cast is kept in place in most horses for 4-5 weeks.

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Mid-Body sesamoid fractures in foals are not easy to repair with either of the above techniques (at least in my hands). A simple suturing technique with a high tensile strength multifilament suture, e.g. Fiberwire® or ultra-high molecular weight polyethylene can work well enough in young foals. Surgical repair is usually only selected in significantly displaced fractures because minimally displaced fractures heal quite quickly without internal fixation.

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Fixation of Fractures of the Sinuses and Mandible

Chad J. Zubrod, DVM, MS, Diplomate ACVS
Fixation of Fractures of the Sinuses and Mandible
Chad J. Zubrod, DVM, MS, Diplomate ACVS

Learner Objectives:

- Assess patients with fractures of the sinuses and mandible to determine the need for fixation
- List the pros and cons of each fixation method
- Identify complications which could arise following injury and repair
Fixation of Fractures of the Sinuses and Mandible
Chad J. Zubrod, DVM, MS, Diplomate ACVS
Oakridge Equine Hospital

Head trauma is a relatively common occurrence in young horses following kicks from another horse, collisions with solid objects, or being startled while chewing on an object. Although these fractures can be cosmetically disfiguring and prevent prehension and mastication of food, most are amendable to repair and will heal with a quite acceptable appearance. The high success rates achieved with fixation of these fractures is mainly due to the extensive blood supply, good soft tissue coverage, and the direction of forces to which these bones are subjected.

External trauma to the sinuses can result in closed depression fractures, or open wounds with both depression and avulsion of fracture fragments. Evaluation of these fractures should include evaluation of the orbit, cranial nerves, tooth roots, and nasal passages. Oblique radiographic views may help determine the extent of the fractures, however digital palpation of the orbit and fracture site can provide valuable information. A dorsal-ventral radiographic projection of horses with depression fractures of the sinuses and nasal bones can be useful in determining if there is concurrent damage to the nasal septum. It is important to inform clients that even without radiographic injury at the time of trauma, the horse could develop thickening of the nasal septum over time which could necessitate removal. Some closed depression fractures can be elevated into the normal anatomic location using a bone hook or bent Steinmann pin through a stab incision and drill hole. The fragments can frequently be elevated and wedged into their anatomic location. In cases of instability, or open wounds the fragments can be stabilized with monofilament absorbable suture, or fine gauge wire, after predrilling holes in the fragments. Fragments with even minimal soft tissue attachments will frequently survive in this location. It is important to accurately oppose the soft tissues over the sinuses to prevent formation of fistulas due to the movement of air. This can be enhanced with a good pressure bandage post-operatively. Reconstruction plates and 3.5 mm cortical bone screws can also be used to reconstruct fractures of the sinuses and orbit, however they are frequently unnecessary, and frequently become infected since they are being placed in a contaminated environment. The use of absorbable suture to repair these fractures decreases the incidence of infection and fistula formation.

Most fractures of the mandible and maxilla result in avulsion of the incisors alone or with varying portions of the mandible and maxilla. If the fractures are not displaced or unstable, surgical repair may be unnecessary. It is important to remember that the oral surface is the tension surface of these bones, and a tension band effect is frequently all that is necessary to establish anatomic reduction, stability, and return to function. Avulsion fractures of the incisors are very common and easily repaired with cerclage wiring of the affected teeth to those that remain stable. If all of the incisors are avulsed, a tension band can be created to the canine teeth, or behind the second premolar. The wire can be threaded around and between the incisors using 14 gauge needles inserted between the teeth just below the gingiva. The wire is started into the needle and passed between the teeth as the needle is retracted. The wire can be laced between multiple teeth and tightened to secure the avulsed incisors. The ends of the wire can be embedded in the gingival, and the wires covered with methyl methacrylate to prevent irritation to the inside of the mouth. If wiring behind PM2 is necessary, drilling between the teeth at the gumline can be achieved through a stab incision in the cheek and use of a soft tissue protector.
The wire can then be threaded through the hole with a 14 gauge needle. If the fracture is unstable, tightening of the wires can result in collapse of the fracture. This can be overcome by using methyl methacrylate to create an intraoral splint, or using a U-shaped aluminum rod that is wired to the incisors and cheek teeth.

Fractures of the horizontal ramus of the mandible can be stabilized with intraoral wiring, dynamic compression plating, or external fixators. Using a narrow dynamic compression plate is relatively straightforward, although care must be taken to avoid the salivary duct, neurovasculature, and tooth roots. These fractures usually communicate with the oral cavity and must be considered contaminated. The fractures frequently involve the tooth roots, however the teeth will frequently survive or can be removed later when they are obviously devitalized and loose.

Perioperative antibiotics are indicated in all instances, and should be continued post-operatively in most cases to decrease the incidence of sequestrum formation. These fractures are usually most easily repaired under general anesthesia with nasotracheal intubation and the horse in lateral or dorsal recumbency depending on the fracture. Sinus fractures are frequently recovered in a padded helmet to decrease the incidence of fracture displacement. In most cases implants can be removed in 2-3 months if necessary due to drainage, or if they have been placed in the oral cavity.
Implant Removal in the Horse – How, When and Why?

Janik C. Gasiorowski VMD, DACVS
Implant Removal in the Horse – How, When and Why?
Janik C. Gasiorowski VMD, DACVS

Learner Objectives:

- Identify the indications for implant removal
- Describe the appropriate time frame for removal of implants from various types of fixation
- Describe the principles of minimally invasive implant removal
Implant Removal in the Horse – How, When and Why?
Janik C. Gasiorowski VMD, DACVS
Mid-Atlantic Equine Medical Center

Indications for implant removal include infection, interference with development in the immature animal, impingement on the surrounding tissues and to enable return to full function.

Why
Once established, infection is potentiated by the presence of orthopedic implants. Formation of biofilm makes successful medical management of surgical site infection nearly impossible. Infection may be controlled but resolution often requires removal of the implant(s).
Orthopedic implants can interfere with development in the immature animal. The situation of interference may be created by necessity, by design, or occasionally by mistake. Most plates applied to long bones in immature horses should be removed if the bone in question is not close to skeletal maturity. Fractures involving a growth plate and causing axial instability often require internal fixation that makes use of the bone on both sides of the physis. The physis of the developing animal heals quickly but the implant, if left in place, will impede asymmetrically growth of the bone as the animal continues to grow. A surgeon makes use of this same principle when bridging surgically the physis of a foal with an angular limb deformity. Asymmetric physeal retardation corrects the deformity but the implant must be removed to avoid “over correction”. Occasionally during fracture repair, physes are inadvertently bridged or the radius is accidentally engaged during ulnar fracture repair. Correction of such mistakes is not immediately critical but must happen before they result in growth deformity.

Placement of an orthopedic implant is always associated with some degree of soft tissue impingement. Most often it is tolerated well. In some instances the offending implant must be removed once healing is complete to achieve comfort or soundness. Instability will cause implant loosening and screw back out. Loose screws can be removed or re-tightened depending on the integrity of the thread hole and the stage of fracture healing.

Orthopedic implants are often removed from athletic animals to encourage safe and complete return to function. Plates on long bones and diaphyseal cortex screws are removed before return to athletic activity. Implants used for arthrodesis are typically left in place but can be removed if causing an issue and fusion is complete. Screws placed in short bones and sesamoid bones are not removed unless associated with discomfort or infection. Orthodontic wires are always removed once the fracture is healed.

When
Timing of implant removal is based on the reason of the implant’s use and degree of achievement of its goal. There exists little scientific investigation of implant removal in the horse so the decision making process is largely subjective, no matter what the reasoning. Timing is based on case progression and not time elapsed.

Lameness, heat, swelling and/or fever are often the first signs of infection. Drainage and progressive radiolucency of the bone around the implant are highly indicative of infection. Implants associated with infection do not have to be removed immediately. Bone can heal in the presence of infection. Aggressive measures of infection control (systemic and local) are implemented instead, prolonging the function and stability of the biomechanical construct. If infection and instability are both present it is better to revise the fixation since this combination
of complications nearly always results in acute failure (support limb laminitis, contralateral growth deformity or implant fatigue) or non-union.

Implants used for correction of angular limb deformity are removed when the desired correction is achieved. If the physis is not near closure the implants are removed just prior to achievement of perfect conformation since transphyseal bridging can result in a lag between implant removal and resumed growth. If a physis must be bridged during fracture repair, implant removal is recommended if the physis retains the potential for growth. If age or physeal damage limits the potential for growth the implants can be left in place. Timing must be predicated on fracture healing but plates can often be removed from foals between 4 and 8 weeks, weanlings between 3 and 4 months and yearlings or adults between 4 and 6 months. Implants can be removed from incomplete fractures, demonstrating primary bone healing, at 90 days (mid-sagittal fractures of the proximal phalanx, plate fixation of medial condylar fractures, etc.). Implants used for olecranon fracture repair in horses less than 15 months old must be removed if the radius is engaged. Failure to do so will result in luxation of the humeroulnar joint as continued growth of the radius “drags” the attached ulna distally.

If lameness persists after healing, investigation of the potential for soft tissue impingement should be included in the workup. Radiographs should be taken in planes tangential to the tip of each screw, looking for protrusion. Ultrasonography is a useful tool to look at the implant/soft tissue interface and to measure proximity to critical structures. Dynamic sonographic imaging during flexion and extension may provide additional information about the interaction of the soft tissues and the implants. Computed tomographic imaging offers excellent anatomic detail but requires general anesthesia in most hospitals. The imminent arrival of equipment capable of CT imaging in the standing horse will undoubtedly make this a valuable and common post-operative imaging modality.

There have been no controlled studies investigating specifically implant removal as it pertains to athletic function in the horse. In horses returning to racing, certain implants should be removed to prevent pathologic fracture or pain during work. The author removes cortex screws in the diaphysis of the proximal phalanx and 3rd metacarpal/tarsal bone. Plates should be removed from any long bone other than the humerus or femur. The humerus and femur experience predominantly axial loading, decreasing the risk of fracture and the likelihood of pain from the implants. The long bones distal to the elbow and stifle experience bending and torsion and are at far greater risk of fracture or pain during loading.

How

Implant removal should be performed without general anesthesia whenever possible. During healing the bone remodels to accommodate the implants. From screw holes to re-aligned microstructure, these changes alter the way stress moves through the bone. Additionally, horses with very stiff biomechanical constructs or horses that have not borne full weight for extended periods of time may be osteopenic. Standing removal avoids exposure of the horse and the unsupported bone to the extreme forces generated during recovery from anesthesia.

The goal is improved comfort and/or athleticism after implant removal through a minimally traumatic approach. Since implants are almost always removed through smaller incisions in the same location as the original surgical approach, the surgeon is already familiar with the anatomy, especially the pertinent neurovascular concerns.

Imaging can play an important role in implant removal but is not always necessary. In the distal limb the implant is often palpable directly beneath the skin and no imaging is needed. In
many cases removal is guided by radiography with radio-opaque skin markers used for localization and targeting. Radiographs are also useful to remind the surgeon what type of screw is in which plate hole and thus which style driver will be necessary for each site. For backed-out screws beneath substantial muscle coverage, ultrasonography can be used to locate the screw head. A spinal needle (or even the metallic shaft of the driver) can be guided sonographically to the screw head. To keep things minimally invasive, however, nothing can replace tactile mapping. Tactile mapping is the ability to create a mental map of the screw head or plate hole by touching it repeatedly with the tip of the driver (or other surgical implement). Using tiny, consistent movements while mentally mapping the “thunk” of bone, the “tink” of metal, and which direction the driver slides off or around target will enable rapid and solid engagement of the implant through an incision just long enough to accommodate the shaft of the hand driver. Without tactile mapping and patience, larger incisions will be required to allow direct view of the implant.

Basic equipment includes a small surgical set, the necessary hand driver(s) and a plate hook or vise grips. Stripped and broken screw removal implements are optional. Stabs incisions are made over each screw/plate hole. It is useful to have a duplicate of the plate being removed in one’s hand to use as a template for stab incisions. The incision large enough for plate removal should be made proximally to avoid encountering the floor by attempting to slide the plate out distally. The author usually extends the most proximal stab incision proximally for this purpose. It is convenient to begin removal distally so blood flow does not obscure the site of subsequent removals. Stripped screws are easily removed with a screw removal device; a counter-threaded driver that screws into the stripped head counterclockwise until fully seated so torque can be applied in the direction that will loosen the screw. A similar device, a counter-threaded funnel, exists to remove screws broken off at the neck. A cylindrical cutter is used to remove the bone around the broken screw. The threaded funnel of the instrument is screwed onto the exposed neck of the screw until tight. Counterclockwise torque can be applied and the implant removed.

Postoperative care begins with stall rest until the incisions are healed. Gradual reintroduction to exercise begins with controlled hand walking and progresses over 1-2 months to ridden work. Ridden work and turnout should not be allowed before 30 days. Antimicrobials are indicated if infection exists or if the location of implant removal precludes adequate postoperative bandaging.
COMPLICATIONS / PROBLEMS IN THE REPAIR OF SAGITTAL P1 FRACTURES

Robert K. Schneider, DVM, MS
Learner Objectives:

- Apply the technique of lag screw fixation to the repair of sagittal P-1 fractures in the horse
- Use knowledge of anatomy and intra-operative radiographic control, participants can use a standard surgical approach to aid them in accurate placement of screws to repair sagittal P-1 fractures
- Familiarity with retrospective studies will allow the participant to accurately prognose horses with sagittal P-1 fractures for owners
Sagittal P1 fractures can be challenging without a working knowledge of the anatomy of the first phalanx and overlying soft tissues, without adequate preoperative radiographic evaluation of the fracture, or without using appropriate lag screw technique.

1. **Preoperative Radiographic Evaluation:** It is essential that high quality radiographs be made when evaluating horses with sagittal P1 fractures. Multiple views are especially critical with this fracture because it is not uncommon to have comminuted fractures that could be difficult to see with just one or two views of P1. At least 4 views, a DP, lateromedial, and 2 obliques should be taken in every horse.

2. **Intraoperative Radiographic Control:** High quality radiographs during surgery are also necessary to accurately place lag screws across a sagittal P1 fracture. Knowledge of anatomy and careful palpation of the limb can help the surgeon locate the screws. The top screw is usually located proximal to the extensor branch of the suspensory ligament. In this location, the insertion of the distal fibers of the collateral ligament can be seen. Placing the screw between these two soft tissue structures places it in the ideal location. The second screw is normally placed distal to the extensor branch of the suspensory ligament in the center of P1. While these locations can be consistently found on the limb, even experienced surgeons place a marker drill bit into the bone and take an A/P and a lateral radiograph, to assist them in lining the screws up across the fracture. Following placement of the screws, a second set of intraoperative radiographs are taken to be sure the screws are in their appropriate location and of the appropriate length.

3. **Technical Errors:** Careful palpation will avoid inserting the marker drill bit into a joint or into the screw location. The marker drill bit should be placed a little above or a little below the screws. Bending the screw during its insertion, also commonly occurs in the repair of this fracture. The bend occurs due to inadequate countersinking. The screw head does not have a concentric depression to sink into as it is tightened and an abnormal bending force is created on the screw head. This is a minor complication, although bending the screw does weaken it and could potentially result in screw breakage due to failure from cyclic loading. This is not commonly observed with the appropriate repair of this fracture.

   Leaving screws too long can result in a bump on the medial side of P1. They are a cosmetic blemish, but may be blamed for lameness if the horse does not perform well. For these reasons, if the screw is too long on the postop films, replace the screw.

   The use of suction and lavage during surgery to remove the fine fragments of bone from drilling avoids placing a bone graft around the screw head or outside the far cortex. Bone drilling can result in a bump that could also be blamed for future lameness.

   Stripping the screw during insertion is a common technical error. There is usually room for a second screw to be placed close to the stripped screw. However, another solution, if the screw that is stripped is a 4.5 screw, is the use of a 5.5 mm cortical screw in its place, or a 6.5 mm cancellous screw with a bare shank. If the cancellous screw is used, it is important that the bare shank extend beyond the fracture line when the screw is tightened or compression of the fracture will not occur.
4. **Screw Selection:** This fracture has been successfully repaired with 4.5 mm cortical screws for many years. While there are some advantages to the use of a 5.5 mm screw, it is normally not needed for the repair of this fracture.

5. **Older P1 Fractures:** P1 fractures that have gone undiagnosed or have been treated conservatively initially, can be successfully repaired with lag screw fixation. Lag screw fixation should be considered the treatment of choice in all displaced P1 fractures, even those that are several weeks old. In a retrospective study of P1 fractures treated with lag screw fixation, the duration of the fracture prior to surgical repair did not affect the postoperative racing performance.

6. **Cast Support for Recovery:** While opinions vary on the use of casts following surgical repair of sagittal P1 fractures, cast support does protect the horse's limb during anesthetic recovery. Cast support is recommended for every horse that has a sagittal P1 fracture repair because a smooth recovery can never be guaranteed. A half-limb cast has been shown to decrease the strain on P1 to 1/3 the normal strain measured in an unprotected limb. This study demonstrates the ability of a 1/2 limb cast to decrease the transfer of weight bearing loads to P1.
Application of a Standard and Transfixation Cast

Janik C. Gasiorowski, VMD, DACVS
Standard and Transfixation Cast Application
Janik C. Gasiorowski, VMD, DACVS

Learner Objectives:

- Describe the principles of cast and transfixation cast application in equine patients
- Identify the indications for both forms of cast application
- Describe the potential complications associated with both methods of casting
Standard and Transfixation Cast Application
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The main function of a cast is to support compromised tissues by eliminating or mitigating the forces acting on the site of injury. Bending forces are eliminated by maintaining axial alignment of the limb. Tension on soft tissue structures is mitigated by preventing flexion or extension of nearby joints. Torsion is controlled by including the foot in the cast and designing the walking surface to spin easily and break over smoothly in all directions. A cast can serve as primary means of stabilization or function as adjunctive support to other means of orthopedic fixation. Injuries compromising completely the axial stability of the limb are poorly managed by standard casting techniques alone and almost always require surgical reduction and internal fixation. Transfixation casting incorporates bicortical bone pins into a standard cast to prevent axial collapse of a fracture that cannot be stabilized by a standard cast or internal fixation alone.

Principles
To fulfill these requirements, above all else a cast must be rigid. Rigidity and ultimate strength are clearly determined by thickness but as importantly, are predicated on cohesion and thus proper application. In the horse, immediate weight bearing and constant motion are essential so all parts of the cast must be resistant to cyclical loading. It must be padded strategically to reduce pressure points, yet thinly enough that the limb cannot move within it. Excess padding compromises the rigidity of the construct by allowing motion within the cast and by increasing the distance from the central axis of the limb to the wall of the cast. This increased moment arm can also potentiate cast failure. A cast must extend far enough beyond the focus of compromise to support effectively the damaged structure(s). It should terminate at the proximal metaphysis or epiphysis of the long bone beneath it. Ending the cast in the diaphysis of a long bone can focus tremendous bending force and result in catastrophic fracture. Ending the cast near the proximal metaphysis allows these forces to be diffused through the soft tissues of the joint.

A transfixation cast eliminates axial loading at the site of injury by transferring the forces of weight bearing to the intact skeleton via bicortical pins placed proximal to the damaged tissue. A transfixation cast can be used alone or in conjunction with internal fixation. Severe comminution and financial restrictions (no option for surgical reduction and internal fixation) are the most common reasons for using a transfixation cast as the primary means of stabilization. Fractures that are severely comminuted have a better prognosis than those with a simple configuration when managed with a transfixation cast (Nemeth, 1991), presumably because the comminution diffuses interfragmentary strain. Severely comminuted fractures, especially those involving the articular surface of a high-motion joint, may have a better outcome if anatomically reconstructed. These repairs are tenuous at best and a transfixation cast must be applied to eliminate or reduce cyclical loading after internal fixation. Transferring load proximal to the site of injury also allows earlier return to weight bearing, reducing the likelihood of support limb laminitis.

Indications
Indications for cast application include injuries disruptive of musculoskeletal integrity, traumatic or surgical wounds requiring immobilization and orthopedic fixation requiring protection during recovery from general anesthesia. Indications for transfixation cast application
include fractures lacking axial stability and internal fixation unable to support immediate weight bearing and in need of protection from cyclical loading.

**Application of a standard cast**

The strength of a cast is predicated on the material properties but also on cohesion of its layers. As long as cohesion is achieved, a thicker cast will be stronger. Without cohesion, thickness will not add strength. Immobilization of a joint above and below the lesion is ideal but not always achievable or necessary. The desired primary dressing is applied over the wound (if present). The upper half of twice-long stockinet is rolled over the limb. The lower half is twisted at the toe, and rolled up the limb over the first layer. An orthopedic felt collar is placed around the proximal metaphysis where the casting material will end. Very little extra padding is required. Cotton is commonly used but modern synthetic materials perform very well, affording better air circulation and limiting accumulation of moisture. Before the cast tape is applied the limb must be placed in its anatomic weight bearing position. For full limb cast application the carpus or stifle must be locked in extension. It is difficult to extend fully the distal limb in the anesthetized horse. To gain leverage, a heel loop is created by running orthopedic wire through holes drilled in the distal centimeter of hoof wall at the caudal aspect of each heel. The tip of a farrier’s rasp is placed between the wire loop and the heels, parallel to the axis of the frog, with the handle extending dorsal to the toe. In order to maintain full extension of the digit, an assistant applies dorsoproximal force until the cast cures. Except in special situations, the foot should always be included in the cast. A 3° - 5° heel wedge should be applied to the sole before (or during, and casted over) casting. The wedge will help diffuse weight bearing over the entire sole instead of just at the toe. Too large a wedge will predispose the horse to sores over the proximal sesamoid bones, whereas too small a wedge will exacerbate pressure at the dorsal aspect of the coronary band and proximal cannon bone. Gigli wire (run through tubing to protect the skin) can be incorporated into the cast if the veterinarian removing it does not have access to an oscillating saw. Fiberglass casting tape is soaked thoroughly immediately before use. Excess water is allowed to drip out; do not squeeze the roll. Warmer water will decrease curing time. Inexperienced surgeons benefit from the extra time allowed by the use of cooler water when first learning to apply a cast. Narrower rolls of casting tape are easier to conform to the shape of the limb. Begin with a 3” or 4” wide roll (especially around the foot and pastern) and switch to 4” or 5” wide rolls as casting progresses. Cast material is applied smoothly and swiftly without folds or creases, overlapping at least 50% between wraps. Cast tape is applied with only enough tension to get the material to unroll; excess tension can result in pressure necrosis. A minimum of 6 layers of fiberglass is recommended but more will be necessary over stress points (the bend in the fetlock or hock) or to support transfixation pins. Expect to use 5-6 rolls for a distal limb cast and 10-12 rolls for a full limb cast. Polymethyl methacrylate can be applied in the form of a convex dome to the solar surface of the cast to increase durability and to decrease torsional forces on the limb. Without solar reinforcement, a weight bearing horse will break through the bottom of a fiberglass cast in a matter of days. It is advisable to put a boot, pad, or specialized shoe on the contralateral foot. It will offer support during chronic excessive weight bearing and will correct the limb length disparity that results from casting.

Foot, foot/pastern and distal limb casts can be applied without general anesthesia. The same principles of application apply. Ideally, the horse should be able bear weight safely without the cast if casting is to be attempted with the horse standing. Adequate physical and chemical (too little is better than inducing ataxia with too much) restraint is a prerequisite. An assistant holds
up the limb during cast application, making sure it is as close to the anatomical weight bearing position as possible. Once the entire cast is applied, but before it cures, the horse is allowed to bear weight on the newly casted limb. The cast hardens with the limb in perfect weight bearing position.

**Application of a transfixation cast**

Transfixation pins are placed proximal to the fracture, 2-4cm apart, 30° divergent from the frontal plane but parallel in the transverse plane (McClure, 1994). For a distal limb transfixation cast, pins are placed in the distal metaphysis (and occasionally the epiphysis) of the 3rd metacarpal or metatarsal bone. The diaphysis should be avoided due to increased risk of ring sequestrum formation and pathologic fracture. The cancellous bone of the epiphysis and metaphysis diffuses evenly the strain exerted by the pins, whereas in the diaphysis all the strain if focused on the cortices. Two ¼” pins are used most commonly, but some surgeons prefer to use 4 or smaller Steinmann pins instead. Centrally threaded positive-profile pins of ¼” diameter are an excellent option. Stab incisions are made at the sites of pin entry and exit. Standard drilling technique generates excessive heat with a drill bit of this size. Thermogenesis is mitigated by drilling a pilot hole with a 4.5mm bit, then sequentially enlarging it with a 5.5mm, then 6.2mm bit, or by using a purpose-built step drill (Bubeck, 2009). The diameter of the prepared hole is 0.1mm smaller than that of the core diameter of the pin, creating radial load at the bone-pin interface. Pins are inserted under irrigation and advanced until the threads engage both cortices.

Both ends of the pins are cut 3-5cm from the skin prior to application of the cast. Cutting the pins obliquely leaves sharp ends that can facilitate piercing the casting materials. Stockinet, orthopedic felt and the heel wedge are applied as with a standard cast, allowing the pins to pierce the stockinet. Cast tape is also applied in a similar fashion, with the pins piercing the tape (an assistant can facilitate this process with a #11 scalpel blade). The pin-cast interface will be the focus of weight bearing forces so proper lamination/cohesion of the layers is absolutely critical. Different methods of interfacing the pins and cast have been investigated (McClure, 1996) but none were significantly different from the rest and the strength of the fiberglass cast material was the most important determinant of axial stability. The pins are either covered with acrylic or cut flush with the cast and covered with another roll of cast tape. Leaving the pins standing slightly proud to the cast facilitates pin extraction without cast removal.

Lescun et al. (2012) compared hydroxyapatite-coated centrally threaded positive-profile pins to uncoated pins in vitro and found a marginal increase in construct stability with the coated pins but inconsistent osteointegration. Brianza et al. (2011) investigated a pin-sleeve construct in vitro, finding that it reduced strain at the bone pin interface and did not compromise axial stiffness. Hopper et al. (1998) found that up to three ¼” pins could be used in the radius for a full limb transfixation cast without compromising significantly the strength of the bone. Three-eighth inch holes, however, significantly decreased the torsional strength of the radius.

**Complications**

Complications are common with standard and transfixation casts. Horses wearing any kind of cast, and the cast itself, should be evaluated closely multiple times per day. Lameness (or decreased use of the limb if the horse is already painful) is often the first sign of an issue. The cast should be palpated daily for focal areas of increased heat and for cracks or weak spots. The cast should be visually inspected for damage and for strike-through. Cast sores are the most
common complication of cast application and are almost always due to motion within the cast, but occasionally to pressure necrosis. Cast failure occurs most commonly from improper application. Folds and ridges in the casting tape prevent lamination and create weak spots. Slow application of the material allows partial curing of one layer before the next is applied, resulting in little to no cohesion. Pathologic fracture of the limb is possible, especially with full-limb casts or if the cast ends in the diaphysis of a long bone. A full hind limb cast fixes the hock but not the stifle, allowing the powerful hamstrings to overpower the passive stay apparatus, resulting in rupture or avulsion of the peroneus tertius. Use of any rigid coaptation in an immature animal will result in laxity of the supporting tendons and ligaments.

All of the complications associated with standard casts apply to transfixation casts. The most common complication specific to transfixation casts is pin loosening. Bone necrosis (thermal damage), ring sequestrum formation, pin tract infection and pathologic fracture through the pin holes are also possible.
Evaluation and Treatment of Angular Limb Deformities by Transphyseal Bridging and Periosteal Transection

Alan J. Ruggles, DVM, DACVS
Evaluation and Treatment of Angular Limb Deformities by Transphyseal Bridging and Periosteal Transection

Alan J. Ruggles, DVM, DACVS

Learner Objectives:

- Identify the common angular deformities in growing horses
- Examine the relationship between multiple levels of angular deformities in the horse
- Describe the indications and application for surgical management for angular deformities in the horse
Evaluation and Treatment of Angular Limb Deformities by Transphyseal Bridging and Periosteal Transection

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Introduction

Orthopedic deformities in foals can be both congenital and acquired. Congenital problems are present at birth and usually obvious. Congenital angular and flexural deformities can lead to dystocia and in some cases necessitate fetotomy or Caesarean section to relieve the dystocia. Many foals are born with some degree of flexural or angular limb problem. The most common appearance is a degree of flexor laxity and carpal and/or tarsal valgus deformity. Fortunately, these deformities usually self-correct with exercise and age and should be considered normal findings in a newborn foal. Likewise congenital flexural deformity of both the metacarpal/tarsal phalangeal joint, distal interphalangeal joint and carpus may be present. Mild forms of these conditions will self-correct with age and exercise but in my experience moderate to severe congenital flexural deformity usually requires some type of intervention.

Orthopedic evaluation of a foal can be difficult and foals will often look different inside and outside of a stall. For example a foal with even a mild lameness may be non-weight bearing when turned in a stall but look much less lame when walked with the mare. Also it is difficult to accurately assess flexural and angular deformities with a foal standing in a stall. For this reason I usually evaluate conformation and gait with the foal outside of the stall. Historical information regarding conformation of siblings or half-siblings should enter into the equation regarding future conformation and management. Likewise the conformational tendencies of the mare and stallion should be considered as well.

Consideration of the entire limb is paramount when deciding on therapies. Conformational abnormalities of the foot should be corrected and use of foot trimming or extension by themselves can be very effective in correcting conformation abnormalities of the fetlock and carpus. Often foals will have opposite conformational abnormalities of the fetlock and carpus. For example, most foals with significant carpal valgus deformities tend to accommodate this problem by developing a fetlock varus deformity. It is important to keep this in mind as the carpus is corrected because failure to address this may lead to a permanent fetlock varus deformity despite a straight carpus.

Angular Deformities

Most foals are born with some degree of tarsal and carpal valgus deformity. This is generally considered normal. As the foal matures many angular deformities completely improve. Moderate to severe (>10 degrees) valgus deformities that are still present at 6 weeks are considered abnormal and require evaluation. Causes of valgus deformity include ligamentous joint laxity, physeal dysplasia and cuboidal bone abnormalities. Ligamentous joint laxity can be assessed by manipulation of the foal’s limb. Radiographs are required to diagnose physeal
dysplasia or cuboidal bone problems. Dorsopalmar radiographs reveal the location of the angular deformity by the center of the angle formed by lines drawn down the center of the metacarpus and radius. If the lines meet in the physis or epiphysis than the abnormality originates from the physis. If the lines meet in the carpus then the source are the cuboidal bones. It should be noted however that concurrent rotational deformities of the limbs may make radiographic interpretation of the exact location of the deformity somewhat inexact. Fortunately, most of the boney causes for angular limb deformities are in the physis, which is more easily corrected surgically.

Periosteal elevation and transection has been accepted as an effective means of correcting angular limb deformities in growing horses. The surgery is performed on the “short” side of the bone (in the case of a valgus deformity on the lateral side) and the transection performed 2 cm proximal to the physis. Growth acceleration occurs on the operated side and overcorrection is not possible. Surgical correction for fetlock deformities should be performed before 8 weeks of age and for carpal deformities by 4 months of age. The earlier the surgery is performed the more rapid the correction, however case selection is important since some foals will self-correct.

In cases of severe angular deformity or in older foals and yearlings physeal retardation with screws and wires or transphyseal screws are necessary to slow the growth on the “long” side of the bone. In our practice physeal retardation of the fetlock is exclusively accomplished with transphyseal screws and that of the carpus with screws and wires up thorough approximately 12 to14 months of age > after 14 months it seems to be safe to use transphyseal screws with limited risks of overcorrection of the carpus in yearlings after removal. In the tarsus I am more aggressive with the placement of transphyseal screws in the distal tibia and have used them in foals as young as 4 months of age without overcorrection. I prefer this technique to screws and wire in these cases do faster correction, lower risks of incisional complications and improved cosmetic outcome.

Corrective osteotomy is occasionally used to correct severe deformities of the carpus / tarsus distad when physeal manipulation is not possible either due to the age of the animal, physeal dysplasia or premature closure or location of the deformity (e.g. mid-metacarpus/tarsus). Frontal step osteotomy is the preferred method when appropriate since correct limb alignment is more easily achieved than when using a collapsing wedge ostectomy. The ability to place cortex screws in lag fashion across the osteotomy helps secure the construct which typically consistent of a single plate on the dorsal aspect of the bone.

**Surgical Procedure Transphyseal Screw Fetlock:**
Placement of transphyseal screws across it the distal metacarpal / tarsal physis is performed with the foal under general anesthesia in dorsal recumbency. After aseptic preparation of the distal limb the skin is rotated and the physis identified with 2, 20 gauge hypodermic needles which fixes the rotated skin such that the skin incision and the implant will not be directly over each other when the needles are removed. Once the physis is identified a stab incision is made over distal lateral cannon bone, for varus deformities, or the distal medial cannon bone for the less common valgus deviation of the fetlock, approximately 20 mm proximal to the physis. A 3.2 mm drill bit is placed at first somewhat perpendicular to seat the drill bit and then angled approximately 30 degrees to the long axis of the bone pointing distally. The hole is drilled
approximately 44 to 46 mm and then tapped with a 4.5 mm tap. The hole is not countersunk and a 4.5 mm diameter x 36 or 40 mm cortex screw is placed. Placement of the screw is confirmed by radiographic control. Closure of the incision can include subcutaneous sutures and adhesive strips or skin sutures. Alternatively, 3.5 mm cortex screws can be used. The implants are removed when the conformation improves.

**Surgical Procedure Transphyseal Bridge Carpus:**
In foals and yearling less than 12 to 14 months of age, a transphyseal bridge of the distal radial physis using a screw in the physis and metaphysis and a 1.25 mm wire is accomplished with horse under general anesthesia in dorsal recumbency. The skin on the distal radius is rotated and fixed with 2 needles in the distal radial physis. Two stab incisions one in the mid - distal epiphysis and one in the distal metaphysis of the radius, approximately 60 to 70 mm proximal to the first incision are made. The incisions are made over distal lateral radius, for varus deformities, or the distal medial radius for the valgus deviation of the carpus. A length 1.25 wire, shaped into a figure of eight is passed subcutaneous using a Kelly hemostat with free ends of the wire positioned proximally. The holes are drilled and tapped for a 3.2 mm cortex screw. The screws are placed but left about 10 mm from final tightening while the wire is tightened. No countersink is used. The wire is then twisted over the screw and tightened. The ends are cut and the end of the twist pushed against the bone. Final tightening of the screws is by hand. Care must be taken not to over tighten the epiphyseal screw which could allow the wire to slip over the screw head, especially in young foals. Closure of the incision can include subcutaneous sutures and adhesive strips or skin sutures. The implants are removed when the conformation improves.

In yearlings greater than 14 months of age single transphyseal screws may be placed. Typically a 50 mm, 4.5 mm self –tapping screw in placed in a method similar to that used for the fetlock

**Surgical Procedure Transphyseal Screw Tarsus:**
Placement of transphyseal screws across it the distal tibial physis is performed with the foal under general anesthesia in dorsal recumbency. After aseptic preparation of the distal limb the skin is rotated and the physis identified with 2, 20 gauge hypodermic needles which fixes the rotated skin such that the skin incision and the implant will not be directly over each other when the needles are removed. Once the physis is identified a stab incision is made over distal aspect of the lateral tibia, for varus deformities, or the distal aspect of the medial malleolus for valgus deviations of the tarsus. Radiographic control is needed prior to placement of the screws since penetration of the tibial-tarsal joint is possible. After conformation of correct location for the drill a 3.2 mm drill bit is used to drill the shaft hole for the 4.5 mm screw. The hole is drilled approximately 60 mm and then tapped with a 4.5 mm tap. The hole is not countersunk and a 4.5 mm diameter x 50 or 54 mm cortex screw is placed. Alternatively, 4.5 mm self-tapping screws can be used. Placement of the screw is confirmed by radiographic control. Closure of the incision can include subcutaneous sutures and adhesive strips or skin sutures. The implants are removed when the conformation improves.
Intra-operative placement of the Figure of 8, 1.25 mm wire subcutaneously

Intra-operative radiograph of a transphyseal bridge placed carpal valgus deformity in a foal

Postoperative radiograph of a distal radial transphyseal screw to correct a carpal varus deformity in a yearling

Intra-operative radiograph of placement of transphyseal screw in for tarsal valgus deformity in a foal

Radiograph prior to removal of transphyseal screw after correction of a fetlock varus deformity
Principles of Managing Orthopedic Injury in the Foal

J.P. Watkins, DVM, MS, DACVS
Principles of Managing Orthopedic Injury in the Foal
J.P. Watkins, DVM, MS, DACVS

Learner Objectives:

- Describe the reasons foal fractures are good candidates for internal fixation
- Describe the potential complications of major orthopedic injury in foals
- Identify methods to minimize complications related to orthopedic injury in foals
Foals, due to their relatively small stature and healing capacity, are good candidates for fracture treatment. The active periosteum and rapid rate of bone remodeling allow healing to proceed faster than in adults. The forces acting at the fracture site are less than in full size horses and therefore the devices used to provide fracture stability are under less stress. Less stress on the bone-device construct allows us to provide constructs that impart substantial strength and stability as well as having an extended fatigue life. These mechanical advantages translate into greater patient comfort and reduced incidence of construct failure when compared to adult horses.

Additional advantages of treating fractures in foals compared to adults include the ability to better control recovery from anesthesia reducing the risk of catastrophic failure of the bone-implant construct during this critical period. In addition, laminitis does not occur in foals as a consequence of overloading the support limb. Finally, the cost of therapy is generally less prohibitive.

Potential disadvantages include the development of angular deformities, especially varus, and failure of the fetlock suspensory apparatus as a consequence of overloading the support limb. Contractures are also more common in foals as a consequence of inadequate loading of the injured limb. Although pediatric patients in other species are often characterized as having soft or poor quality bone for implant purchase, this has not been my experience with foals, with the exception of the apophysis of the olecranon in neonates.

Open reduction and internal fixation (ORIF) should be considered the technique of choice for foals with axially unstable long bone fractures. Although an open approach increases the risk for introducing infection to the fracture site, an early return to full weight bearing on the injured limb following anatomic reduction and compressive fixation is highly advantageous compared to alternative methods of fracture management.

Appropriate internal fixation usually entails application of two plates, although there are a few fractures that can be adequately stabilized with a single plate. Current state-of-the-art fixation incorporates LCP technology. Implant selection is dependent on the size of the foal, bone affected and characteristics of the fracture. Principles of equine plate fixation should be adhered to and include anatomic reduction and compressive fixation of major fracture fragments. Plates should be applied at right angles to each other, with one plate positioned on the tension surface of the affected bone. A plate should be positioned over butterfly fragments or cortical defects resulting from areas of small comminution which cannot be reconstructed. The fixation should span from the proximal to distal ends of the bone, but avoid crossing the physis unless the fracture dictates otherwise. All screw holes in the plates should be utilized, and when possible, screws crossing fracture lines are placed in lag fashion. In general, we strive for bi-cortical purchase with a minimum of 7 screws in the major proximal and distal fracture segments, the majority of which are either 5.5mm cortex screws or 5.0mm locking screws. Locking screws are most advantageous when placed adjacent to the fracture and at the ends of the plate(s). Furthermore, when a unicortical screw is necessary, a locking screw should be used.

Axially unstable fractures of the proximal limb must be addressed by ORIF as they are NOT amenable to alternative methods of fracture management. There are exceptions, including some fractures of the humerus. Although internal fixation with an intramedullary interlocking
nail alone or in conjunction with a bone plate provides the best outcome, it is possible to have a successful outcome with conservative therapy. Conservative management has also been successful in a small subset of fractures where displacement is minimal; e.g. apophyseal fractures of the olecranon in neonates.

Certain axially unstable fractures of the distal limb may be better managed by external methods alone or in conjunction with limited internal fixation. Choosing between ORIF and external methods requires weighing the advantages and disadvantages of each with regards to attaining the biological and mechanical requirements for healing while at the same time minimizing potential complications. Consideration should be given to external methods of fracture management when there is substantial disruption of the soft tissue envelope overlying the fracture with stripping of the periosteal sleeve and/or considerable contamination or established infection. In these instances, the widely invasive surgical approach used for direct reduction and fixation will further compromise the blood supply to the injured bone as well as spread contamination throughout the surgical site. In addition, fractures with characteristics that preclude ORIF may be candidates for external methods including excessive comminution that disallows anatomic reconstruction and when the fracture is located near the end of a bone preventing adequate implant purchase in the short fracture segment.

A major disadvantage of external methods of fracture management is the necessity to incorporate the digit into the cast or transfixation cast. Although the digit could be spared in some fractures by employing external skeletal fixation (ESF), such devices lack the mechanical attributes needed for fracture management, even in small foals. Currently, the technique of choice for fractures not amenable to conventional cast application is transfixation casting. However, either method will result in substantial laxity of the weight supporting ligamentous and tendinous structures of the digit. The resulting hyperextension is a major disadvantage and requires a substantial period of rehabilitation to resolve once the support device is removed. A gradated reduction in support in conjunction with heal extension foot plates can result in a successful outcome, however, there are instances when even with appropriate rehabilitation, long term disability can result.

Prolonged, painful convalescence during fracture healing results in a number of complications, both to the injured limb as well as the support limb. Tendon / joint contractures can occur in either, but are most common in the injured limb as a result of reduced weight bearing. The most common contractures occur at the fetlock and coffin joints. The carpus can also be affected. In most cases, these can be managed once the inciting cause, i.e. pain from the healing fracture, is resolved. Transection of the check ligaments is indicated for contractures of the digit. When carpal contracture occurs, check ligament transection in conjunction with tenotomy of the ulnaris lateralis and flexor carpi ulnaris is usually curative.

Complications in the support limb are usually some combination of hyperextension of the digit and varus angulation of the limb. Fortunately, laminitis is rare (nonexistent) in the support limb of foals. However, excessive weight bearing, secondary to a prolonged, painful period post fracture, overloads the weight supporting ligamentous and tendinous structures of the digit. With chronic overload, these structures undergo stress-relaxation, effectively increasing their functional length. This can be exacerbated by support bandages, where stress-relaxation is compounded by support-induced laxity. Clearly, the most important aspect of prevention is an early return to pain-free status and full weight-bearing on the injured limb. In addition, there appears to some benefit to applying a foot plate with ample heel extension. Regarding angular deformities of the support limb, it seems these result from the foal taking a tripod stance, where
the support limb is positioned at or close to midline. In this alignment, they often rotate the digit internally, and place excessive tensile forces on the lateral aspect of the fetlock and carpus / tarsus. This stance puts the lateral periarticular support structures under constant tension causing them to elongate as a consequence of stress-relaxation and external bowing of the limb occurs. With bowing, the lateral support structures are placed under further tension, exacerbating the problem, and the medial aspects of the physes are compressed excessively, decreasing growth and compounding the deformity. Although most foals will become varus as a result of overload, some foals, who assume the tripod stance but rotate the digit externally, will develop excessive inward bowing. The resulting valgus deformity occurs by the same sequence of events, but is due to excessive tension on the medial support structures and compression on the lateral aspects of the physes. Application of a hoof plate which extends laterally (for varus) or medially (for valgus), may be beneficial in preventing these deformities. If deformity occurs, and adequate growth remains, growth plate retardation may aid in correcting the angulation.
Principles and Technique of Plate Application in the Horse

Prof. em. Dr. Dr. h. c. Jörg A. Auer, Dipl. ACVS, ECVS
Principles and Technique of Plate Application in the Horse
Prof. em. Dr. Dr. h. c. Jörg A. Auer, Dipl. ACVS, ECVS

Learner Objectives:

- Identify the techniques of plate application
- Describe where to apply the different implants
- Apply the correct principles
Principles and Technique of Plate Application in the Horse

Prof. em. Dr. h. c. Jörg A. Auer, Dipl. ACVS, ECVS
Past Chairman AOVET

Basic facts for plate application include the following statements: The shape of the plate and its adaptation to the anatomic situation does not dictate its function. Therefore the same plate may be applied to fulfill different functions, which include Compression, Neutralization (Protection), Buttress- und Tension band plating. A single plate may fulfill several functions at the same time.

Compression

Compression may be achieved 1. with the Dynamic Compression Plate (DCP), 2. with the tension device, 3. through over-bending at the fracture site and 4. through the combination of compression and lag screw insertion through the plate.

DCP: The DCP principle is based on a ball rolling down an incline (Fig. 1). The screw head represents the ball and the incline is incorporated into the plate hole (Figs. 2 & 3). When the screw head makes contact with the top part of the incline in the plate hole it has a tendency to slide down along its surface while being inserted into the underlying bone. After being completely tightened, the screw head finds itself in the center of the plate hole.

The screw is inserted into the bone underneath the plate and it is impossible to elongate or change the plate. Therefore, the only change that can occur is the movement of the screw including the underlying bone. This movement facilitates axial compression of the bone ends. To facilitate asymmetric drilling of the screw hole, special drill sleeves were developed. The neutral drill guide allowing concentric drilling of the screw hole within the plate hole as marked green (Fig. 4). The load guide, providing 1 mm of compression is marked yellow (Fig. 5).
On each side of the fracture a maximum of two screws may be inserted in load position. Before the second screw can effectively produce compression, the first screw on the same side has to be loosened.

Application of a plate is carried out as follows: Initially a soft aluminum template of the same length and width (Fig. 6) With the help of the bending pliers (Fig. 7) or the large bending press (Figs. 8 & 9), the plate is subsequently contoured to match the shape of the template and the bone.

The next step is the preparation of the first screw hole across the plate – in plate screw function (threads in both cortices) – and the plate inserted, but not completely tightened. The plate is then drawn toward the fracture line, which places the first screw in load position. Subsequently a second plate screw is inserted either in load (Fig. 10) or neutral position – dependent upon the need of additional compression - on the other side of the fracture line. Once both screws are in place, they are solidly
tightened, bringing the fracture plane under axial compression. Subsequently the remaining screws are inserted through all plate holes either as lag- or simple plate screws and tightened (Figs. 11 & 12).

**Tension device:** Prior to applying the tension device (Fig 13) the plate is attached to the bone through at least one plate screw (Fig 14) - better several plate screws - in neutral position. The tension device is the hooked into the opposite end of the plate, attached to the bone with the help of a short screw, and the device tightened with wrench (Fig. 15). Tightening of the device pulls the bone opposite the fracture plane nearer to the tension device and in doing so compresses the fracture. As soon as adequate compression is achieved, a plate screw in neutral position is inserted through a plate hole near the tension device. The tension device can then be removed and the remaining screws implanted. It is possible to also insert screws in lag fashion across the fracture.

**Over bending of the plate:** If axial compression is applied in a fractured bone through application of a plate, which perfectly matches its surface, the compression is only achieved directly under the plate, whereas on the opposite bone side a gap develops (Fig. 16). Through minimal acute over bending of the plate at the fracture site (± 1mm) and subsequent insertion of the screws into the identical holes circumferential compression can be achieved (Fig. 17)
Compression along the fracture plane is demonstrated with the help of a liquid crystal model. On the two pictures on the left (Fig. 16), the compression across the vertical line is shown before (above) and after tightening of the two central screws. Initially no compression is seen (above) and after tightening the screws, compression is concentrated under the plate (below). On the right pictures (Fig. 17) the situation is shown with same plate after slightly over bending it at the fracture site. By partially inserting the screws into the identical holes (above) no compression is achieved. Once all screws were tightened, compression is achieved along the entire line (below).

**Combination of compression and lag screw:** (Fig. 18) The combination of compression and lag screw is achieved after initially inserting a plate screw on either side of the fracture plane, as described above. However, the screws are not tightened completely. Subsequently the plate holes over the fracture plane are filled with one or two screws inserted in lag fashion, approximately at a right angle relative to the fracture plane. After tightening the screw(s), the two initially inserted, but not tightened plate screws are tightened solidly. The fracture is now under compression and the remaining screws can be inserted in neutral position.

**Fig. 18:** Two shaft screws were inserted at a right angle relative to the fracture planes as lag screws through two plate holes. The rest of the plates were inserted in neutral position.

In oblique - and spiral fractures it is important that a plate is applied over the lowest point of the proximal fragment. Because the proximal fragment has a tendency, as a result of load-bearing, to slide distally along the fracture plane, it should be pressed “into” a plate, which results in superior stability.

**Neutralization:** The neutralization plates are applied over a bone, which was previously reconstructed with the help of lag screws (Fig. 19). The fragments are under interfragmentary compression, but would not withstand normal axial loading. The pate(s) effectively neutralize the shear forces created during loading. The pate(s) effectively neutralize the shear forces created during loading and prevents collapse of the repair. Initially the large fragments are reduced and fixed in that position with the help of at least two lag screws. Subsequently, two plates covering together the entire length of the bone are applied at a 90-degree angle relative to each other. Screws crossing the fracture plane are implanted in lag fashion, whereas most of the remaining screws are implanted in neutral position.
Abb. 19: Fracture of the tibia of a heifer fixed with 2 compression screws (arrows) and 2 DCP’s, applied at a 90° angle relative to each other

Buttress plate: (Fig. 20) The buttress plate has the function to bridge a bone defect or an area in which the cortex is destroyed into many small pieces, and prevent a breakdown at this place. Such defects are found mainly in the diaphyseal region, where the cancellous bone is predominant and the cortex is relatively thin. Initially, a solid fixation and reconstruction is achieved, followed by application of the buttress plate over the defect. The plate prevents a collapse of the relatively weak aspect of the bone. However, because of the fact that most plate holes are oval in shape and therefore allow a certain degree of movement. Filling the plate holes around the screw with bone cement prevents such minimal movement effectively.

Angling of the screws within the plate holes (21)
Most screws – except the locking screws – can be angled within the plate holes: - 4.5mm screws along the longitudinal axis 25° to each side and sideways 7° left and right. With the use of thicker plates the potential angling degree diminishes accordingly. Such an angling is often indicated to avoid placing a screw into a fracture plane in the opposite cortex etc.
The introduction of LCP technology to Equine fracture management is a great step forward and undoubtedly this technology has established itself as THE state of the art technique. However there ARE differences relative to conventional fracture treatment that have to be recognized and dealt with. The purpose of this presentation is to show you how to apply this exciting technology.

**Application**

Locking head screws have to be inserted perpendicular to the long axis of the plate. Interlocking of the screw head with the threads in the plate hole results in an angle stable fixation – an INTERNAL FIXATOR. This makes double plating difficult. It is better manageable when only locking head screws are used. Pre-planning is really necessary when cortex screws and locking head screws are used because the different screws are inserted in different locations within the combi-holes.

Insertion of two locking head screws in each major fragment is adequate to maintain axial stability and prevents micro-movement of the fixation. A study revealed that the LCP is significantly stiffer than all the other ones applied in Equine surgery today, making it the implant of choice. Anatomic contouring to the bone surface is not a prerequisite for a functional and successful fixation, because of the locking technology. However, if the plate needs to be pressed onto the bone surface, the cortex screws need to be inserted first. Once the locking screws are inserted no change relative to plate-bone position is possible anymore.

Insertion of locking head screws under large muscle packages is difficult because of the vertical nature that the screws need to be placed. This can be achieved through transmuscular stab incisions orthogonally over the respective plate hole.

The LCP is a universal plate because all fractures can be treated with either cortex screws only (like DCP & LC_DCP), a combination of locking head and cortex screws, or exclusively locking head screws. LCPs are minimally more expensive than DCPs and LC-DCPs. All that is needed to get into locking fixations is some special instruments and the more expensive locking head screws.

**Suggestions for preventing complications**

1. **Initially use only Locking screws in double plate fixations**

   The geometry of the combi-hole (axially longer) is different than the DCP-hole (axially shorter). Also in the combi-hole the surgeon has the possibility to insert screws at either end of the plate hole. These two facts make application of a DCP in combination with an LCP very difficult. The principle of perpendicular screw insertion relative to the long axis of the plate / bone cannot be upheld in most situations. The locking screws HAVE to be inserted perpendicularly, so the cortex screws have to be
placed to MISS the locking screws. If an LC-DCP is used the problems are lessened because the DCU has about the same axial length as the combi-hole. However the fact the locking screws and the cortex screws are inserted at different special locations within the combi-hole still cause problems in planning the cortex screws in the LC-LCP. Therefore it is a wise and timesaving decision to initially apply only LCP’s when you apply two plates at right angles relative to each other – but it IS more expensive!

2. *Do not underestimate the forces that act on the implants*
   LCP technology does increase the stiffness of the construct, but the biomechanical forces also cause cyclic loading and eventual failure in LCP’s. Keep the basic principles for plate fixation in horses in mind, when you apply LCP’s. If the cranial plate in a radius fracture breaks because it is to short, act immediately, because the laterally applied LCP can’t prevent complete construct failure. Note: even locking screws can retract when they are inserted into an unstable fracture line.

3. *If you want to pull the plate to the bone insert the strategic cortex screws first*
   In conventional plate application in horses it is possible to press an inadequately contoured plate completely to the bone with the cortex screws inserted into all the plate holes. This is impossible with LCP technology unless you use the “pull-push device. Therefore it is of great importance to initially insert the strategic cortex screws and press the plate onto the bone as good as possible of desired, before applying locking screws. Note, because LCP technology represents an internal fixator, it is NOT imperative that the plate is absolutely contoured to the surface of the bone – but it still is better.

4. *Don’t forget to assure bone-to-bone contact at the palmar/plantar aspect of the bone*
   As mentioned earlier it still is important to remember the basic principles of plate fixation. The necessity of bone-to-bone contact at the palmar/plantar aspect of the bone still holds true.

Apply LCP’s carefully and properly and you will be totally convinced by this fascinating technique.

**Literature:**


Treatment of Small Metacarpal / Tarsal Fractures

José M. García-López, VMD, DACVS
Learner Objectives:

- Describe the anatomy of the splint bones
- Identify patients with complicated splint bone fractures
- Recognize the most appropriate treatment of simple and complicated splint bone fractures
- Explain new developments and implants for the treatment of splint bone fractures
- Identify complications of splint bone fractures and how to manage them
Distal Fractures of the Small Metacarpal/Metatarsal Bones

Background:
Splint bone (MC/MT-2&4) fractures can occur in any area of the bone, but the majority involve the distal 1/3. Distal splint fractures are typically seen in performance horses. In general, this population of horses is older than that of horses with proliferative periostitis (typically 5-7 yrs. old for distal fractures vs. 2-3 yrs. old for acute “splints”). Overall, fractures in the forelimbs are probably more common than those in the hind limbs (but the incidence varies with each breed).

i.e. TBs: left MC-2, right MC-4 most frequent.
STBs: left MT-2, right MT-4 most frequent.

Etiology:
Internal Trauma: Related to hyperextension of the fetlock joint with tension on the interosseous and suspensory ligaments. The suspensory ligament attachments to the distal aspect of the splint bones are stronger than the bone itself. This injury can be a “fatigue” fracture (cyclic trauma) or a single traumatic event. In TBs they result from increased axial loading at speed, in the forelimbs. In STBs the fractures are suspected to result from a snapping or “bow string” effect of the suspensory ligament at speed in the hind limbs.

External Trauma: Theoretically, any form of trauma, but kicks and interference (one leg hitting another) are very common causes.

Key Point:
There is a high incidence of concurrent suspensory desmitis associated with distal splint bone fractures. Bowman, et al, 1982: 81% of STBs and 67% of TBs with distal splint fractures had concurrent suspensory desmitis. Whether the desmitis is primary or secondary to the fracture is sometimes unclear, but in most cases it precedes the fracture. In the case of primary suspensory desmitis, the swelling/inflammation predisposes the bone to a greater likelihood of fracture (through various proposed mechanisms).

History & Clinical Signs:
Typically an acute lameness. The degree of associated signs of inflammation varies with the severity of the associated suspensory desmitis and the time from injury. Acutely, the horse may point the foot. A chronic fracture may resemble a simple “splint”; and some horses will be able to perform (with variable success) with a chronic splint bone fracture once the acute inflammation subsides.

Diagnosis:
Fairly straightforward. Direct palpation and observation during the physical/lameness examination usually localizes the source of pain to the region of the fracture. The lameness is often worse when the affected limb is on the outside of a circle (particularly medial splint injuries). Radiographs, obviously, are the most important modality for confirming the diagnosis (and also to rule in or out osteomyelitis or sequestration in the case of open fractures). Ultrasound should be utilized when available to evaluate the suspensory ligament.
Treatment:

Conservative:
Stall rest, bandaging, cold therapy (Game Ready), NSAIDs, and other systemic and topical anti-inflammatory medications.

Surgical:
Excision of the distal aspect of the bone (osteotomy proximal to the fracture/callus site). In many cases, these fractures heal by delayed union or non-union, due, in part, to the inherent instability and high motion at the fracture site. Excision is not always necessary for soundness, but the motion and residual inflammation results in unsoundness (as well as a cosmetic blemish). Surgical excision can shorten the convalescent period, and also decrease the potential for formation of an impinging callus (causing secondary lameness).

Prognosis:
This depends in large part on the presence or absence of any concurrent suspensory desmitis. The prognosis is generally good for returning to the previous level of soundness/performance in those horses with minimal or no suspensory desmitis. In horses with significant associated desmitis, the prognosis is often less favorable.

Mid-to-Proximal Fractures of MC/MT-2&4

Etiology:
Fractures of the mid-shaft or proximal aspect of these bones are typically the result of external trauma (i.e. a kick or hitting a solid object). As such, they are frequently associated with an open wound, and therefore are contaminated and prone to infection. Initial treatment involves routine wound debridement and removal of any loose bone fragments, along with bandaging, antibiotics, etc.

Diagnosis:
Radiographs confirm the presence and characteristics of the fracture. Advanced imaging modalities such as CT can be beneficial in the pre-operative planning of complex fractures or in cases where radiographs fail to effectively show an accurate fracture configuration.

Treatment:
Conservative/Semi-Conservative:
Relatively simple fractures can heal without further intervention (obviously with extended rest). Bone sequestra should be excised under local or general anesthesia if present.

Surgical:
Unstable fractures, those that have healed with an exuberant callus, or those with evidence of delayed union, etc. require further intervention. Often this involves excision of the distal portion of the bone leaving a relatively “clean” proximal portion. In some cases, this results in instability and associated lameness as the support of the proximally located carpal tarsal bones is compromised. This is most often a concern with proximal MC-2 fractures. Various forms of internal fixation can be employed to increase the stability of the remaining proximal aspect. Usually this involves several cortical screws placed in lag fashion (typically 3.5-mm) between the splint bone and the cannon bone or the use of a narrow 3.5-mm LC-DCP plate/ 3.5-mm Reconstruction plate/ 3.5-mm LCP contoured along the length of the small MC/MT bone and down onto the MC-3/MT-3. Standard AO/ASIF techniques are used to contour and apply the
plate. It is important to remember that every effort should be made to eliminate an infection before proceeding with the application of metallic implants.

In cases of proximal fractures where there is adequate stability or those that we want to preserve the entire splint bone due to the location of the actual fracture line, a narrow 3.5-mm LC-DCP plate/ 3.5-mm Reconstruction plate/ 3.5-mm LCP can be contoured along the length of the small MC/MT bone. In these cases it is preferable not to engage MC3/MT3 and rather maintain the screws within the thickness of the splint bone.

**Prognosis:**
The prognosis for soundness is generally good, unless DJD of the CMC or TMT joint has developed, an exuberant callus impinges on the suspensory ligament, residual instability is present, or implant associated discomfort exists.

**References:**


AOVET North America

Principles in Equine Fracture Management Course

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Management of Patellar Problems in Horses

Dean W. Richardson, DVM, Diplomate ACVS
Management of Patellar Problems in Horses
Dean W. Richardson, DVM, Diplomate ACVS

Learner Objectives:

- Describe the detailed anatomy of the patella as it relates to fracture diagnosis and repair
- Describe a specific surgical strategy for removing patellar fragments
- List the unique difficulties of internal fixation of patellar fractures
Patellar fractures occur primarily as a result of single traumatic events, the most common of which is a horse striking the stifle on a fixed object as it jumps (or, more properly fails to jump) a fixed obstacle. Hence, 3-day event horses are over-represented. The most common configuration by far is a fracture involving the proximal medial aspect of the bone but a variety of fractures occur, especially after the less typical trauma.

Diagnosis of lameness referable to the stifle is not difficult with these fractures because they often have a history of direct trauma and there is always significant effusion. Most horses stand with the stifle flexed. There is rarely crepitus but often pain with direct palpation and manipulation of the patella.

Unfortunately, “routine” lateromedial and caudocranial radiographic projections do not always clearly reveal the fracture, especially if there is an inadequate index of suspicion. Oblique and flexed proximocranial-distocranial (“skyline”) projections should always be a routine view in a horse with a known history of direct stifle trauma. (Figures 1,2) Most horses with the fracture will allow positioning for the skyline projection following adequate sedation. The key to positioning is to use the flexed hock to externally rotate the limb as much as possible. This makes it easier to properly position the tube and the cassette. The stifle should not be excessively flexed because it will slide the patella too far proximally.

Patellar Fragment removal:

Obviously, arthroscopic technique is the current standard technique although many fragments are so large that removal may involve a large enough “portal” that the latter will need to have deep sutures placed, making it an arthrotomy. The horse should be positioned in dorsal recumbency with the limbs extended. It is not necessary to distend the femoropatellar joint prior to entering it with the arthroscope cannula. The portal is usually made between the lateral and middle patellar ligaments about 1/3 of the distance between the distal tip of the patella and the palpable most proximal tibia. A 6 mm skin incision is made and then the cannula with sharp trocar used to gently puncture the very thin cranial fascia/joint capsule. The conical obturator is then place and firmly positioned in the joint. The fluids are attached and allowed to distend the joint completely before any effort is made to maneuver the scope. As the joint is distended, the patella floats up laterally and allows the scope to be placed into the suprapatellar pouch. Typically, multiple fragments of the major fracture are found swirling in the suprapatellar pouch. The proximal medial patella is readily visible. A 3.5 inch 18 g spinal needle is used to help define an acceptable instrument portal in the suprapatellar region. Once the needle is visible within the joint, a scalpel with #11 blade is slid down next to it until it too is visible. The incision is several centimeters deep, often half the length of the handle in a large horse. In my opinion, this is one of the very few indications for the use of an aggressive motorized arthroscopic cutting instrument. I use a 5.5 mm full radius resector to remove the soft tissue attachment to the fragment. The instrument can be palpably and visually guided along the abaxial rim.
of the fragment until the latter can be mobilized. In large fragments, a medial scope portal between the middle and medial patellar ligaments and a second instrument portal along the more distal aspect of the fragment are made and the detachment of the fragment continued. After the fragment is well enough defined, a decision is made whether it can be removed intact or cut in pieces for removal. The former requires a mini-arthrotomy that should be sutured closed. The latter can be done with more traditional arthroscopic technique but has the disadvantage of creating more loosely floating fragments that will have to be tracked down. Cutting the fragment is done with an appropriate sized osteotome (usually 6-12 mm) and a mallet. It is important to verify the positioning of the osteotome arthroscopically before it is struck. The blow should be directed away from intact, healthy joint surfaces. Large-jawed Ferris-Smith rongeurs are useful because of the very large fragment size. After the major fragments are removed, the entire joint should be scrupulously examined for loose pieces. The suprapatellar recess may be flushed/”vacuumed” with a long, large bore cannula.

It is important to remember that the arthroscope can also be placed directly in the suprapatellar pouch either through the original suprapatellar instrument portal or an additional portal. I find it easiest to place a 3” spinal needle as a guide for the correct insertion point and direction of the suprapatellar scope portal. Then use a second arthroscope cannula/trocar to enter the joint. This makes the safe intra-articular position of the scope absolutely certain.

The practical limit for the size of a fragment suitable for removal is not known but it is apparent that remarkably large pieces can be removed from this location without destabilizing the stifles joint. The prognosis in general for horses with proximal patellar fragments is surprisingly good. The published retrospectives 1,2 and our own experience suggest that >80% of treated horses will return to successful athletic activity. It is important to emphasize that conservatively treated horses also may return to satisfactory function but there is less information available. Arthroscopic treatment has the distinct advantage of allowing the retrieval of loose fragments within the joint and providing a more predictable time course for return to function.

Distal patellar fragments have been primarily reported as a consequence of medial patellar desmotomy3 but I have also seen horse develop fragments without this surgery. At least one had intermittent upward fixation of the patella suggesting that any abnormality of patellar tracking may cause some fractures to occur here. OCD lesions can also rarely be present on the distal patella.

The surgical removal of distal patellar fragments is easier than proximal fragments. The only change in technique is that the scope portal should be placed in the distal third of the gap between the tip of the patella and the proximal tibia. Horses with distal patellar fragments also have a favorable prognosis unless there is significant degenerative joint disease evident at the time of surgery.

Internal fixation of patellar fractures is relatively uncommon. Fractures can occur in either transverse or sagittal/parasagittal planes. The former are quite rare in horses and should be treated with a tension band technique combined with lag screws for interfragmentary reduction.4 Sagittal/parasagittal fractures are treated with lag screws. In adults, 5.5 mm screws are used for their strength. Any internal fixation of the patella requires either direct exposure through an aggressive surgical approach or extensive intraoperative imaging. The optimal incision in most cases is made directly through the
fracture plane. Although arthrotomies exposing the patella are easily done with few complications in miniature horses, such incisions are risky in “real” horses.

**Patellar Luxation:**

The most common equine patients with luxated patellae are miniature horses so the methods of treatment and the success of that treatment might appear to be similar to dogs. Although medial luxations have been reported, most are lateral. However, the congenital luxating patella of the miniature horse must not be considered equivalent to two other conditions in horses that result in luxating patellae. Some young foals suffer traumatic tearing of the muscles and tendinous/aponeurotic attachments to the medial side of the patella. If these foals have lax or torn medial femoropatellar ligaments lateral luxations can occur. These are typically different than the congenital form because they are more painful and the foals have more diffuse swelling of the stifle region. The importance of recognizing the difference is that surgical repair by lateral release and medial imbrication is much more difficult because the medial tissues will not support sutures. Also, some older foals, yearlings and even two year olds with severely dysplastic lateral trochlear ridges can laterally luxate their patellae. Such cases also are not good candidates for “simple” repair techniques.

For congenital luxated patellae, I prefer to use a combination of lateral fascial release and medial imbrication with or without recession sulcoplasty. The latter is used only in those cases with obviously flattened distal femoral trochlea. It should be kept in mind that the depth of the trochlear groove increases with age so one should not expect a juvenile distal femur to have the same shape as an adult. The recession sulcoplasty is really only necessary in those cases where there isn’t enough of a depression to “track” the patella.

**Technique:** A slightly curved incision over the craniomedial aspect of the stifle is made that extends from the distal metaphysis to the proximal tibia. The center of the incision is over the axial margin of the medial trochlear ridge. The deep incision is made by a scalpel stab into the femoropatellar joint. Mayo scissor are then inserted and a single layer cut made with the scissors proximally and distally to complete the arthrotomy. The incision transects the medial femoropatellar ligament. A towel clamp (or similar instrument) is used to grasp the patella with its attached fascia and the bone is pulled medially as far as possible. The lateral skin is then pulled laterally as far as possible to expose the lateral patellar attachments. A fresh scalpel then transects all of the lateral attachments including the lateral femoropatellar ligament. This is done carefully with the patella pulled medially so that it is evident when the release is complete. Although it isn’t always possible, in most horses the lateral attachments can be separated without cutting through the synovial lining on the lateral side. This seems to help minimize postoperative incisional swelling. After the lateral release is complete, the medial fascia is imbricated with interrupted Mayo-overlap sutures of #2 polyester or similar strength material. The caudal tissue is overlapped on top of the more cranial tissues. It is easiest to preplace 6-10 sutures (depending on size), tagging each with a hemostat. After all are placed, the mass of sutures and forceps are all pulled together to overlap the fascia. Each is tied tightly. Subcutaneous tissues and skin are closed according to the surgeon’s preference. A padded bandage restricting hock flexion is used for recovery but then removed after the patient stands. An adhesive bandage is used to
keep a clean covering on the incision. Postoperative exercise should be limited for at least 6 weeks.

If a recession wedge sulcoplasty appears to be necessary, a broad (~25mm) thin bladed chisel or osteotome is used to cut a wedge over the entire length of the trochlear groove. The wedge is approximately three times as long as its width and about 15-18 mm deep. If possible, it is left “hinged” at its proximal margins. The osteotome is then used to gradually remove more bone from the parent portion until the replaced wedge sits in an acceptably recessed position. Finger pressure is all that is required to make the wedge sit securely. The thickness of the articular cartilage here is such that bone is often not even exposed. A scalpel can be used to even up the axial edges of the trochlea.

Prognosis is generally excellent in foals and especially good in miniatures. As emphasized above, however, traumatic luxations or those associated with dysplastic femoral trochlea have a much less favorable prognosis.

Figure 1A: Skyline view of a typical proximal medial patellar fracture

Figure 1B: Caudolateral-cranio-medial oblique projection of same horse
References:


Lag Screw Technique and Plate Application for Pastern Arthrodesis for Degenerative Arthritis and Fracture Treatment

J.P. Watkins, DVM, MS, DACVS
Lag Screw Technique and Plate Application for Pastern Arthrodesis for Degenerative Arthritis and Fracture Treatment

J.P. Watkins, DVM, MS, DACVS

Learner Objectives:

- Identify the indications for use of the axial plate / transarticular screw method of pastern arthrodesis
- Describe the surgical approach and technique for axial plate / transarticular screw method of pastern arthrodesis
- Describe the expected results for the axial plate/transarticular screw method of pastern arthrodesis
Lag Screw Technique and Plate Application for Pastern Arthrodesis for Degenerative Arthritis and Fracture Treatment

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Biomechanically, the proximal interphalangeal joint (PIJ) is a low-motion/high-load joint and combined with the non-interdigitating nature of the articulation, results in a joint which is characteristically unforgiving of injury. Acute and chronic injury to the PIJ is frequent in western performance horses and attempts to manage the majority of common conditions of the PIJ by methods other than arthrodesis usually fail to provide long-term success. In many instances, the only method to manage the injury and provide lasting comfort for the patient is by arthrodesis of the PIJ. This includes conditions with normal stability as well as those that have disrupted the axial stability of the pastern.

At our hospital, the most common patient presented for PIJ arthrodesis has chronic degenerative joint disease (high ringbone). The pastern is axially stable but will frequently have varying degrees of axial deformity secondary to asymmetric loss of articular cartilage and collapse of the joint space. Other common indications for arthrodesis of a stable pastern include uniaxial fracture of the palmar/plantar eminence, subchondral cystic lesions, and dorsal subluxation. Patients presented with acute injuries resulting in axial instability most commonly have disruptive trauma to either the middle phalanx or the palmar/plantar support structures. Comminuted middle phalanx fractures are most common followed by biaxial fracture of the palmar/plantar eminences and palmar/plantar luxation or subluxation.

Arthrodesis for both stable and unstable pastern injuries is accomplished by the standard approach to the pastern. An inverted-T incision in the skin and underlying fascia followed by an inverted-V in the extensor tendon with proximal and distal dissection exposes the dorsal aspects of the distal end of the proximal phalanx and the proximal end of the middle phalanx. Longitudinal incision along the lateral border of the extensor tendon increases exposure of the proximal phalanx if needed. The collateral ligaments are transected to allow dorsal luxation of the joint and the articular cartilage is removed. Osteostixsis is performed through the subchondral plates of the proximal and middle phalanges.
Proximal Interphalangeal Arthrodesis for conditions NOT accompanied by axial instability is best accomplished using an axial plate accompanied by two, transarticular lag screws. We have abandoned the three screw technique for a variety of reasons. With the 3 screw technique one is likely to penetrate the navicular region when attempting to cross the center of the joint. The angle required to properly position the screws results in hole placement near the distal extent of the palmar/plantar cortex of the middle phalanx. Penetration of the cortex distally will most likely invade the navicular area and may cause secondary disease of this structure. Techniques using screws alone, also fail to provide adequate stability, particularly in patients with significant axial instability. Even with a stable pastern, screws alone are likely to have dorsal instability which can result in patient discomfort and promote excessive new bone formation which may impinge upon the extensor tendon and/or coffin joint and cause lameness. With middle phalanx fractures, screws may enter fracture lines and fail to produce a mechanical environment necessary for bone union. In addition, with screws alone, 6 to 8 weeks of post arthrodesis cast support is usually necessary, which is both costly and increases cast related morbidity.

Arthrodesis of stable pasterns using an axial plate in conjunction with abaxial, transarticular lag screws is a far superior option. In vitro mechanical testing has shown the axial plate construct to be substantially more stable across the dorsal aspect of the PIJ and to have a significantly longer fatigue life than the three screw method.\textsuperscript{1,2}

The original axial plate technique utilized a 3 hole narrow DC or LC-DC plate contoured to the dorsal midline. The solid center of the plate (DCP) is positioned over the pastern joint space with the single plate screw located in the proximal aspect of the middle phalanx. The screw hole in the proximal aspect of the middle phalanx is prepared just below the subchondral bone plate to accommodate a 5.5mm cortex screw. The plate is affixed to the proximal phalanx with a 5.5mm cortex screw adjacent to the center of the plate using the DC principle but not tightened until the abaxial, transarticular screws are placed and tightened. These abaxial screws should be 5.5mm cortex screws and are placed transarticularly in lag fashion medial and lateral to the plate. The abaxial screws should cross the PIJ and enter the eminences of the middle phalanx at a point midway between the center of the articulation and the palmar / plantar aspect of the joint. Once the transarticular screws are tightened, the previously placed plate screws are tightened. Finally, the remaining hole at the end of the plate is filled with a 4.5mm or 5.5mm cortex screw placed through only the dorsal cortex of the proximal phalanx. The size of the screw in this location is determined by the length of screw which can be placed in monocortical fashion without impingement by the palmar/plantar cortex (the shortest 5.5mm cortex screw is often too long to allow monocortical placement in horses of small stature).

More recently, a 3-hole LCP plate (PIP plate) has been developed for proximal
interphalangeal arthrodesis. A similar construct is achieved as described above, however
the order of screw placement is varied. The plate is temporarily affixed to aligned
pastern using the push-pull device positioned in the dorsal cortex through the middle
plate hole. With the plate pressed against the bone, a 5.0mm locking screw is placed in
the distal stacked combi-hole. The proximal most hole is prepared for a unicortical screw
in the load position, but the screw is not fully tightened. After removal of the push-pull
device and the abaxial, transarticular lag screws are tightened, the proximal screw is
tightened to provide dorsal transarticular compression using the dynamic compression
principle of the plate. Finally, the middle plate hole is prepared and filled with a 5.0mm
locking screw.

Closure of the tendon is accomplished with #1 PDS and the skin is apposed using
a combination of 0 Prolene and skin staples. Standard distal limb cast immobilization is
advisable in the immediate postoperative period to protect the fixation during recovery
and support healing of the soft tissues. As a matter of routine, we remove the
postoperative cast and about one-half of the skin sutures 10-14 days after surgery, with
the patient standing. The limb is protected with a bandage, and the remaining sutures are
removed at the next bandage change. Following discharge from the hospital the horse is
confined to a stall and exercise is limited to hand walking for 3 months.

Our experience with arthrodesis of the stable pastern affected by a variety of
conditions have been published. Fifty-nine arthrodesis procedures were performed on
54 horses. Forelimbs accounted for 57% of the cases. Arthrodesis was performed in
48% of the cases to treat primary DJD (high ringbone). A 3-hole nDCP was used in 68%
of the arthrodeses and a 4-hole in the remainder. Ninety-three percent of the horses were
in a cast for less than 15 days. Long term follow up revealed 41 of 44 horses (87%) were
considered successful, 81% and 95% of the forelimbs and hindlimbs respectively.
Overall, 33/39 (85%) of horses intended for performance were successful, (forelimb
76%; hindlimb 94%). Outcomes were not affected by intended use, limb affected, pre-
operative radiographic changes, primary lesion or length of plate.

Arthrodesis for axially unstable injuries is best performed using
2 plates positioned dorsomedial and dorsolateral. Using the single plate
technique as described above for patients with significant palmar/plantar
instability is likely to place excessive bending forces on the construct
resulting in fixation failure. Double plate fixation of unstable pastern
injuries allows implants to be positioned where they will provide
maximal support. The stability provided by double plate fixation
increases patient comfort and encourages and early return to weight
bearing on the injured limb which reduces the risk of support limb
laminitis. Further, a very strong bone-implant construct is achieved,
which will minimize the likelihood of construct failure.

References:

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Use of CT for Fracture Repair

Dean W. Richardson, DVM, Diplomate ACVS
Learner Objectives:

- List a logical sequence of steps using skin markers to accurately locate screw insertion
- Identify the cases most suitable for CT-assistance
- Describe the most common complications associated with this surgery
Internal fixation of equine fractures has advanced over the last few decades primarily because of the improving expertise of practicing surgeons and correct application of implants according to proven mechanical principles. The unfortunate reality of fracture repair in horses, however, is that failures still occur commonly because of infection, delayed union and implant failure. Delayed union in species other than the horse is a lesser issue because the consequences of severe lameness and overload of the contralateral limb are less and the expectations for return to function are usually lower. In horses, we still generally recognize that immediate comfort (i.e. stability) is an important element of successful fracture repair and that delayed union is a major complication because of implant failure and contralateral limb problems. Equine surgeons have naturally tended towards aggressive open fracture repairs in order to minimize mechanical “errors” that might reduce stability. Arthroscopy and fluoroscopy/intraoperative digital radiography are already routine adjuncts to many internal fixation procedures but intraoperative CT has enormous potential to minimize the errors that are inherently more likely with minimally invasive techniques.

CT is especially valuable in complex fractures that are difficult to “figure out” from standard films (e.g. comminuted P1), fractures that do not allow adequate fluoroscopic projections that can assure accurate screw placement (e.g. tarsal slab fractures) and bones with a complete lack of direct exposure (P3 and navicular).

Our most highly specific experiences with CT guided fixations are probably within the hoof but the same principles apply when using the CT for intraoperative guidance in other types of fractures or arthrodeses. Use a skin marker to help define the intended site of implant insertion. Use a skin marker on the extended line for the drill bit. Take post-insertion CT to triple check placement.

CT assistance is certainly not “essential” for most fractures but it provides one more level of guidance to help assure accurate fixations. Although the machine we have used in these cases (CereTom made by NeuroLogica Corporation, Danvers MA) has limitations because of its size, the portability of the unit and its speed make it very practical for intraoperative use in the distal limb of horses.

Some key points about CT assisted internal fixation:

1- Try to get your radio-opaque skin markers as perfect as possible. It is better not to have to make adjustments. If you scan selectively, it usually saves surgical time if you get the markers exactly where you want them.

2- Skin markers are more reliable in locations with minimal overlying soft tissue.

3- Place markers on the projected “exit” site of your drill, i.e. where the drill would come through the skin on the far side of the bone. This greatly helps your aim and
is particularly critical if you are using an aiming device in a small target, e.g. the navicular bone or a smaller P3 wing fracture.

4- If in doubt on really difficult fractures, take intraoperative CT images. Plan your positioning and draping to allow this whenever possible.

5- Use fluoroscopy or digital radiography when possible to check the length of glide holes. Measurement off the CT is reasonably accurate but not foolproof.

An aiming device with appropriate sized drill guides is invaluable for CT guided internal fixation. If the entrance site for the drill and its “projected” exit site can be marked on the skin (or hoof), extremely precise placement of the screw can be consistently achieved.
Figure 2: Computed tomography can also help accurate placement of screws in small fractures in locations such as the distal tarsal bones where tangential views are unavailable.

A- Scintigraphic study showing focal intense radiopharmaceutical uptake in dorsolateral T3.  B- DMPLO radiograph demonstrating displaced slab fracture of T3  C- Barium paste blebs and/or steel staples can be used as skin markers to help define the exact center of the fracture fragment.  D- Postoperative CT showing exact central placement within the small fragment.  E- Postoperative DMPLO projection.  F- The fracture was radiographically healed in less than 90 days.
Figure 3: Dorsopalmar (A) and palmar tangential (B) views of an acute navicular bone fracture in an 11 year old Thoroughbred gelding. In (C) a 2.0 mm hole is made to check drill placement. (D) A 3.5 mm glide hole is made to the fracture plane. (E) The 2.5 mm thread hole is continued through the larger fragment of the navicular bone. (F) The final placement of the 3.5 mm screw. Orthogonal dorsopalmar (G) and lateromedial (H) projections confirm central placement of the screw.
Nonsurgical and Surgical Management of Fractures of the Third Phalanx

José M. García-López, VMD, DACVS, DACVSMR
Learner Objectives:

- Recognize different types of fractures that occur in the distal phalanx
- Explain non-surgical management of non-articular and articular fractures of the distal phalanx
- Describe the use of advanced imaging modalities such as CT for preoperative planning of articular fractures
- Explain surgical repair of mid-sagittal fractures of the distal phalanx with a 4.5 mm cortical lag screw-technique and identify potential complications and advantages compared to non-surgical management
Background & Etiology

The majority of distal phalangeal (P3) fractures are incurred during high-speed exercise, although they can also occur from kicking a stationary object (such as a stall wall) or taking a “bad step”. Although Standard bred racehorses can be particularly prone to P3 fractures, they can occur in horses of any breed or age, including foals. There is evidence (clinical and anecdotal) that suggests that many P3 fractures develop over a period of time from progressive inflammation and weakening of the bone subsequent to repetitive trauma. Fractures of P3 have been classified into 6 common types (see figure below). Wing fractures (articual and non-articular) are the most common type.

History & Clinical Signs

With most fracture types horses present with an acute, relatively severe lameness (often walking lame) shortly after a race or other high-intensity exercise. Clinical signs besides lameness include heat in the hoof wall, marked pain in response to hoof tester examination, elevated digital pulses, and DIP joint effusion if the fracture is articular.

Classification

Type I fractures are nonarticular palmar or plantar process fractures of P3. Type II fractures are articular, oblique, parasagittal fractures that enter the joint along its abaxial margin. Type III fractures are midsagittal fractures with joint involvement. Type IV fractures are extensor process fractures which can be subclassified as displaced and nondisplaced. Type V fractures are

Figure 1: Classification of Distal Phalangeal fractures: I, Abaxial non articular fracture; II, Abaxial articular fracture; III, Axial and periaxial articular fracture; IV, Extensor process fracture; V, Multifragment articular fracture; VI, Solar margin fracture. (From: García-López JM, “Adult Orthopedic Emergencies”, Equine Emergencies Treatments and Procedures 4th Ed, Orsini & Divers (eds), 2014.)
comminuted fractures with joint involvement. Type VI fractures are solar margin fractures which are nonarticular.

**Diagnosis**

Along with the history and clinical signs, radiographs are necessary for definitive diagnosis. Diagnostic anesthesia (palmar [plantar] digital nerve block or intra-articular local anesthetic injection of the distal interphalangeal (coffin) joint) may be very helpful if the clinical signs are not highly suggestive of an injury in the foot.

Although typically radiographs confirm the presence of the fracture, occasionally they can be difficult to detect due to minimal displacement of the fragment(s), irregular border of P3 and the presence of debris in the solar region. In these cases it might be necessary to repeat the radiographs 7-10 days later in order to properly identify the presence of a fracture. The use of nuclear scintigraphy (bone scan), CT or MRI can be particularly helpful in identifying obscure or occult fractures. In addition the use of CT or MRI has the added advantage of evaluating the condition of the articular surface with regards to comminution and alignment, and is becoming an important tool for pre-operative planning of fractures managed surgically.

**Treatment**

Treatment of P3 fractures varies depending on the location (articular vs. nonarticular), the size of the fracture (large vs. small extensor process fractures), and the age and use of the horse. Although historically conservative therapy has been selected for all types of P3 fractures, except for extensor process fractures, surgical management of fractures with an articular component, such as Type III and large Type II fractures, consisting of the application of a cortical screw(s) in lag fashion is being performed with increased frequency thanks to advances in imaging capabilities such as digital radiography and CT. These modalities are allowing equine surgeons to have a better pre-operative plan and more accurate assessment of screw placement.

**Non-surgical**

For the majority of fractures (other than extensor process fractures) treatment involves the application of a steel bar shoe with two pairs of side clips, one at the level of the toe/quarter junction and the second close to the quarter/heel junction (to minimize expansion of the foot and maximize “compression” of the fracture). The shoe is changed every 6-8 weeks in order to minimize the development of contracted heels. Alternatively, the use of either a shoe with a rim drawn across the entire perimeter or the application of a fiberglass cart around the hoof capsule can be used effectively. Healing of these fractures is slow and often up to 6 months rest (stall rest only, then hand-walking, then small paddock turnout) is needed before returning to exercise. It may take 6-12 months for the fracture line to completely “heal” radiographically since P3 fractures often heal with a prolonged fibrous callus due to the lack of interfragmentary compression. Foals are best treated with stall rest alone and can heal as quickly as 8-10 weeks.
**Surgical**

*Type III and II (close to midsagittal):*

Fixation of these types of fracture will require the use of one (at times 2) cortical screw placed in lag fashion. Sizes typically used include 4.5 mm, 5.5 mm and 3.5 mm. Since any fixation of P3 will involve penetration of the hoof wall, it is imperative that the entire hoof wall and solar surface be appropriately cleaned and disinfected. Whenever possible this should be done the day before surgery.

Surgery is performed with the horse under anesthesia and in lateral recumbency. If available, performing a CT of the affected foot immediately prior to surgery can allow for adequate measurement of the hoof wall thickness, bone and fracture fragment width, screw length and screw orientation. Alternatively this can be done, although not as precisely, by using a combination of intra-operative radiography and fluoroscopy. For midsagittal fractures, evaluation of the articular surface by inserting an arthroscope in the dorsal joint pouch can help in ensuring adequate anatomical reduction of the fracture fragments. Once the appropriate position and direction of the screw has been determined, an 8-10 mm drill or Forstner drill bit is used to create a hole through the hoof wall up to the level of P3. In order to ensure accurate screw placement, a small pilot hole is done just beyond the level of the fracture. If position is deemed adequate, the appropriate glide hole is created. Following this, the drill bit is removed, the centering drill sleeve is inserted and the thread hole is created. Care is taken to make sure that the sensitive lamina is not affected on the other side of the opposite fragment by overdrilling and/or using too long of a screw. Following countersinking and confirming the desired screw length, the thread hole is tapped, and the screw is inserted and tightened.

Following radiographic confirmation of screw placement, the hole created in the hoof wall is packed with antibiotic impregnated PMMA and the edges are sealed with cyanoacrylate glue. Alternatively the defect can be covered with a combination of a Kevlar strip with hoof acrylic. If arthroscopy was also performed, the incisions are closed routinely and a sterile bandage is applied. Post-operatively these cases will undergo a similar rest/rehabilitation schedule as those treated conservatively.

*Type IV:*

For smaller extensor process fractures arthroscopic surgical removal is the treatment of choice. The procedure can be done either in lateral or dorsal recumbency based on surgeon’s preference. Based on the degree of articular damage created by the fracture, adjunctive intra-articular therapy might be beneficial. Post-operatively, the distal limb is maintained in a sterile bandage for 2 weeks and a period of 8-12 weeks of rest/rehabilitation.

Large fragments are quite difficult to manage surgically with internal fixation. Some fragments can be removed successfully arthroscopically by dividing it into smaller pieces prior to removal. In some cases the fragment is too large to remove without causing joint instability. In these cases the placement of 1 or 2 cortical screws in lag fashion (3.5 mm, 4.5 mm) can be attempted; however this rarely results in a sufficiently rigid fixation. For this reason many surgeons opt to manage this fracture conservatively.
if removal is deemed not feasible. If fixation is attempted, a distal limb cast can be applied for 2-4 weeks.

Palmar/plantar digital neurectomy offers a better prognosis for returning horses with residual lameness to athletic use. Neurectomy is also an option at the outset for horses with wing fractures (non- or minimally articular) to reduce the convalescent time and allow the horse to go back to competition earlier.

**Prognosis**

The prognosis for wing fractures that are non-articular or only involve a minimal portion of the articular surface is relatively good for returning to athletic soundness. As the fracture moves closer to the midline (mid-sagittal) the prognosis worsens. The prognosis for athletic soundness for mid-sagittal and badly comminuted P3 fractures is guarded. The prognosis for extensor process fractures that are relatively small (i.e. can be removed arthroscopically) is generally good if treatment is undertaken before any degenerative changes have taken place. For large extensor process fractures – particularly the rare type requiring screw fixation – the prognosis is typically guarded to poor due to the resulting degree of OA.

**References:**

Postoperative Considerations and Management after Articular and Non-articular Fracture Repair

L.R. Bramlage DVM MS
Post-Operative Considerations and Management after Articular and Non-articular Fracture Repair
L.R. Bramlage DVM MS

Learner Objectives:

- Assess an injury for bone and soft tissue healing needs
- Predict the proper amount of time needed for healing of the bone injury
- Modify the aftercare for soft tissue considerations
Post-Operative Considerations and Management after Articular and Non-articular Fracture Repair
L.R. Bramlage DVM MS
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Selection of the appropriate aftercare for an injury should be based on the injury being treated, and an understanding of the healing tissues involved and their healing needs. This needs to be tempered and modified by the individual injury and its particular characteristics, the surgeons understanding and perspective of the current procedure and the aftercare results of the surgeon’s past procedures with similar characteristics. Therefore universal aftercares have less validity than ranges of options that can be modified to fit the case being treated and the surgeon’s preferences and experiences.

Considerations to be applied to cases of articular and non-articular fractures

Healing of soft tissue, joint capsule

Healing of Soft Tissue
- Inflammatory Phase, 0 til 4-6 days
- Proliferative phase, 5-21 days
- Maturation Phase, (Collagen cross-linking) Half strength in 6 weeks, 80% in one year, size of wound figures in
- Remodeling Phase, overlaps maturation and lasts for years, affected by tissue biomechanics

Factors that affect healing
Blood Supply
- Venous return is more important than arterial supply, therefore the distal limb of the horse can be a concern.
- The value of bandaging increased with the propensity for edema,
- Duration
- Site

Medication
- Corticosteroids
  - Acute, no effect
  - Chronic, reduced vascular ingrowth
- NSAIDS, no significant evidence of negative effect

Healing of Bone
- Stable, Primary healing
  - Stable No Gap
    - Bone Remodeling Unit
  - Stable Gap
    - Bridge, about 60 days
    - Remodel greatly influenced by loads
- Unstable, secondary bone healing
  - via Callus
  - Motion/Gap dependent
Remodeling
    Bone Remodeling Unit
Overlap?

Healing of articular cartilage
Weight bearing sites
    Hyaline Cartilage
    Fibrocartilage
Non-weight bearing sites
    Protected sites
Chronology
    Soft tissue Healing
        Inflammatory Phase (Lag)
        Proliferative phase (Fibro-proliferative)
        Maturation Phase
        Remodeling Phase, Imperfect Hyaline Cartilage

Does it matter?

Augmentation Techniques
    Chondrocytes
    Cartilage grafts
    Micro-fracture
    Osteo-chondral grafts

Infection Consideration
    Key=Prevention
    Factors affecting
        Tissue Damage
        Inoculum, $10^6$ bacteria/gram of tissue=infection
        Surgery Time, affects both of above
    Foreign Bodies
        Implants
        Sutures
        Seroma/hematoma
    Stability

Treatment
    Broad Spectrum, gram + and gram –, Routine, Exotic
        Know your frequent isolates
    Safe for the patient
    Duration?

Prophylaxis Duration
    No serious tissue damage, just to lessen inoculum
    Tissue damage, until all tissue viable, fibro-proliferative phase
Estimation of Necessary Exercise Restrictions for Ideal Healing
Priorities
  Bone
    Healing
    Remodeling
    Overlap?
  Soft Tissue
    Function
    Cosmesis
  Articular Cartilage

Retraining Injuries increase after 120 days of no training

Post-op Physical Therapy
  Hand walking
  Passive flexion
  Vibration
  Water Treadmill
  Swimming
  Massage
  Electro-magnetic fields
  Therapeutic Ultrasound

Augmentation of healing
  $O^2$
  PRP
  Tildren
Notes
Surgical Approach and Plate Application of Simple Olecranon Fractures

J. P. Watkins, DVM, MS, DACVS
Surgical Approach and Plate Application of Simple Olecranon Fractures
J. P. Watkins, DVM, MS, DACVS

Learner Objectives:

- Identify the principles affecting patient selection for repair of simple olecranon fractures
- Describe the surgical approach and technique for plate application for simple olecranon fractures
- Describe the expected results of plate fixation for simple olecranon fractures
Fractures of the ulna and olecranon are the most frequently repaired longbone fractures in equine practice. They usually result from some form of direct trauma, such as a kick from another horse or falling onto the affected limb. In general, these fractures are excellent candidates for open reduction and internal fixation. Prognosis for healing is excellent and athleticism is an obtainable outcome in most patients.

There are a number of fracture configurations encountered. In neonates, separation at the physis may occur without involvement of the bony apophysis or metaphysis (type 1a). In older foals, the fracture usually involves the caudal aspect of the physis, then enters the metaphysis and propagates cranially towards the anconeal process (type 1b). The cranial aspect of the fracture may be either articular or nonarticular and occasionally, the anconeal process will be comminuted. Fractures distal to the physis include transverse or short oblique fractures extending from the caudal cortex to the cranial metaphyseal cortex (type 3); simple transverse fractures entering the joint at the midpoint of the semilunar notch (type 2); simple oblique fractures entering the semilunar notch in the synovial fossa (type 5); and comminuted fractures (type 4). Fracture displacement varies from minimal to marked. The degree of soft tissue trauma accompanying the injury is also quite variable and occasionally the fracture is open.

In most instances, internal fixation using a plate applied as a tension band on the caudal aspect of the olecranon and ulna is recommended. Although nondisplaced, nonarticular fractures managed conservatively can heal and the patient return to full function, our experience has been that the duration of healing, and therefore lameness, can be quite prolonged. In addition, there is the added risk of fracture displacement. Furthermore, fractures which communicate with the synovial cavity may become a true pseudoarthrosis. Therefore, we encourage plate fixation in nearly all instances, after the client has been informed of the economics, and potential complications.

**SURGICAL APPROACH:** The skin incised over the caudolateral aspect of the olecranon with the proximal aspect of the incision positioned to prevent it from lying directly over the point of the elbow. Following incision of the skin and subcutaneous fascia, the septum between ulnaris lateralis and ulnar head of DDF is identified and separated as far proximally as possible. As the dissection nears the olecranon process, deep fascial attachments to the underlying bone are sharply dissected along the site intended for plate application. Fractures of the proximal olecranon, will require additional sharp dissection cranially, over the top of the olecranon process to allow application of a highly contoured plate over the top of the olecranon process. Dissection proximal to the level of the physis (or physeal scar in the adult) is usually not necessary in more distal fractures.

**PLATE APPLICATION:** A 4.5mm narrow plate applied to the caudal aspect of the ulna / olecranon as a tension band is the fixation of choice in most instances. In adults with comminuted fractures, a 4.5mm broad plate is applied caudally or double plate fixation with caudal and lateral 4.5mm narrow plates may be utilized. The degree
of plate contouring is dependent on the level of the fracture; proximal fractures require substantial bending to allow the proximal aspect of the plate to extend cranially over the top of the olecranon process. Plate application for distal fractures requires less contouring since adequate fixation can be achieved with a plate that extends from the physis (physeal scar) distally. Care should be taken to avoid under or over contouring the plate, as articular congruency may be affected. With the fracture held in reduction (ASIF pointed reduction forceps work well for this purpose) the plate is attached to the proximal and distal fragments, judiciously using the dynamic compression principle to provide interfragmentary compression. Intraoperative radiographs are used to ensure fracture reduction and appropriate implant positioning.

**POSTOPERTIVE CARE:** Open fractures and those with severe soft tissue swelling at the time of surgery may benefit from instillation of a closed suction drain for the first 24 hours postoperatively. However, drains are not used in most fractures. When there is elevated concern regarding the potential for postoperative infection we routinely place prefabricated antimicrobial containing PMMA beads in the depths of the surgical wound. Closure of the surgical wound is routine. Following closure, the surgical wound is protected with a stent bandage for the first 48 to 72 hours postoperatively. In addition, a full limb bandage is maintained during the immediate postoperative period until removal of skin stitches. Radiographs are taken prior to discharge from the hospital, which usually occurs 7 to 14 days after surgery. The patient is confined to a stall for 2-3 months, depending on their age, with a progressive program of hand walking exercise prescribed during the second 4-6 weeks of confinement. Follow up radiographs are taken at this time to determine readiness for the patient to begin the transition from stall confinement to paddock exercise. Young horses will often have an abbreviated convalescent period because of their shortened healing time.

There are a number of pitfalls to be avoided during fixation of ulna / olecranon fractures. The medial aspect of the proximal olecranon is concave and care must be taken to avoid penetration and subsequent placement of screws through the medial cortex of the olecranon process where they may impinge on the medial epicondyle of the humerus. With proximal fractures, it is important to avoid “over-fixation” of the proximal fragment potentially weakening it and predisposing to construct failure. At the level of the semilunar notch, screw holes should not penetrate cranially into the joint, necessitating careful technique to prevent stripping the screws (ie tapping depth and screw length should be less than the depth of the hole). In foals, screw placement into the caudal cortex of the radius should be avoided; otherwise elbow dysplasia is likely to develop. Identification of anconeal process fragmentation with removal at the time of fracture repair is also important. Postoperative complications include; failure of fixation, especially important in proximal fractures; postoperative infection, most likely with substantial soft tissue trauma or open fractures; support limb compensatory lameness, resulting primarily from a delay in weightbearing on the repaired limb; and tendon contracture in the affected limb, also due to delayed weight bearing postoperatively. With articular fractures, development of degenerative joint disease may also affect long term outcome.
We previously reviewed our case population of ulna / olecranon fractures at Texas A&M. During the 12 year evaluation period, 77 horses with ulna / olecranon fractures were admitted. In contrast to the veterinary literature, our most common fracture types were 1b and 5. Over one-half of the fractures occurred in patients less than 1 year of age, and 60% of these were type 1b fractures. A total of 24 type 1b fractures were recorded (31%), the second most common in our case population. The most common fracture recorded was type 5, totaling 26 (34%). The vast majority of these patients were adults. Results of open reduction and internal fixation, using the tension band plating principle, were very encouraging for both fracture configurations. Of the combined type 1b and 5 fracture populations, 35 were treated by tension band plating (type 1b = 20; type 5 = 15). Only one patient was not discharged from the hospital, a foal which developed a cecal impaction that subsequently ruptured in the early postoperative period. A high percentage of the horses available for long term follow up were being used as intended in a wide variety of athletic endeavors. Complications were not common, but included implant infection necessitating implant removal, tendon contracture in the affected limb, and persistent lameness.
AOVET North America

Principles in Equine Fracture Management Course

SUNDAY LECTURE ABSTRACTS
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Sunday, April 10, 2016

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Facilitated Ankylosis of the Distal Intertarsal and Tarsometatarsal Joints

Chad J. Zubrod, DVM, MS, Diplomate ACVS
Facilitated Ankylosis of the Distal Intertarsal and Tarsometatarsal Joints
Chad J. Zubrod, DVM, MS, Diplomate ACVS

Learner Objectives:

- Assess the patient's clinical status, history, and radiographs to determine if the horse is a candidate for facilitated ankylosis.
- List the pros and cons of each method of facilitated ankylosis.
- Determine which method of facilitated ankylosis is most appropriate for the individual case.
Osteoarthritis of the distal intertarsal (DIT) and tarsometatarsal (TMT) joints is a common cause of lameness and decreased performance in all disciplines of horses. Athletic performance in many horse’s results in repetitive compression, torsion, and shear strains on the lower hock joints, resulting in osteoarthritis. Some horses are predisposed to osteoarthritis as the result of osteochondrosis (juvenile spavin), articular fracture, or traumatic joint injury. Osteoarthritis of the DIT and TMT joints can be suspected based on the history and lameness examination. Definitive diagnosis relies on observing improvement in lameness following intra-articular anesthesia of the DIT and TMT joints or hock radiographs demonstrating signs of osteoarthritis including peri-articular osteophytes, subchondral bone lysis, subchondral bone sclerosis, joint narrowing and ankylosis.

Multiple techniques have been developed to facilitate ankylosis of the distal two tarsal joints in horses. Current techniques being utilized include: surgical drilling (SD), sodium monoiodoacetate (MIA) injection, laser surgery, and ethyl alcohol injection of the distal hock joints. A retrospective study evaluating the use of SD, reported that 59% of the horses returned to their previous level of athletic performance. Clinical success using MIA to facilitate ankylosis has varied from 40 to 90% in performance horses. Laser facilitated ankylosis, using a Nd:YAG or diode laser, has a reported clinical success of up to 90%. Although long term clinical results of ethyl alcohol injections for treatment of osteoarthritis of the distal hock joints has not been reported, the technique has successfully created areas of fusion of the TMT joint in normal horses. The last two techniques result in minimal pain following treatment, and have a shorter period of convalescence compared to other methods of facilitated ankylosis.

Laser facilitated ankylosis is performed under general anesthesia with the horse in dorsal recumbency. The distal tarsus is prepared and draped for aseptic surgery. Eighteen gauge, 1½-inch needles are placed in each DIT and TMT joint on the medial, lateral, and dorsal sides. Needle position is confirmed with radiographs or fluoroscopy. A 600 micron contact laser fiber is stripped and inserted through the needles one at a time; and the laser fiber and needle are advanced across the joint as the laser was activated. Approximately 1200 joules of laser energy is applied to each joint. Needles were cooled by irrigation with chilled saline during the procedure. The distal tarsus is placed in a sterile adhesive bandage. In some horses with more severe ankylosis it is necessary to perform the lasering at multiple locations around the joint using radiographic guidance, after pre-drilling with a 2.5 mm bit.

Injection of MIA is performed under general anesthesia to ensure precise needle placement. The distal tarsus is aseptically prepared. A 22-gauge, 1-inch needle is inserted into the TMT joint, proximal to the fourth metatarsal bone and directed distal-medially at a 45 degree angle. A 22-gauge, 1-inch needle is inserted into the DIT joint at the junction of the fused first/second, third, and central tarsal bones on the medial side of the tarsus, distal to the cunean tendon. Confirmation of needle placement is made by retrieval of synovial fluid or radiography. Each
joint is injected with 100 mg sodium monoiodoacetate diluted in 2 mls saline that has been aspirated through a 0.22 \( \mu \text{m} \) filter to eliminate bacteria. It is important that these horses are treated aggressively with analgesics before and in the immediate post treatment period.

Surgical drilling is performed under general anesthesia with the horse in dorsal recumbency. The distal tarsus is prepared and draped for aseptic surgery. The cunean tendon is identified by palpation. A 30 mm vertical skin incision is made over the distal 2 tarsal joints on the medial side of the tarsus using a # 10 scalp knife, distal to the cunean tendon. A 20-gauge, 1-inch needle is then inserted into the DIT and TMT joints. The position of the needle within the joint is confirmed with fluoroscopy. A 3.2 mm drill bit is then passed into each joint and placement of the drill is again confirmed with fluoroscopy. A 4.5 mm drill bit is then used to create 3 drill holes across each joint in a diverging pattern. The incision is lavaged and closed routinely in 2 layers. The distal tarsus was placed in a sterile adhesive bandage.

Injection of ethyl alcohol can performed standing or under general anesthesia to ensure precise needle placement. The distal tarsus is aseptically prepared. A 22-gauge, 1-inch needle is inserted into the TMT joint, proximal to the fourth metatarsal bone and directed distal-medially at a 45 degree angle. A 22-gauge, 1-inch needle is inserted into the DIT joint at the junction of the fused first/second, third, and central tarsal bones on the medial side of the tarsus, distal to the cunean tendon. Confirmation of needle placement is made by retrieval of synovial fluid or radiography. Each joint is injected with 2.5 mls ethyl alcohol qs to 3 mls with sterile saline that has been aspirated through a 0.22 \( \mu \text{m} \) filter to eliminate bacteria and create a 70\% solution.

Some level of forced exercise is necessary with each of these techniques in order to encourage ankylosis. This is probably most important with laser surgery and ethyl alcohol injection, and easiest to accomplish due to the level of comfort in these horses.

A comparative study has been performed in sound, radiographically normal, horses comparing diode laser surgery, to SD and MIA injection of the DIT and TMT joints. Group 1 (n = 6) had laser surgery performed on the DIT and TMT joints of 1 tarsus and MIA injection of the contralateral joints; and group 2 (n = 6) had laser surgery performed on the DIT and TMT joints of 1 tarsus and SD of the contralateral joints. The study evaluated post-operative comfort, lameness, and amount and quality of joint fusion based on radiographs, microradiographs, and histology. Laser surgery produced the least morbidity in the immediate post-operative period. Most horses were less lame in the laser surgery treated limb, compared to the MIA treated limb at 6 months, and compared to the SD treated limb at 6 and 12 months. Microradiographs revealed that MIA resulted in more bone bridging than laser surgery at 6 months, and surgical drilling resulted in more bone bridging the joint at 12 months, than laser surgery. Significantly more of joint space was bridged by bone in the MIA and SD treated joints, compared to the laser surgery treated joints at 6 and 12 months, respectively.

Ethyl alcohol injection of the TMT joint has been evaluated for performing facilitated ankylosis. The injection ethyl alcohol resulted in areas of articular cartilage degeneration, followed by localized areas of mature osteonal bone bridging. The horses in this study had sporadic episodes
of mild lameness during the study. The facilitated ankylosis occurred over 4 months, however the fusion was concentrated in the area of the injection site, including the area between the third tarsal bone, fourth tarsal bone, third metatarsal bone and fourth metatarsal bone, as well as in the areas of the intertarsal ligaments and joint capsule. Clinical cases of osteoarthritis have been treated following contrast arthrography. These horses did not appear to as much radiographic evidence of joint fusion as normal horses following ethyl alcohol injection. For unknown reasons, clinical cases with osteoarthritis of both joints had resolution of the lameness even when only the TMT joint was treated. There are reports of increased lameness, and development of osteoarthritis in the proximal intertarsal and tarsocural joints, even after contrast arthrography did not reveal communication with these joints.

Horses treated with laser surgery and ethyl alcohol may be more comfortable and less lame because less damage was done to the joints compared to the other 2 treatments. It is also likely that laser surgery and ethyl alcohol cause damage to nerve endings in the subchondral bone, synovium, and joint capsule, which can result in decreased pain perception in horses following these treatments.

Like any procedure, complications can and will occur in a small number of cases, when facilitated ankylosis is performed. Complications that can be associated with any surgery or intra-articular injection obviously include infection and those associated with general anesthesia such as myopathy, neuropathy, fracture and death. While these is rare and not procedure specific, they must be mentioned for completeness.

Not achieving athletic soundness is somewhat of a complication, or more accurately a failure of the technique, which can occur with any of the procedures.

The most common complication that I have seen with ethyl alcohol injection, is the recurrence of lameness, typically 4-8 weeks after the injection. Most of these horses became sound, and the clients were very happy, only to have the lameness return. Frequently the lameness not only recurs, but is more severe than prior to injection. A few of these horses will become sound with another injection of ethyl alcohol, however many will require some other form of facilitated ankylosis to become sound. An additional complication that can occur infrequently is the inadvertent injection into a joint that communicates with the tarsocural joint. This can result in severe osteoarthritis of the tarsocural joint, and ultimately can necessitate destruction of the horse. This may be avoided in most cases with an arthrogram prior to injection.

The most common complication with laser facilitated ankylosis is local skin necrosis at the laser sites that are due to not properly cooling the needles during lasering, or not getting the needle into the joint resulting in a local heat sink. Both of these can be avoided with saline irrigation of the needles while lasering, and radiographic guidance with needle placement. Overzealous lasering can in some cases result in exuberant bone proliferation around the joints. This can be prevented by accurately monitoring the energy placed in each joint.

Surgical drilling can also result in the complication of exuberant bone proliferation, which may be due to localized heating during drilling, instability associated with removing too much
articul cartilage and subchondral bone, or chronic inflammation at the surgery site. The incidence of exuberant bone proliferation can be reduced with proper irrigation while drilling and prior to closure of the incision, and limiting the drilling to just 3 drill tracts across the joint.

Each of the techniques currently used to facilitate ankylosis of the distal two tarsal joints in horses has distinct advantages and disadvantages based on the individual case, and the degree of osteoarthritis that is present at the time of treatment. Horses that have minimal joint narrowing, subchondral bone lysis and sclerosis, and minimal natural ankylosis, appear to be the best candidates for treatments that involve joint injection including MIA and ethyl alcohol. Horses amendable to treatment with these products need to have joints that are amendable to easy injection of 3 mls. This is necessary to ensure distribution throughout the joints, and prevent leakage into the surrounding soft tissues. Additionally, distribution of these products through joint communication into the tarsocrural joint can occur, resulting in catastrophic destruction of a high motion joint. Although this is uncommon, it is a potential risk associated with the procedure that must be considered. These two techniques have the distinct advantage that they require minimal special equipment or training in order to be performed. MIA injection can result in substantial short-term soreness, which is not seen with ethyl alcohol. Horses having laser surgery or ethyl alcohol treatment of the DIT and TMT joints have minimal post-treatment pain, minimal lameness and a short convalescent period. Neither treatment appears to result in wide spread bone fusion, however this may not be necessary or desirable to achieve long term soundness. Laser surgery, MIA and ethyl alcohol injection can be difficult to perform in horses with substantial osteoarthritis of the distal two tarsal joints. This can be overcome with the laser surgery technique by performing the technique through multiple different portals, or predrilling the portal for laser fiber insertion using a 2.5 mm drill bit. Surgical drilling can be performed in horses with substantial osteoarthritis of the distal two tarsal joints, however the technique can result in moderate post-operative pain and lameness, and a prolonged convalescent period.

Each of the four techniques currently used for facilitated ankylosis of the DIT and TMT joints in horses has its’ own set of advantages and disadvantages. The radiographic appearance of the joints and the horses anticipated performance schedule must be considered when determining which technique is most appropriate to perform on a horse with osteoarthritis of the DIT and TMT joints. The best technique can vary with each individual case and each surgeon’s experiences. With modifications in certain cases, laser surgery is probably the most versatile technique to perform, and is likely to have a good prognosis for soundness and a short convalescent period. The other techniques can also result in a successful outcome when performed correctly on appropriate cases.
Technical Failures in Lag Screw Fixation

Alan J. Ruggles, DVM Diplomate, ACVS
Technical Failures in Lag Screw Fixation
Alan J. Ruggles, DVM Diplomate, ACVS

Learner Objectives:

- Identify technical errors in internal fixation in the horse
- Critique internal fixation repairs for technical errors
- Analyze internal fixation technical errors for biomechanical reasons for failure
Technical Failures in Lag Screw Fixation
Alan J. Ruggles, DVM Diplomate, ACVS
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Technical errors using the lag screw technique occur to all surgeons and under all circumstances. Obviously with experience the failure rate is reduced (we hope!!). Technical failures occur in the following categories; poor preoperative planning, improper intra-operative radiographic control, improper use of the equipment, improper application of the implant and any combination of the above. This lecture will demonstrate many of technical errors that can happen using lag screw technique.

Careful preoperative radiographic evaluation and technique will reduce the rate of technical errors. Imaging control during surgery whether by radiographs or fluoroscopy will prevent errors, insure proper placement and use of implants improve results and allow the surgeon to gain confidence in the surgical techniques.

In my personal encounters with technical failures, improper use of the equipment and failure to have adequate radiographic control has led to the most frequent cause of failure.

Some examples of mistakes using lag screws are given

**Poor preoperative planning**
- Too long a glide hole – poor or no compression
- Failure to identify all fractures lines – post operative fracture or poor reduction

**Inadequate radiographic control**
- Screw head incompletely seated – reduce compression, soft tissue pain
- Screw has bottomed out - failure to compress fracture
- Screw in fracture line – additional fractures
- Screw too long – soft tissue problems

**Improper use of equipment**
- Instrument breakage – little morbidity
- Improper countersinking – poor compression, bent screw head
- Failure to completely tap pilot hole – failure to compress fracture

**Improper application of implants (screws alone)**
- Fractures where excessive bending or torsional forces are present – construct failure

Lag screws reduce shear forces and provide interfragmentary compression of fracture fragments. They should be used whenever possible even through plates or in concert with other repair techniques. When high torsional, bending or compressive forces are present lag screws are relatively weak when compared to plate fixation. It is common and recommended to use lag
screws when possible in plate fixation.

Breakage of 3.5 mm screw due to bending force

Failure of splint bone fracture repair. Failure to counteract tension force of collateral ligament

Improper tapping, inaccurate measurement and poor radiographic control

Drilling of glide hole too far with 4.5 mm bit
The Use of Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) in the Diagnosis of Orthopedic Injury in the Horse

Robert K. Schneider, DVM, MS
The Use of Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) in the Diagnosis of Orthopedic Injury in the Horse
Robert K. Schneider, DVM, MS

Learner Objectives:

- Contrast CT and MRI and describe the indications for their use in the horse
- Describe the use of CT for repair in fractures in the horse
- Discuss how sectioning the limb with slice plains when evaluating horse limbs with MR imaging can add information that affects treatment
The Use of Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) in the Diagnosis of Orthopedic Injury in the Horse
Robert K. Schneider, DVM, MS
Robert D. McEachern Distinguished Professor
Washington State University

The continued advancements in technology have improved our ability to evaluate and treat horses with fractures or injuries to the bones in the distal limbs. Computed tomography (CT) should be thought of as sectional radiographs. This technology allows us to see sectional radiographs of the horse’s leg. The images obtained are extremely useful for determining the exact plane of a fracture and the amount of comminution that is present. Magnetic resonance imaging (MRI) can also determine the plane of the fracture on sectional images of the limb, but has the added advantages of being able to detect bone damage other than fractures and to detect abnormalities within the supporting soft tissues. CT and MRI each have their advantages and indications in evaluating horses with fractures or acute, severe lameness. At Washington State University’s Veterinary Teaching Hospital both of these technologies are available. CT is less expensive, can be performed in a shorter period of time, and gives better visualization of fracture lines and small comminuted fragments associated with the fracture. MRI gives increased options for sectioning the limb because sections can be oriented in any direction through the limb. MRI has much greater diagnostic capabilities because bone injury other than fractures can be detected and injuries to ligaments or tendons can be easily seen. It also has the advantage of determining the relationship of overlying soft tissue structures to fractures and joints that can help in selecting a new surgical approach.

CT is normally performed in horses where more information about the fracture is valuable to the surgical treatment. Comminuted fractures of P1 are an example of clinical cases where information about the plane of the fracture and the location of the large pieces can avoid the need to open the horse’s joints for lag screw placement. CT is valuable for horses with palmar carpal fractures because the number and specific location of the fragments can be accurately determined. Another example is tarsal slab fractures which have considerable variation in their location and plane of orientation through the central or third tarsal bone. In most horses that have CT performed in our hospital, a diagnosis has already been made. CT images can usually be obtained in 20 minutes. The value of the information obtained must be weighed against the increase in anesthetic time in a horse with an unstable fracture. In horses with stable fractures, like palmar carpal fractures, the CT is usually performed on a different day than the surgery because of my personal opinion that two shorter anesthesia events are safer for the horse than one long anesthetic period.

MRI is most frequently performed in our hospital when an accurate diagnosis cannot be made in a horse with a lameness problem using radiographs, ultrasound, or nuclear scintigraphy. Several hundred horses have had an MRI since the technology first became available for routine use on live horses in 1997. It has proven to be a valuable tool allowing us to make diagnoses in horses that were not previously possible. It is not necessary to use MRI to make a diagnosis of a fracture; however the technology has been used to find fractures that could not be found on radiographs. More importantly it has allowed us to find bone contusions and subchondral bone
abnormalities that could not be seen on radiographs and could only be suspected with nuclear scintigraphy. Making an accurate diagnosis in these horses has allowed us to select the treatment most likely to return the horse to athletic function. The value in any imaging modality is the ability to find the problem when you do not know it is there. MRI allows us to make accurate diagnoses in horses with both bone and soft tissue abnormalities, something few other imaging modalities can do. Therefore, it is our technology of choice when clinical examination and radiographs fail to yield a diagnosis and we have localized the problem to a specific anatomic area. Our experience has clearly demonstrated the ability of MRI to find bone abnormalities that cannot be found other ways.
A Review of First Aid for Equine Fracture Patients

L.R. Bramlage, DVM MS
A Review of First Aid for Equine Fracture Patients
L.R. Bramlage, DVM MS

Learner Objectives:

- Assess the needs for stabilization for first aid for fractures of the fore and hind limbs
- Properly select splinting materials for temporary stabilization of a fracture
- Apply a first aid splint for limb fractures in the horse
A Review of First Aid for Equine Fracture Patients
L.R. Bramlage, DVM MS
Rood and Riddle Equine Hospital

After a fracture occurs horses tend to add to the trauma that has been done to an injured limb. The objective of first aid treatment is to minimize this additional damage. Immediately after injury horses are often more scared than painful so careful sedation is usually needed.

When a fracture patient is first attended, the degree of damage to the limb must be assessed. Some limbs are too severely damaged for an attempt at repair. Severe loss of soft tissue or loss of bone constitutes a situation where treatment may be hopeless because of the extent of the damage. Even if the fracture or luxation is hopeless, if the horse can be loaded in the ambulance and removed from the track or performance area, that is preferable. If the limb is in a reasonable condition for repair or if there is any doubt about the possibility of repair, then the soft tissue is in urgent need of protection. Soft tissue receives severe trauma as a horse attempts to use a disabled limb. Protective splints should be applied immediately; other manipulations, such as radiography, can be done with minimal risk of further damage after splinting. Radiography is actually facilitated by properly applied splints. A twitch is a useful initial and primary means of gaining control of the horse. Sedation and analgesia are then used as needed to allow manipulation of the limb.

Emergency first aid measures should be directed at minimizing any further damage to the injured limb and maintaining it in a condition that warrants repair. The objectives of emergency first aid are to:

1. prevent damage to the neural and vascular elements of the limb.
2. keep the bone from penetrating the skin and becoming an open fracture and/or protect the limb from contamination through any existing skin damage.
3. stabilize the limb to relieve the anxiety that accompanies an uncontrollable limb in a horse.
4. minimize any further damage to the bone ends and surrounding soft tissue.

Hemorrhage due to laceration of a major vessel is infrequent after equine fractures therefore, hypovolemic shock, due to blood loss, is also uncommon in horses. Thrombosis following continual stretching and direct trauma to the blood vessels often leads to the loss of vascularity to the distal limb. Immobilization is more essential to preserve the vascularity to the distal limb than to prevent bleeding at the fracture site, but proper immobilization can accomplish both.

While circulatory compromise seldom results from blood loss, it may follow the marked anxiety that often accompanies a fracture. Severe anxiety and accompanying voluminous perspiration can cause the loss of large amounts of body fluid and bring about a state of
compromised perfusion that requires fluid therapy. Prompt sedation and limb stabilization will generally allay the anxiety and limit the amount of fluid lost by perspiration. The horse's anxiety over its fractured limb results more from the inability to control the limb than from the pain. Once a splint is applied and the horse is able to regain control of the limb, the animal relaxes somewhat and becomes more tractable even though the limb cannot bear weight. Musculo-skeletal pain in the horse does not evoke the uncontrollable response that gastro-intestinal pain creates, once the fracture is splinted. A properly applied splint also imparts counter pressure over the swollen area. Counter pressure over the fracture site protects the soft tissue by preventing it from imbibing blood and edema fluid. The pressure also controls the swelling and some of the pain.

The most important tissue to protect, from the repair aspect, is the skin. An intact skin cover greatly reduces the chances of infection. Equine skin is so thin that it offers little resistance to sharp bone fragments. If skin penetration has occurred, the wound should be covered with a water-soluble antibiotic ointment, and a sterile dressing should be applied immediately to reduce the amount of subsequent contamination. Then the appropriate splint should be applied over the sterile bandage to prevent further damage.

Proper splinting helps to protect the bone from abuse. The horse will generally make repeated attempts to place an unstable limb in its normal position. The continuous lifting and replacing of the limb grinds the bone ends against each other complicating the reconstruction. Once splinted, the horse will better protect the limb by resting it instead of continually trying to place it in a normal stance. The pain associated with the fracture is usually severe enough to preclude any serious attempts by the horse to use the limb for weight support. Splint application does not encourage the horse to walk and cause unnecessary abuse of the limb; instead it encourages the horse to rest the limb until treatment can be instituted.

After the limb is splinted and the horse quieted medication should be aimed at:
1. preserving the vascular supply
2. minimizing inflammation
3. protection against infection

Each of the anatomic areas of the limb have differing biomechanical needs. The limb can be roughly divided into the distal cannon bone and phalanges, the mid-limb, the upper axial limb below the trunk, and the limb attached to the trunk. Each area requires its own splint. These needs have been well defined and should be kept in mind when splinting the limb.