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# FRACTURE HEALING AND NONHEALING

Goals
* be able to monitor for normal bone healing
* be able to identify factors that can interfere with normal bone healing
* be able to diagnose and determine treatment options for delayed and nonhealing fractures
* be able to list causes of malunions and be able to describe preventative measures
* be able to determine when and whether to remove implants
* understand species and age differences in fracture healing

I. Determining status of bone repair

- **Clinical usage and appearance**
  - persistent lameness, minimal use of the limb, muscle wasting, and movement at fracture site indicate poor or incomplete healing
  - ideally, patients should be bearing normal weight on the fractured limb if fracture is stable (either due to implants or healing)

-**Radiographs**

- monitor as frequently as finances will allow
- maintain same exposure factors to maximize comparison
  - Immediate postoperatively - get baseline and assess fracture repair so forewarned of possible complications
  - 10-14 days - check soft tissues for evidence of infection and to make sure any swelling is resolving
  - 4-6 weeks - would expect callus to be visible; may note implant failures due to cyclic loading
  - Towards end of healing - decide on implant removal and/or activity level
  - Prior to implant removal - make sure it is ready
  - After implant removal - check for any hidden problems (eg sequestrum under plate)
- amount of bone connecting fracture fragments more important than size of callus

- factors indicating problems
  - **bone loss** - generally associated with increased vascularity
    - -may indicate motion, infection, dystrophy, tumor, implant problems
    - -small amount of resorption normal at fracture line
    - - implant problems : stress protection if beneath; corrosion at bone -implant interface
    - - may detect disuse osteoporosis distal to fracture
    - - severe loss at fracture ends seen with atrophic nonunion (rare)

  - **bone production**
    - -parallel to fracture line may indicate motion and impending nonunion
    - - periostitis : irritation callus - irregular, poorly defined surface; may extend away from fracture line more than expected
      - Normal in young
      - In older may indicate infection or instability
    - - involucrum : sclerotic bone that forms around sequestrum (dead bone)
    - - bone ends may be sclerotic and marrow cavity sealed off
  - **no change in bone over time**
    - - delayed or nonunion
    - - may be avascular- will not change until revascularizes
    - - stress protection occurring - usually some bone loss in cortex
    - - sequestrum

- **Scintigraphy :** nonunions often "cold" with no uptake of isotope
- **Osteomedullography** : inject contrast into bone using a biopsy needle
  Place a tourniquet on the limb; use needle with 1.5mm internal diameter; puncture distal metaphysis approximately 1 cm proximal to physis; use sterile technique; 3-5 ml of full strength medium (any kind of iodinated medium); make an immediate radiograph and on at 5-10 seconds
  If performed between 3 and 10 weeks, should get contrast crossing fracture from distal into proximal; if no crossing by 12 weeks => consider a graft
  should cross even if distracted ends
  may be abnormal between 9 and 18 weeks due to endosteal callus
-Future options : measuring **bone mineral density**
  quantitative computed tomography
  dual energy x-ray absorptiometry

II. Improper healing

**Malunion** : Fracture has healed but with poor alignment that may alter function of that part of skeleton
angular deformities
rotational deformities
shortening of the limb (overriding, compression fractures)
may be due to improper or insufficient fixation or interference with growth
(bend when put on cast or twist as put on plates; damage physis)
if nonfunctional, may require osteotomy/ostectomy to correct deformity

**Delayed union** : Fracture seems to be taking an excessive amount of time to heal (but will if given enough time); can progress to nonunion; difficult to differentiate

**Nonunion** : Fracture has not healed and is not likely to do so without change

**Viable nonunion :** usually the result of instability or failure to reduce fracture

**Hypertrophic** (elephant's foot) : abundant callus (lots of vascular supply)
**Slightly hypertrophic** (horse's foot) : moderate callus
**Oligotrophic** : minimal callus. Bone ends joined by fibrous tissue. Rounding of fragment ends seen

**Pseudoarthrosis** : type of nonunion where there is so much movement at the fracture site that a false joint has formed with a synovial cavity

**Nonviable nonunion** : blood supply interrupted with presence of necrotic bone fragments or bone loss

**Dystrophic** : intermediate fragment united with one main fragment but not the other; intermediate fragment may be partially necrotic; may be hypertrophic on one side, necrotic on other
**Necrotic**: two or more necrotic fragments and lack of callus; implants may be loose and fail
**Defect** : significant loss of bone at fracture site; may be primary (loss at time of fracture or removed such as a tumor) or secondary to resorption
**Atrophic** : sequel to one of other types of nonviable nonunions; rare but are seen in nonunion fractures of distal radius and ulna of toy breeds

Treatment : replace missing factor or remove problem, stabilize fracture and encourage osteogenesis (bone graft etc)
-nondisplaced nonunion : provide compression + graft
-displaced nonunion : remove callus to replace, open medullary cavity, graft
-other options : distraction osteogenesis, skeletal stem cells, electrical current

**Fracture disease** - despite fracture healing, limb remains with suboptimal function

syndrome of muscle atrophy or contracture, joint stiffness and osteoporosis resulting from prolonged immoblization

- all tissues undergo atrophy when not used
  - muscles: change within 3-5 days; half of total muscle mass lost in first 9 days; generally reversible but takes 2-4 times duration of immobilization to recover
  - bone : bone mass declines rapidly in dogs in first 6 weeks but then slows
    - Production of new bone occurs 10x more slowly than bone removal
    - May not be entirely reversible in young dogs or if immobilized > 12 weeks
  - joints : motion required for circulation of nutrients; changes occur within a few days;
    - intraarticular connective tissue forms within a month and adhesions occur between it and cartilage at 1-2 months
      - Generally reversible with up to 4 weeks of immobilization; may be permanent after 7 weeks
      - Do better if immobilized in flexion than in extension
- elbow and stifle joints most susceptible
  - distal femur fractures treated with external splinting -> stiff stifle joint in 3-7 weeks
- more often a problem if a muscle only crosses one joint (better immobilized)
- young animals can get growth disturbances
- quadriceps contracture - common complication of distal femoral fractures
  - -fibrous adhesions tying down the vastus intermedius to the distal femur with muscle incorporated into the callus
  - -most severe in young growing dogs
  - -rigid hyperextension of the limb and decreased flexion in both hock and stifle joints; muscles firm and atrophied; patella and hip may be luxated or subluxated
- primarily small animal disease
- need early limb use to minimize (internal fixation or early support removal)
- physical therapy useful (swimming, etc)
- prognosis guarded for reasonable function; extremely poor for full function

**Angular limb deformities**

- if damage occurs to the physis (either related to original trauma or to surgical treatment), growth can be slowed or stopped
- if entire physis damaged : shorter bone
  - Compensatory growth does occur in younger animals
- if one side of physis damaged : bone develops angulation due to uneven growth
  - If angled out from the carpus : carpus valgus
  - If angled in from the carpus : carpus varus
- if bridging occurs due to another bone or callus formation, get similar results
  - If ulnar growth stopped but not radial growth (SA)
- if caught early enough, treatment involves slowing growth on opposite side or removing callus
- -if growth is complete, requires osteotomy/ ostectomy to treat
- SA: may be functional malunion
- LA: can lead to significant arthritis due to abnormal weight bearing

**Stress protection**

Occurs when implants are strong enough to unload the underlying bone so that most or all of weight bearing is through the implant and not the bone

- cortices beneath the plate undergo a progressive reduction in density and thickness; can get gap between plate and bone
- -requires careful removal of implants with temporary protection of weakened bone

**Fracture associated sarcomas**

- occur 5+ years after fracture; very rare even in small animals
- usually in diaphysis of long bones, especially femur
- more common if complications occurred, especially infection and nonunion
- if occurs more rapidly, may have been pathological fracture at site of developing tumor

III. Factors that impair or prevent fracture healing

**Motion*** most common**

- improper implants etc
- prevent bony bridging -> persistence of fibrous tissue = hypertrophic nonunion
- osteogenic callus changes to fibrous tissue between edges of external callus => hypertrophic nonunion
- increases strain on tissues : body may decrease strain by widening fracture gap to distribute strain across more tissues - resorption of fracture ends
- bigger callus forms to increase stability : can impinge on other tissues including nerves, muscles and tendons

**No micromotion**

- bone cells very responsive to strain in the matrix
- interfragmentary (micro) movement has been shown to stimulate more rapid progression of indirect healing than totally rigid fixation

**Excessive gap at fracture site**

- bones distracted at fixation, lack of immobilization, interposition of soft tissue, ischemia or infection
- overtraction = 1/4" of distraction causes serious delay in healing in people
- overriding tibia fractures heal more quickly than perfectly reduced fractures
- can lead to oligotrophic nonunions

**Loss of blood supply**

- due to initial trauma or surgical trauma; damage to surrounding soft tissues or nutrient vessels; damage to nerves (avoid excess trauma, excess cautery, keep moist, avoid excess periosteal stripping)
- fractures heal poorly if loss of soft tissues overlying
- some fractures (comminuted pastern fractures in horses) do better if treated without internal fixation due to fragile blood supply

**Infection**

Open fractures, contamination, hematogenous spread from other sites
changes pH and puts calcium into solution, interferes with blood supply, occludes Haversian system, causes bone death and sclerosis, interferes with nutrition, loosens implants
fractures can heal but only if fracture is rigid (unlikely in large animals)

**Hyperemia**

infection can cause; can prevent laying down of collagen and transformation to collagen

**Compression**

If excessive can cause microfractures and vascular compromise

**Severe comminution**

Associated with diminished blood supply, ischemia, sequestration and instability

**Excessive implants**

impede blood supply to periosteum, cortex or medullary cavity

**Use of improper metals or dissimilar metal combinations**

leads to electrolytic reaction and lysis of local bone cells
disperses metal ions into surrounding tissue :gray black discoloration
-> marked lysis, neoplasia, chronic infection

**Implant failure**

especially in large animals; loading on recovery or fatigue through use
at mechanical limits of implants
reflected in fracture classification and bone location (proximal worse)

**Systemic factors**

-secondary hyperparathyroidism can lead to pathological fractures; will often not be suitable for internal fixation due to poor bone strength
- corticosteroids or cytotoxic drugs interfere with healing
- metabolic disorders such as liver failure or porphyria, diabetes and hyperadrenocorticism, osteofluorosis impair healing
- geriatric patients : lower calcium levels in bone and decreased activity
- young animals : more difficult to restrain
-? excessive NSAIDs : bute found to decrease healing of cortical defects in horses (4.4 mg/kg po q12h) - prostaglandins important in early stages of bone healing

**First aid measures**

-other injuries and shock , eg blood loss due to rupture of vessel by fracture fragments, ruptured bladder due to hit by car
- length of time between injury and repair and effectiveness of first aid measures
further damage to soft tissues and bones : closed -> open, bone ends become eburnated, further vascular compromise

**Inappropriate postoperative management**

Excessive weight bearing can lead to implant loosening or motion
need cooperative patient and owner

IV. **Care following fracture repair**

- horses may need temporary support of the fracture for recovery (eg cast or cast bandage); may also need assistance to stand
- in larger animals, the opposite limb is often wrapped to provide support of the soft tissues
young animals will get ligamentous laxity with bandages, so bandages actually decrease support until foals are over a month of age
- patients should be kept comfortable to minimize stress on other limb
analgesic use should be monitored and tapered off when possible so that early signs of problems on either the fractured leg or the good leg can be detected and to prevent overuse of the limb
- equine patients may have a support shoe or pad placed on the good limb to provide support and hopefully minimize laminitis
- controlled exercise (but not free choice) is encouraged in most animals without casts to enhance soft tissue health
- animals in casts should be restricted to stalls, etc

V. **Implant removal**

Implants are foreign bodies and may require removal. Decision for removal depends upon species, use of animal, type of fracture, type of implants and any complications. If implant removal is required or desired, obviously want to have adequate fracture stability prior to removal.

-Premature removal can lead to refractures.
-Removing two plates or large amounts of hardware can leave large bony defects that act as **stress risers**
- defects in bone decrease bone strength
Eg holes from pin placement, sequestration (dead bone fragments)
- in sheep, defect =10% of bone diameter - decreased strength <5%
defect = 20% - decreased strength 34%
defect = 50% - decreased strength 62%
- also important to keep in mind when selecting pin sizes for external fixateurs

Removal of external fixation devices

- obviously most of these will eventually be removed
- staged removal may be useful
- about 6 weeks after surgery, remove additional connecting bars
- let some of holes heal before others left empty to minimize stress riser formation eg remove central pins first
-allow increased weight bearing on fracture site and on other structures

- sometimes required to get callus and fracture healing
(Vs giving enough time for primary healing)
- minimize osteoporosis and soft tissue changes by allowing some weight bearing

- pins do loosen and removing some support (staged removal) will speed loosening of remaining pins so may end up with faster removal than planned on
- pins may need to be removed due to loosening or formation of ring sequestra
    - as pins loosen, the process of weight bearing on the pins becomes acutely more painful - check radiographs for lysis around pins if change in weight bearing
    - ring sequestra are donut shaped bone sequestra around pin tracts, generally believed due to thermal necrosis that occurred at time of pin placement
    - loose pins are easy to remove with pliers
- alternatives include moving the vertical connecting bars further away from the limb to destabilize the fixateur
(not much of an option if a transfixation cast is used)
- because of bone weakening, most animals are put in splint, cast, or heavy bandage following external fixateur removal; exercise should be restricted until the bone has a chance to further remodel and soft tissues are able to support weight adequately
    - 6-8 weeks of restricted activity

Removal of intramedullary pins
- these implants are generally removed due to tendency to migrate
-in many instances migration determines when they are removed...

Removal of interlocking nails
- not usually performed

Removal of lag screws
- lag screws are not often removed unless producing pain or bone reactions
- individual loose screws are removed
- racing horses may require removal especially in colder climates (not done as much anymore)
- partially threaded screws (cancellous) may be impossible to remove

Removal of cerclage wire
- generally only removed if it breaks

Removal of plates
- it depends...
- often removed from long bones of horses intended for performance, especially foals
- staged removal recommended if more than one plate applied (large number of screw holes associated)
- plates applied to deep bones, nonweightbearing bones (olecranon) or for arthrodesis purposes generally left in place
- infection around a plate usually necessitates its removal
- foals : plates may be removed in 5-6 months if all goes well (as early as 6-8 weeks)
    - may need (earlier)plate removal if growth of a bone being inhibited
    eg olecranon plate in which screws cross into radius; if not removed, develop subluxation of elbow joint
- should be removed if evidence of stress protection (SA)

VI. Species differences

Large Animal
- fractures of bone above the fetlock (metacarpo/ metatarsophalangeal joint) are often not repairable in adults and can be difficult in young animals
- recovery from anesthesia can be disastrous, particularly for horses - lots of stress on implants and flight response of the horse

- cattle much calmer; recovery problems not as severe
- horses required to bear weight on four limbs; if try to bear weight on three will develop laminitis (adults), ligamentous breakdown (adults and foals) or angular limb deformities (foals)
- cattle and llamas more often recumbent and tend to save "good" limb but can lead to malformation of healing limb due to abnormal posture (out to side); calves also prone to angular limb deformities
- thin cortices on cattle bone (especially calves) make internal fixation more difficult
- performance often required from horses; need good healing and minimal side effects on other structures (feet, joints)
- for cattle, ability to stand is important prognostic indicator
- optimal repair may not be required for cattle to perform as needed
- almost always retain some motion at fracture site during healing; primary union not expected; minimal problems with stress protection
- fracture disease a minimal problem; can get osteoporosis, particularly of sesamoid bones (can fracture secondarily)
- cattle rapidly get periostitis with infection
- foals develop ligamentous laxity after a short time in a cast or splint. Exercise should be restricted until the soft tissues have a chance to return to normal function
- fracture repair is usually a race between implant failure and bony union

Small ruminants and llamas

- smaller size and weight improves prognosis
- can weight bear on 3 legs more easily
- amputation may be an option, especially for small ruminants
- quiet nature = good patients

Small animals

- better able to minimize weight bearing during healing with slings, etc
- fracture disease a significant concern, particularly with casts
- strength of implants usually adequate
- malunions may be acceptable depending upon breed and owner requirements
- nonunions most likely in distal radius and ulna of small dogs, also tibia and femur; in femur of large dogs
- nonunions uncommon in cats
- amputation may be an option

Avian

- fracture repair is challenging
- bones are brittle with thin cortices; large intramedullary cavity (hard to fit pins)
-only a small amount of soft tissue coverage and vascular supply (and often have open, contaminated wounds with significant soft tissue damage)
-excess callus can interfere with joint or tendon function and therefore with flight
- often highly stressed and poor anesthetic risk : Stabilize and splint first; check for hypoglycemia; keep in warm dark room until calm
- threaded pins help increase pull-out strength
- fractures heal rapidly if stabilized and well-aligned (eg within 3 weeks)
- external skeletal fixation often used if implants required (vs splints or casts)
-malunions not well tolerated; flight muscle place significant rotational forces on bones; radius and ulna must slide separately
- get fracture disease if wing immobilized : joint ankylosis, muscle wasting, scarring

Exotic animals

- handling and restraint may worsen the situation
- capture myopathy can lead to death and increased morbidity
- some forms of splints and fixation types not safe since can't restrict or handle well
- amputation may be an option in some situations

Young animals

- growth abnormalities common
    - good compensatory mechanisms to length but prone to rotational and angular deformities
- minimize effects on growth plate and monitor for evidence of damage
- remove implants as soon as possible in most cases
- faster healing : may heal in as little as 3 weeks
- tend to get more reactive callus (periostitis)
- bone remodeling may cover implants
- nonunions rare
- physeal fractures common - weak site
    - need particular attention if articular component
- soft thin corticies - less holding power for implants
- callus forms quickly - can be a problem if delay in fixation
- rule-out preexisting bone disease (eg nutritional imbalances)
- immoblization of one area can affect other areas : eg stifle immobilization in dogs < 3 months of age can lead to hip subluxation and increased femoral torsion

VII. The future?

- speed healing by adding increased quantities of factors involved in bone healing
- improved detection of delayed or nonhealing fractures
- improved implants to manage fractures in larger animals
- biodegradable implants for SA and avian fractures
- use of electrical current for nonunions?- new bone growth near negative electrode, osteolysis near positive (must have potential for healing and adequate stabilization; doesn't appear to affect normal healing; used for 12 weeks in people)