# BONE

## FRACTURE

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# Fracture

- A bone fails when the loading forces exceed the load bearing capacity.
- Depending on both the force of the injury and the properties of the bone involved, load failure results in a fracture in several unique patterns.
- Three fundamental forces cause fractures: shear, compressive, and tensile.
- Bone is least able to withstand shear forces, followed by tension, then compression

# Fracture

- Tensile bone failure causes fractures perpendicular to the direction of loading (transverse)
- Compression forces cause oblique stresses in a plane approximately 45 degrees to the bone's long axis.
- Bending forces result in a tensile stress to the convex side and a compressive stress to the concave side
- Results in transverse and oblique fractures on the tensile and compressive sides respectively.

# Fracture

- The tensile-compressive pattern from bending can cause a resultant bone wedge referred to as a butterfly fragment or the characteristic greenstick fracture.
- Torsion (rotational) forces lead to more complex fractures by causing a small crack to extend into a spiral pattern.
- Many fractures, however, involve combinations of forces and therefore develop complex fracture patterns.

# Fracture

- Buckle (torus) fractures follow compression failure, often at the junction between the porous metaphysis and the denser diaphysis.
- These injuries typically occur in the distal radius after longitudinal trauma (fall on an outstretched hand), but are also seen in the distal tibia, fibula, and femur.
- Buckle fractures are by definition stable and can often be managed with splinting.
- The greenstick fracture occurs in >84% of forearm re-fractures.

# Fracture

- A plastic deformity (or bowing fracture) occurs when a longitudinal force exceeds the bone's ability to recoil to its normal position.
- If the tension side cannot propagate the fracture, microscopic fractures can occur to dissipate the impact energy, thus creating a plastic deformity.
- Most commonly seen in the ulna, the radius, and occasionally in the fibula.

# Fracture

- If the deformation is less than 20 degrees or if the deformity occurs in a child <4 years of age, the angulation often corrects itself.
- Otherwise, closed reduction or operative intervention may be necessary to straighten the bone.

# Growth plate

- The germinal zone of the growth plate borders the epiphysis.
- The epiphyseal cartilage cells grow toward the metaphysis and form columns of cells.
- These columns degenerate, undergo hypertrophy and then calcify at the metaphysis to form new bone.

# Fracture

- <u>The weakest part of the growth plate is the zone of hypertrophic cartilage and accordingly the most common site for physeal fractures .</u>
- In infancy and early childhood, the physis is relatively thick and the epiphysis is mostly cartilaginous, serving as a shock absorber and transmitting forces to the metaphysis.
- During adolescence, when the epiphysis begins to ossify, these forces are less absorbed and consequently transmitted to the physis.

# Fracture

- Growth plates are susceptible to fracture and represent a weak point in pediatric bone.
- Because the tensile strength of pediatric bone is less than that of the ligaments, the same injury mechanism causing a ligamentous injury in adults (sprain or strain) is more likely to cause a bone injury in children:
- The physis will separate or fracture before disruption or "spraining" of an adjacent strong and flexible ligament.
- Occur in 21 to 30 percent of pediatric long bone fracture, more commonly involving the distal growth plates of the radius and ulna.

# Fracture

- In girls, growth plate injuries occur between ages 9 and 12, while in boys they typically occur later, between ages 12 and 15.
- Although a majority of these fractures heal without incident, approximately 30 percent lead to premature closure and unilateral long bone shortening.
- Appropriate anatomic alignment is critical for optimal growth.

# Epiphyseal fracture

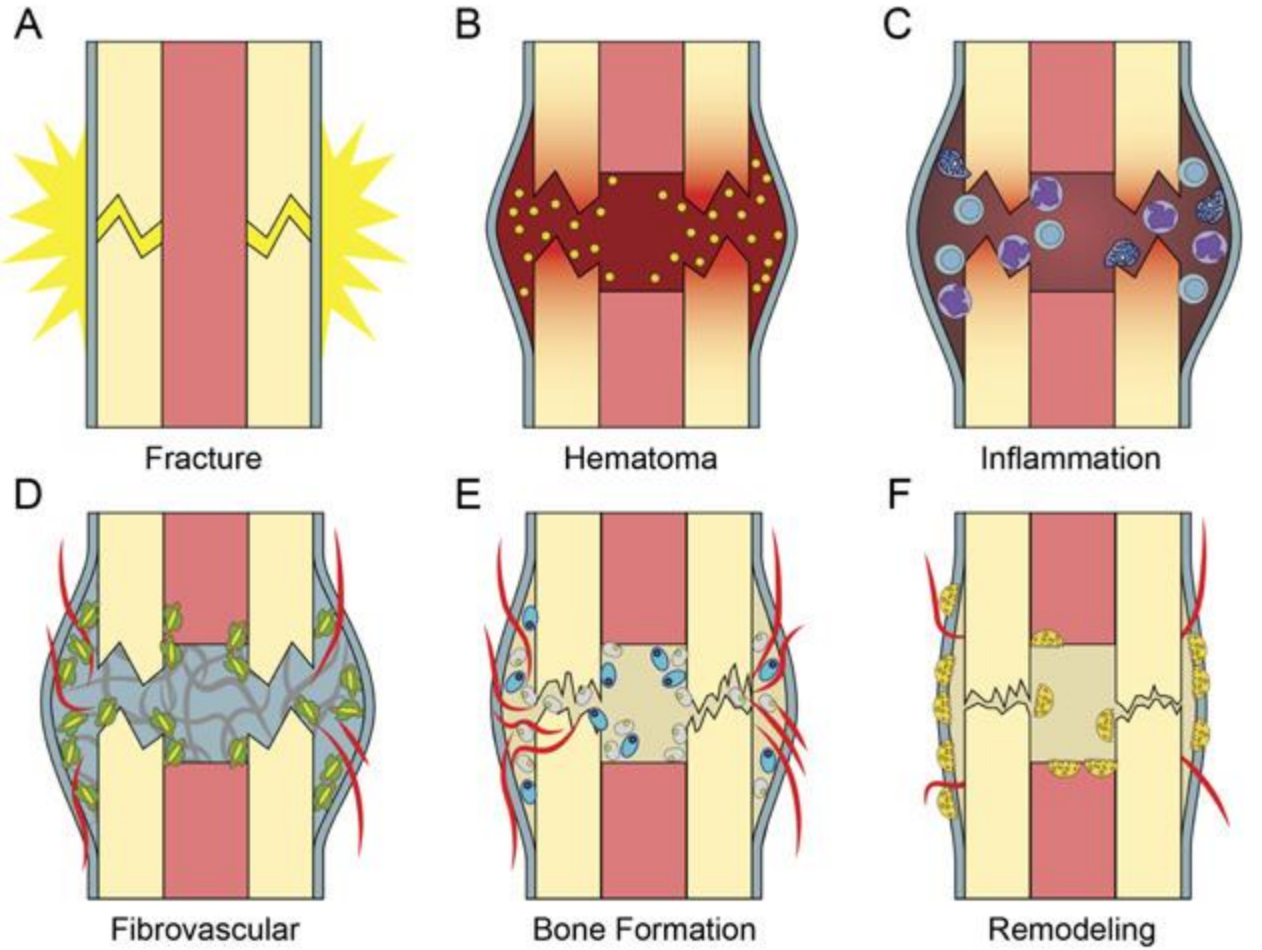
- Salter-Harris classification
- Metaphysis is above the growth plate
- Epiphysis is below the growth plate
- Type I    Straight across the metaphysis
- Type II   Above the metaphysis
- Type III  Below the metaphysis
- Type IV  Through the metaphysis
- Type V   Erasure or crush of growth plate

# Fracture

- Certain growth plates contain fibrocartilage instead of columnar cartilage (tibial tuberosity, inferior pole of the patella).
- These areas are tensile-responsive apophyseal centers and have unique failure patterns that result from the intersection of the ossification center and the fibrocartilage.
- These apophyseal centers are prone to overuse traction avulsions, termed apophysitis.
- Apophyseal injuries do not interfere with growth and are mostly self- limited injuries in adolescent athletes.

# Fracture repair

- Initial inflammatory phase is dominated by vascular events.
- Following a fracture, a hematoma forms.
- Subsequently, reabsorption occurs of the 1 to 2 mm of bone at the fracture edges that have lost their blood supply.
- It is this bone reabsorption that makes fracture lines become radiographically distinct 5 to 10 days after injury.
- Next, multipotent cells are transformed into osteoprogenitor cells, which begin to form new bone.




Fracture healing is temporally-defined process.

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# Fracture repair

- In the reparative phase, new blood vessels develop from outside the bone that supply nutrients to the cartilage which begins to form across the fracture site.
- Nearly complete immobilization is desirable during both the inflammatory phase and the early reparative phase to allow for the growth of these new vessels.
- Once neovascularization is complete, progressive loading and motion of the fracture site are desirable to augment callus formation.

# Fracture repair

- Callus typically forms as a collar of new, endochondral bone around the fractured area.
- Callus is initially highly cartilaginous, but hardens as mineralization and endochondral calcification occur during the remodeling phase.
- Late in the reparative phase, clinical union of the fracture occurs.
- Clinical union occurs when the fractured bone does not shift on clinical examination, the fracture site is non-tender, and the patient can use the injured limb without significant pain.

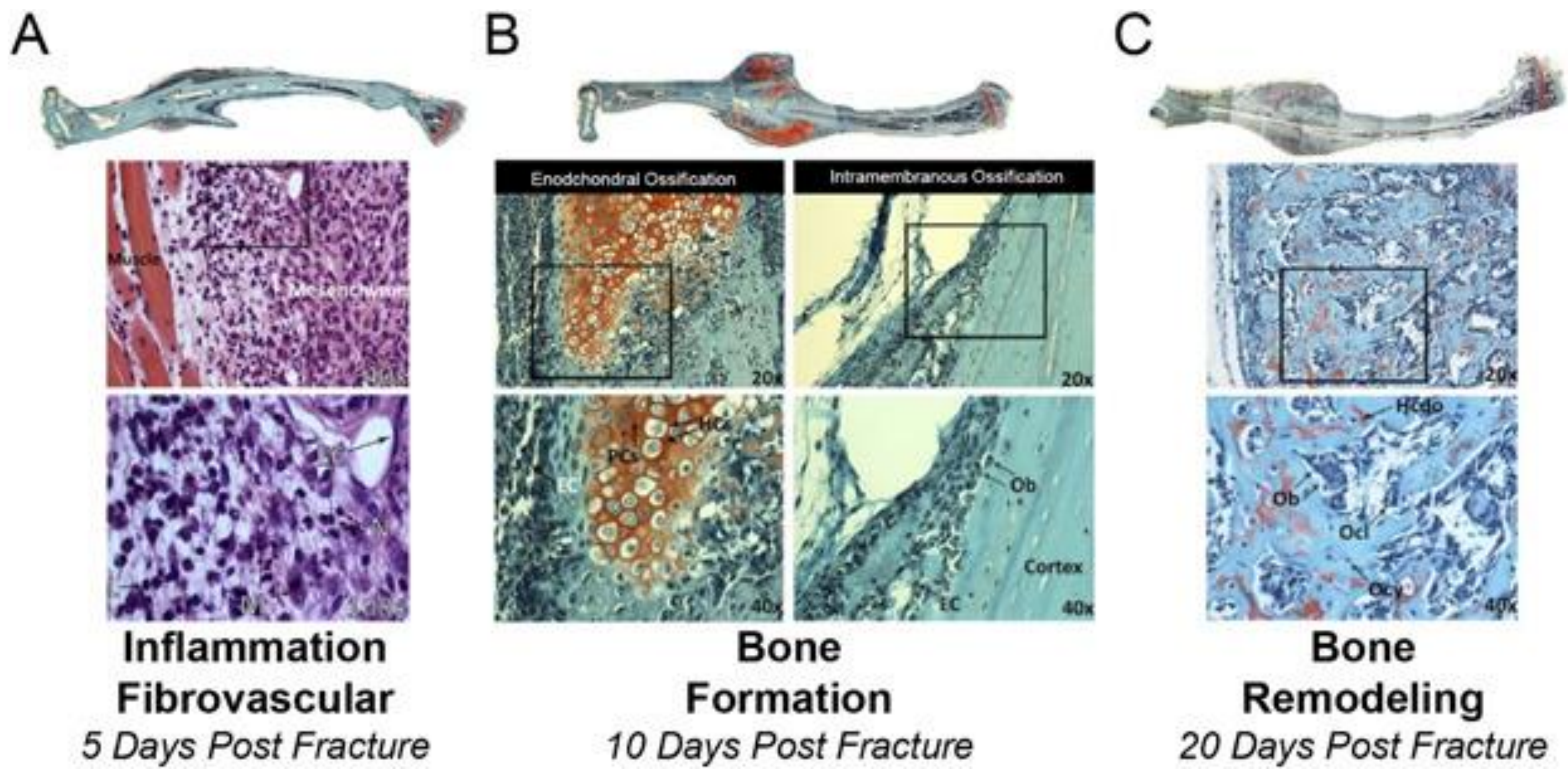
# Fracture repair

- Because the initial callus is cartilaginous, clinical union may occur before evidence of radiographic union is appreciable on x-rays.
- Clinical union classically marks the end of the reparative phase of fracture healing.
- In the remodeling phase, the endochondral callus becomes completely ossified and the bone undergoes structural remodeling.

# Fracture repair

- The process of remodeling occurs quickly in young children, who remodel their entire skeleton every year.
- By late childhood, the rate of skeletal remodeling is approximately 10 percent per year and continues near this level throughout life.

## Cellular biology of fracture healing




(A) undifferentiated mesenchymal cells are present in the callus and areas of inflammation remain (B) 10 days post-fracture there is both endochondral ossification (red staining, safranin-o stains cartilage) and intramembranous bone formation occurring. (C). An extensive network of primary bone has formed and endochondral ossification is complete.

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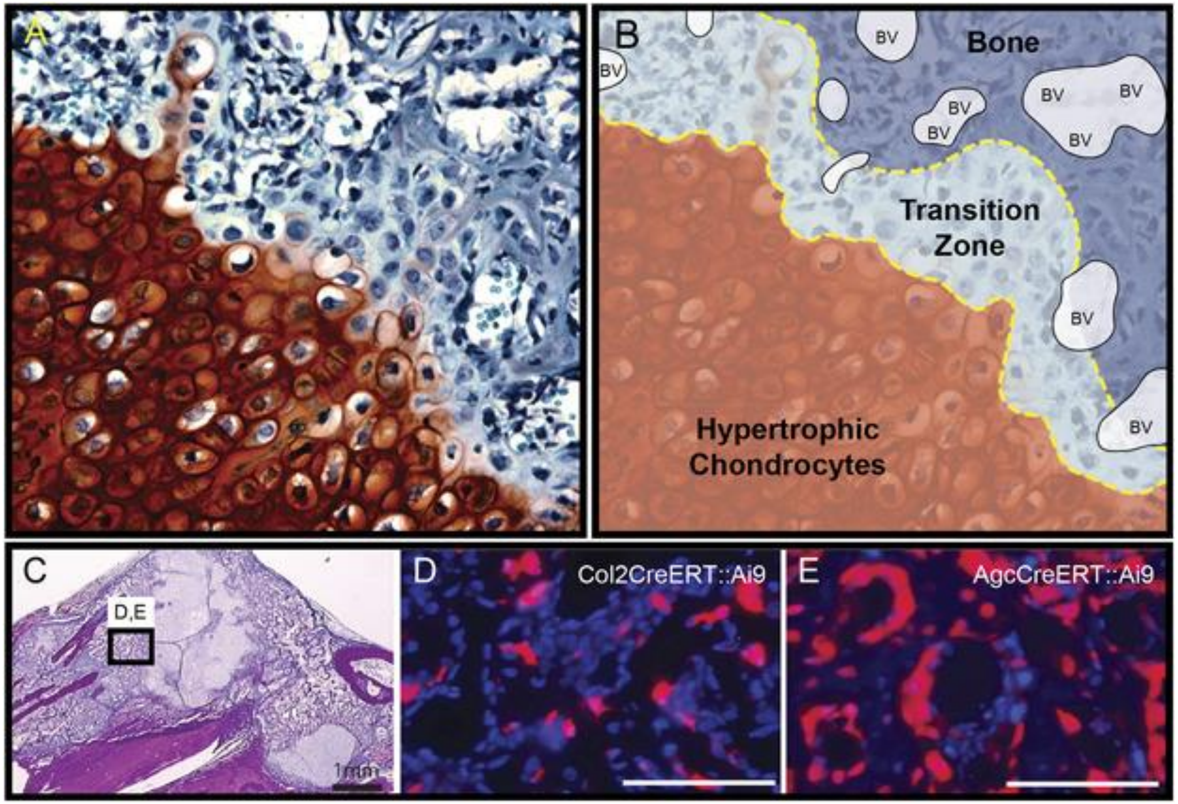


Hypertrophic chondrocytes develop into osteoblasts and osteocytes

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# Acute response

- TNF-α concentration has been shown to peak at 24h and to return to baseline within 72h post trauma.
- During this time-frame TNF-α is expressed by macrophages and other inflammatory cells, and it is believed to mediate an effect by inducing secondary inflammatory signals, and act as a chemotactic agent to recruit necessary cells.
- TNF-α also induces osteogenic differentiation of mesenchymal stem cells (MSC).

# Acute response

- These effects are mediated by activation of the two receptors TNFR1 and TNFR2 which are expressed on both osteoblasts and osteoclasts.
- <u>However, TNFR1 is always expressed in bone whereas TNFR2 is only expressed following injury</u>

# Acute response

- IL-1 and IL-6 are believed to be most important cytokines for fracture healing.
- IL-1 expression overlaps with that of TNF-α with a biphasic mode
- It is produced by macrophages in the acute phase of inflammation and induces production of IL-6 in osteoblasts
- Promotes the production of the primary cartilaginous callus, and also promotes angiogenesis at the injured site by activating either of its two receptors

# Acute response

- IL-6 is only produced during the acute phase and stimulates angiogenesis, vascular endothelial growth factor (VEGF) production, and the differentiation of osteoblasts and osteoclasts.

- BMP-2 is essential for bone repair
- BMP-7 may plays a more important role in the recruitment of progenitor cells.

# Acute response

- Stromal cell-derived factor-1(SDF-1) and its G-protein-coupled receptor CXCR-4 form an axis (SDF-1/CXCR-4) that is a key regulator of recruiting and homing specific MSCs to the site of trauma.
- SDF-1 expression is increased at the fracture site, especially in the periosteum at the edges of the fracture.
- SDF-1 has a specific role in recruiting CXCR-4 expressing MSCs to the injured site during endochondral fracture healing

# Acute response

- Hypoxia inducible factor-1α (HIF-1α) induces the production of VEGF in the revascularization process
- Hypoxic gradients regulate MSC progenitor cell trafficking by HIF-1

# Healing of bone fracture

- Following the initial trauma, bone heals by either direct intramembranous or indirect fracture healing, which consists of both intramembranous and endochondral bone formation.
- The most common pathway is indirect healing as direct bone healing requires an anatomical reduction and rigidly stable conditions.
- When such conditions are achieved, the direct healing cascade allows the bone structure to immediately regenerate anatomical lamellar bone and the Haversian systems without any remodeling steps necessary.

# Contact healing

- Bone on one side of the cortex must unite with bone on the other side of the cortex to re-establish mechanical continuity.
- Under these conditions, osteoclasts which cross the fracture line, generate longitudinal cavities.
- These cavities are later filled by bone produced by osteoblasts residing at the rear of the juncture.
- This results in the simultaneous generation of a bony union and the restoration of Haversian systems formed in an axial direction.

# Contact healing

- The re-established Haversian systems allow for penetration of blood vessels carrying osteoblastic precursors.
- The bridging osteons later mature by direct remodeling into lamellar bone resulting in fracture healing without the formation of periosteal callus.

# Gap healing

- Bony union and Haversian remodeling do not occur simultaneously.
- It occurs if stable conditions and an anatomical reduction are achieved, although the gap must be less than 1 mm.
- In this process the fracture site is primarily filled by lamellar bone oriented perpendicular to the long axis, requiring a secondary osteonal reconstruction.

# Gap healing

- The primary bone structure is then gradually replaced by longitudinal revascularized osteons carrying osteoprogenitor cells which differentiate into osteoblasts and produce lamellar bone on each surface of the gap.
- This lamellar bone, however, is laid down perpendicular to the long axis and is mechanically weak.

# Gap healing

- This initial process takes approximately 3 and 8 weeks, after which a secondary remodeling resembling the contact healing cascade takes place.
- Although not as extensive as endochondral remodeling, this phase is necessary in order to fully restore the anatomical and biomechanical properties of the bone.

# Healing of bone fracture

- Indirect healing
- Involves an acute inflammatory response and the recruitment of mesenchymal stem cells in order to generate a primary cartilaginous callus.
- This primary callus later undergoes revascularization and calcification, and is finally remodeled to fully restore a normal bone structure.

# Healing phase

- Following the formation of the primary hematoma, a fibrin-rich granulation tissue forms.
- Within this tissue, endochondral formation occurs in between the fracture ends, and external to periosteal sites.
- These regions are mechanically less stable
- The cartilaginous tissue forms a soft callus which gives the fracture a stable structure.

# Healing phase

- Peak of soft callus formation occurs 7–9 days post trauma with a peak in both type II procollagen and proteoglycan core protein extracellular markers.
- At the same time, an intramembranous ossification response occurs subperiostally directly adjacent to the distal and proximal ends of the fracture, generating a <u>hard callus</u>.
- It is the final bridging of this central hard callus that ultimately provides the fracture with a semi-rigid structure which allows weight bearing

# Healing phase

- The WNT-family is thought to regulate the differentiation of pluripotent MSCs into the osteoblastic lineage, and, at later stages of development, to positively regulate osteoblastic bone formation.
- As fracture callus chondrocytes proliferate, they become hypertrophic and the extracellular matrix becomes calcified.
- Both osteoblasts and hypertrophic chondrocytes express high levels of VEGF
- Promote the invasion of blood vessels and transforming the avascular cartilaginous matrix into a vascularized osseous tissue.

# Healing phase

- A cascade orchestrated primarily by macrophage colony-stimulating factor (M-CSF), RANKL, osteoprotegerin (OPG) and TNF-α initiates the resorption of this mineralized cartilage.
- During this process M-CSF, RANKL and OPG are also thought to help recruit bone cells and osteoclasts to form woven bone.
- TNF-α further promotes the recruitment MSC with osteogenic potential
- Initiates chondrocyte apoptosis.

# Healing phase

- Mitochondria accumulate calcium-containing granules created in the hypoxic fracture environment.
- After elaboration into the cytoplasm of fracture callus chondrocytes, calcium granules are transported into the extracellular matrix where they precipitate with phosphate and form initial mineral deposits.
- These deposits of calcium and phosphate become the nidus for homogeneous nucleation and the formation of apatite crystals.
- The peak of the hard callus formation is usually reached by day 14

# Remodeling

- The remodeling process is carried out by a balance of hard callus resorption by osteoclasts, and lamellar bone deposition by osteoblasts.
- Although the process is initiated as early as 3–4 weeks in the remodeling may take years to be completed to achieve a fully regenerated bone
- The process of remodeling occurs quickly in young children, who remodel their entire skeleton every year.
- By late childhood, the rate of skeletal remodeling is approximately 10 percent per year and continues near this level throughout life

# Remodeling

- Bone remodeling has been shown to be a result of production of electrical polarity created when pressure is applied in a crystalline environment.
- This is achieved when axial loading of long bones occurs, creating one electropositive convex surface, and one electronegative concave surface, activating osteoclastic and osteoblastic activity respectively.
- By these actions the external callus is gradually replaced by a lamellar bone structure, whereas the internal callus remodeling re-establishes a medullar cavity characteristic of a diaphyseal bone.

# Reparative phase

- Because the initial callus is cartilaginous, clinical union may occur before evidence of radiographic union is appreciable on x-rays.
- Clinical union classically marks the end of the reparative phase of fracture healing.
- Clinical union of the fracture occurs.
- Clinical union occurs when the fractured bone does not shift on clinical examination, the fracture site is non-tender, and the patient can use the injured limb without significant pain.

# Maxillofacial fractures

- Maxillofacial injuries rarely cause immediate threat to life.
- Treatment of the fracture involves maintenance of function, particularly masticatory function.
- CT scanning required to evaluate injuries.
- The angle of the mandible is the most common area of mandibular fracture.
- The mandible is displaced as the pterygo-masseter sling causes the proximal fragment to ride superiorly.

# Maxillofacial fractures

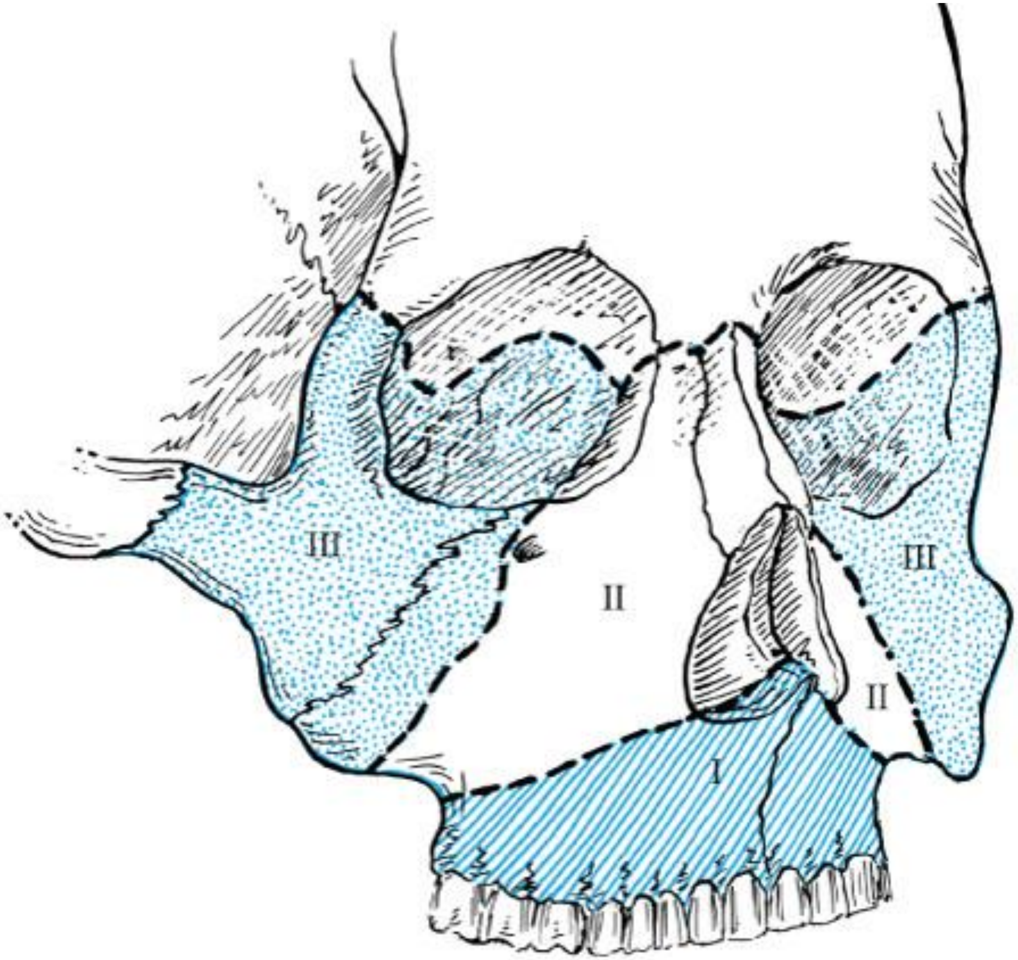
- Unilateral condylar fracture will cause the jaw to deviate toward the side of fracture on maximum opening.
- Bilateral subcondylar fracture presents with an anterior bite and occlusion on the posterior molars. There is no contact with incisor teeth.
- An alveolar ridge fracture is usually associated with a loss in the anterior or incisor region.
- (Mandibular fracture as well often involves the alveolar ridge.)

# Midfacial fractures

- Isolated fractures of the zygomatic arch are uncommon.
- The zygoma may be depressed, impinge on the coranoid process of the mandible, and limit the jaw opening.
- A pure blowout fracture is caused by direct ocular trauma.
- The thin orbital floor is forced into the maxillary antrum.
- Entrapment of extra-ocular muscles may occur.

# LaFort facial fracture

Illustration of the fracture lines of LeFort I (alveolar), LeFort II (zygomatic maxillary complex), and LeFort III (cranial facial dysostosis) fractures.




Source: Knoop KJ, Stack LB, Storrow AB, Thurman RJ: *The Atlas of Emergency Medicine, 3rd Edition:* http://www.accessmedicine.com



Fig. 1.17 Accessed 05/05/2010

# LeFort facial fractures

- In all LeFort fractures, the mandible is free-floating.
- In type I, a horizontal fracture line runs from the lateral nasal apertures, along the lateral wall of the maxillary sinuses bilaterally, and across the pterygo-maxillary tissue to the lateral pterygoid plate.
- The body of the maxilla is separated from the base of the skull above the level of the palate and below the attachment of the zygomatic process.

# LeFort facial fractures

- The dental arch is easily mobilized.
- Displacement is dependent upon muscular pull.
- The fracture may be associated with damage to CN $V_2$ as well as CN VII.
- Labial and maxillary arteries may be involved.

# LeFort facial fracture

- A type II or pyramidal fracture consists of vertical fractures through the facial aspects of the maxilla extending upwards to the nasal and ethmoid bones.
- The fractures extend through the maxillary sinuses and the intfraorbital rims bilaterally across the bridge of the nose.
- CSF rhinorrhea may be present.

# LeFort facial fracture

- There is associated damage to CN $V_2$ as well as CN VII.
- The transverse facial artery may also be involved.
- Frequently the central portion of the orbital floor will also fracture as part of the zygomatic-maxillary complex.
- Entrapment of extra-ocular muscles may occur.

# LeFort facial fracture

- A type III fracture extends through the fronto-zygomatic suture lines bilaterally, across the orbits, and through the base of the nose and the ethmoid region.
- The lateral rim of the orbit is separated and the infra-orbital rim may also be fractured.
- A pyramidal or a horizontal fracture may also be present.

# LeFort facial fracture

- The face is depressed.
- The midface and zygoma move concurrently.
- CSF rhinorrhea is common.
- There may be significant damage to CN $V_2$ as well as CN VII.
- The transverse facial artery and the parotid duct may also be involved.

# Abuse

- Any fracture in a child younger than one year of age or any lower extremity fracture in a non-ambulatory child should raise suspicion of abuse.
- Specific fracture patterns of concern include:
- Posterior rib fractures
- Metaphyseal lesions (bucket-handle or corner fractures)
- Bilateral long bone fractures
- Complex skull fractures
- Spinous process fractures.

# Abuse

- In addition, a repeat fracture occurring at an unusual location for repeat injury is suspicious for child abuse, and careful history and social assessment should be performed.
- Elder abuse should be considered in all elderly patients with falls and fractures.

# Peripheral nerve injury

| Nerve | Motor function | Sensory function | Scenario |
|---|---|---|---|
| Radial | Wrist drop (extension) | Back of forearm and hand (digits 1-3) | Humeral fracture |
| Ulnar | Claw hand (finger abduction) | Front and back of hand (digits 4-5) | Elbow dislocation or fracture |
| Median | Pronation, thumb opposition | Palmar surface of hand (digits 1-3) | Carpal tunnel syndrome; humeral fracture |
| Axillary | Abduction, lateral rotation of shoulder | Lateral shoulder | Humeral fracture or dislocation |
| Peroneal | Foot drop (dorsiflexion, eversion) | Dorsal foot and lateral leg | Knee dislocation; fibular fracture |

# Fat Embolism