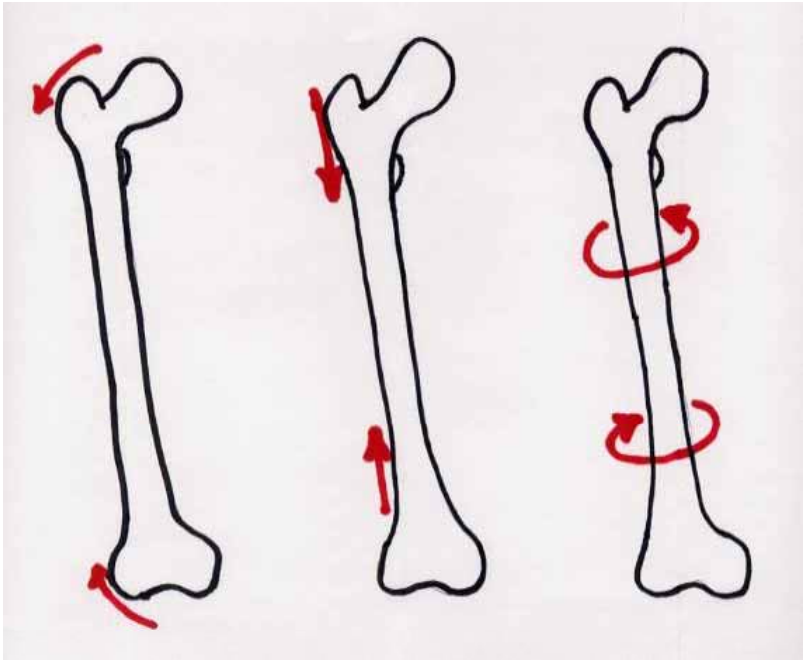
# Section 20: Fracture Mechanics and Healing

# Fracture Mechanics (cont)

- Cortical bone:
  - weak in tension and shear.
  - when subjected to bending force:
    convex side is under tension.
    concave side is under compression.
  - tension (convex) side fails first.

# Basic Biomechanics



Bending Compression Torsion

- Bending
- Axial Loading
  - Tension
  - Compression
- Torsion

# Fracture Mechanics

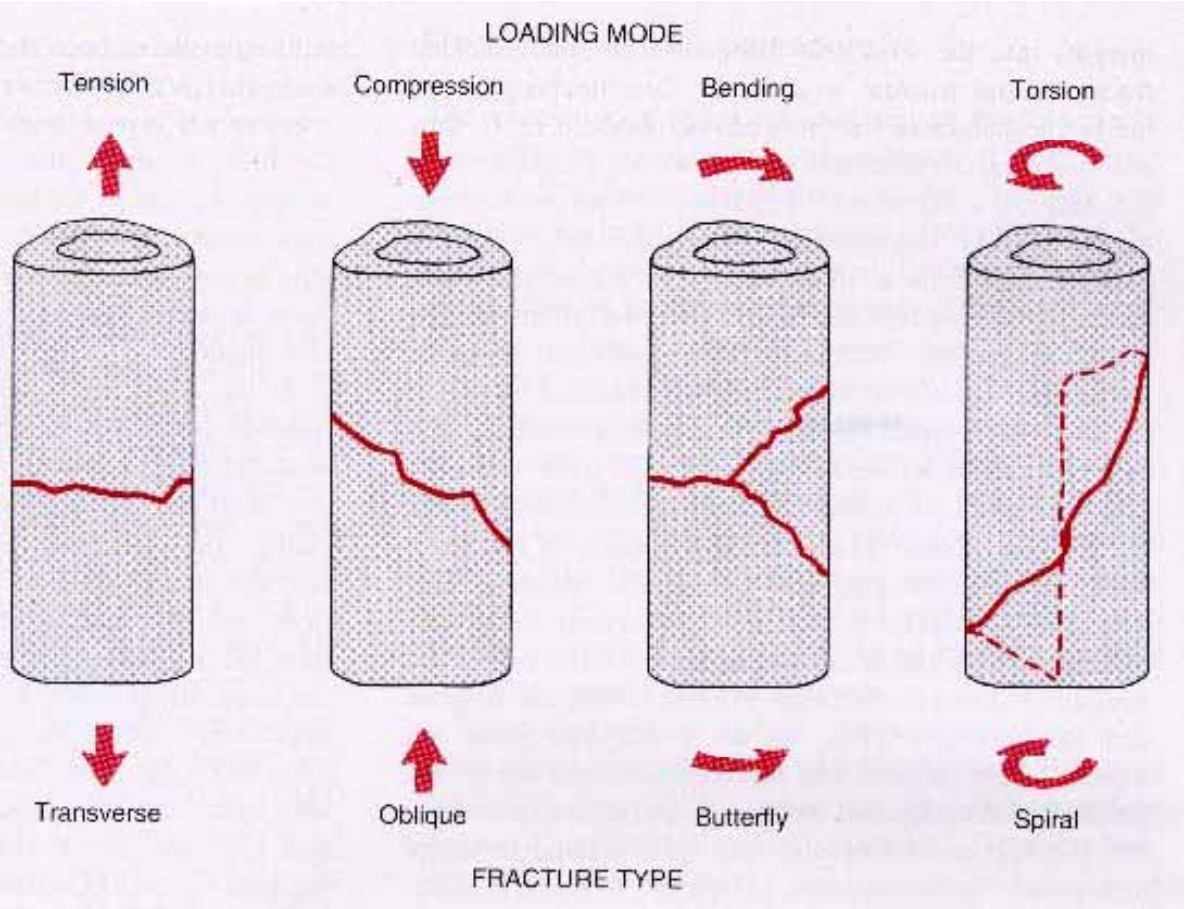


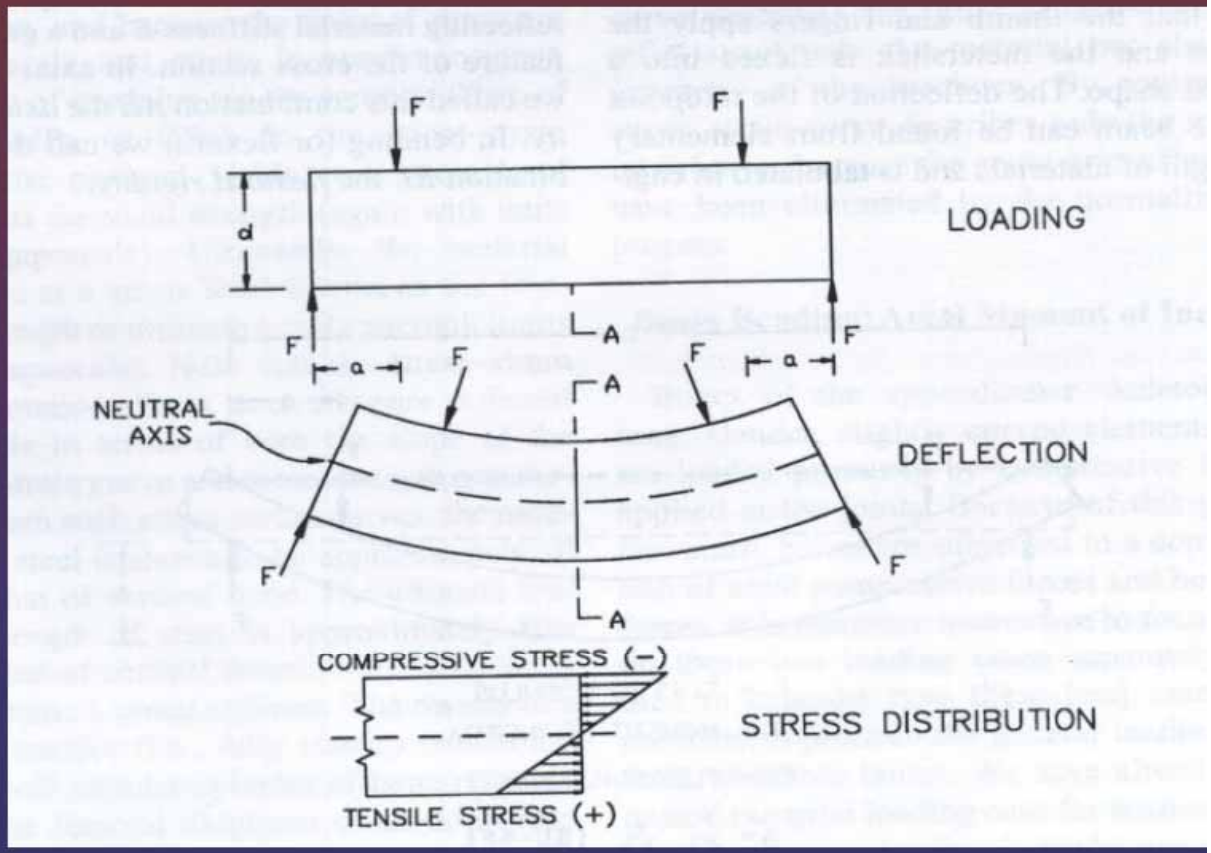

Figure from: Browner et al: Skeletal Trauma 2nd Ed, Saunders, 1998.



From: Le

# Material vs Structural Behavior (cont)

- Flexural Loading.

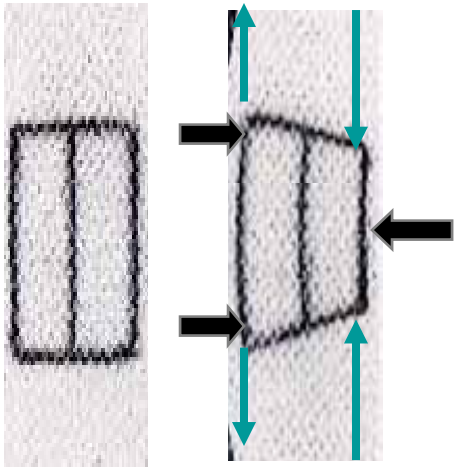





From: Al-Tayyar

# Fracture Mechanics

- Bending load:
  - Compression strength greater than tensile strength
  - Fails in tension



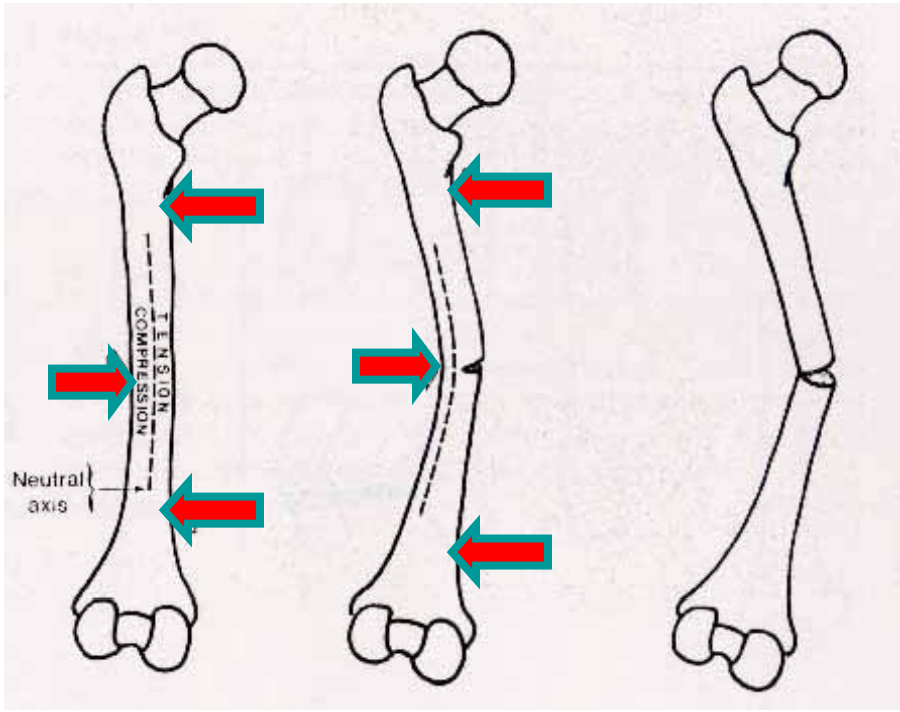



Figure from: Tencer. Biomechanics in Orthopaedic Trauma, Lippincott, 1994.



From: Le

# Fracture Mechanics

- Combined bending & axial load
  - Oblique fracture
  - Butterfly fragment

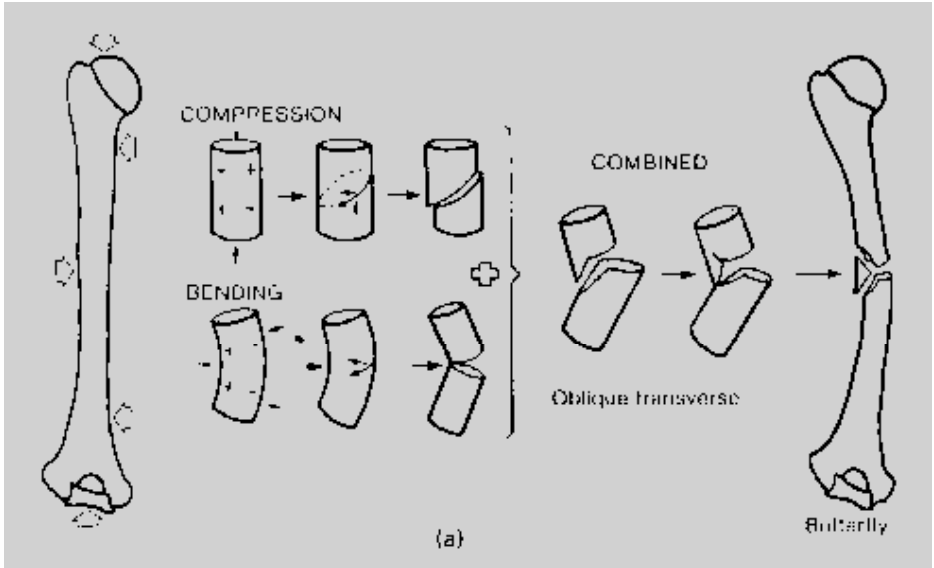



Figure from: Tencer. Biomechanics in Orthopaedic Trauma, Lippincott, 1994.



From: Le

# Ski boots

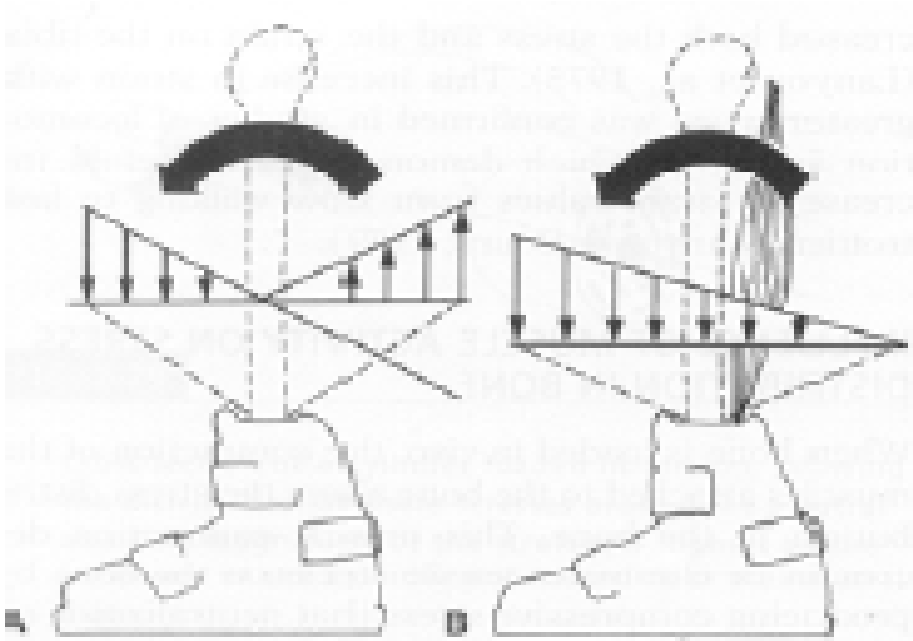


FIG. 2-33

A, Distribution of compressive and tensile stresses in a tibia subjected to three-point bending. B, Contraction of the triceps surae muscle produces high compressive stress on the posterior aspect, neutralizing the high tensile stress.



From: Vanwanseele

# Bone Healing

- Direct
  - Primary bone healing
  - Cutting cones
  - Seen with absolute stability
- Indirect
  - Secondary bone healing
  - Callus formation; resorption at fx site;
  - Seen with relative stability

# Indirect Stages:

- Inflammation
  - 1-7 days
- Soft callus
  - 3 weeks
- Hard callus
  - 3 – 4 months
- Remodeling
  - months => years

# Relative Stability

- ***Motion*** between ***fracture fragments*** that is ***compatible*** with ***fracture healing.***
- Motion is below the ***critical strain level*** of tissue repair.
- Promotes ***indirect*** bone healing!
- Examples:
  - ***IM nails***
  - ***Bridge plate***
  - ***External Fixator***

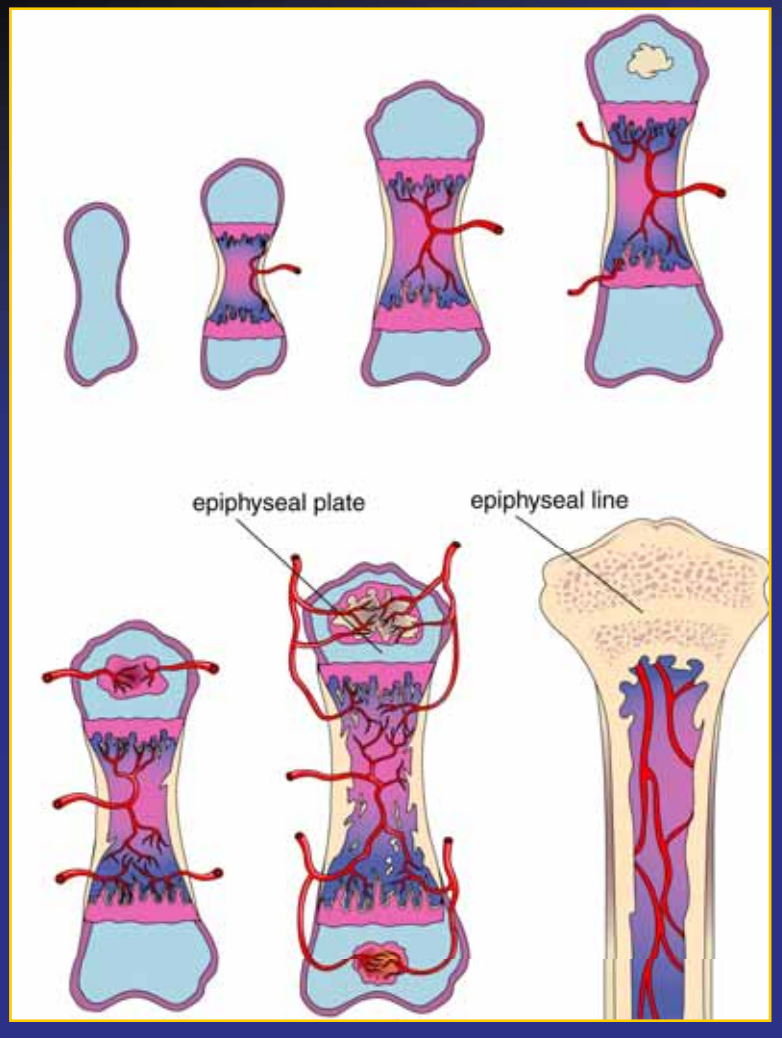
# Absolute Stability

- ***Compression*** of two ***anatomically*** reduced ***fracture fragments***.
- ***No displacement*** of the fracture under ***functional load.***
- Promotes ***direct*** bone healing!
- Examples:
  - ***Lag screw***
  - ***Plate*** => compression, buttress, neutralization
  - ***Tension band***

# Bone Development and Healing

**The process of bone development is called *ossification*. There are two types of ossification: *endochronal* and *intramembranous*.**

**Bone healing occurs in stages: fracture, granulation, callus, lamellar bone, and normal contour.**

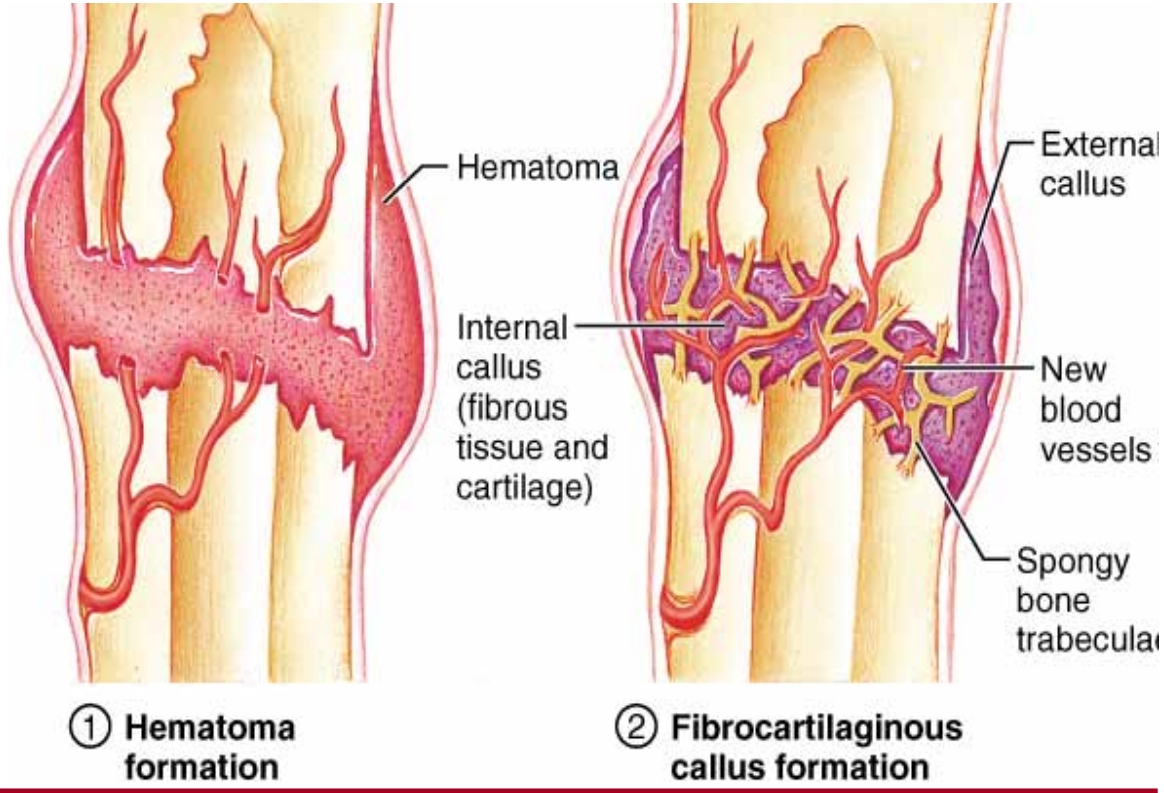





From: Ames

# Fracture Repair

- Step 1:
  - A. Immediately after the fracture, extensive bleeding occurs. Over a period of several hours, a large blood clot, or fracture hematoma, develops.
  - B. Bone cells at the site become deprived of nutrients and die. The site becomes swollen, painful, and inflamed.



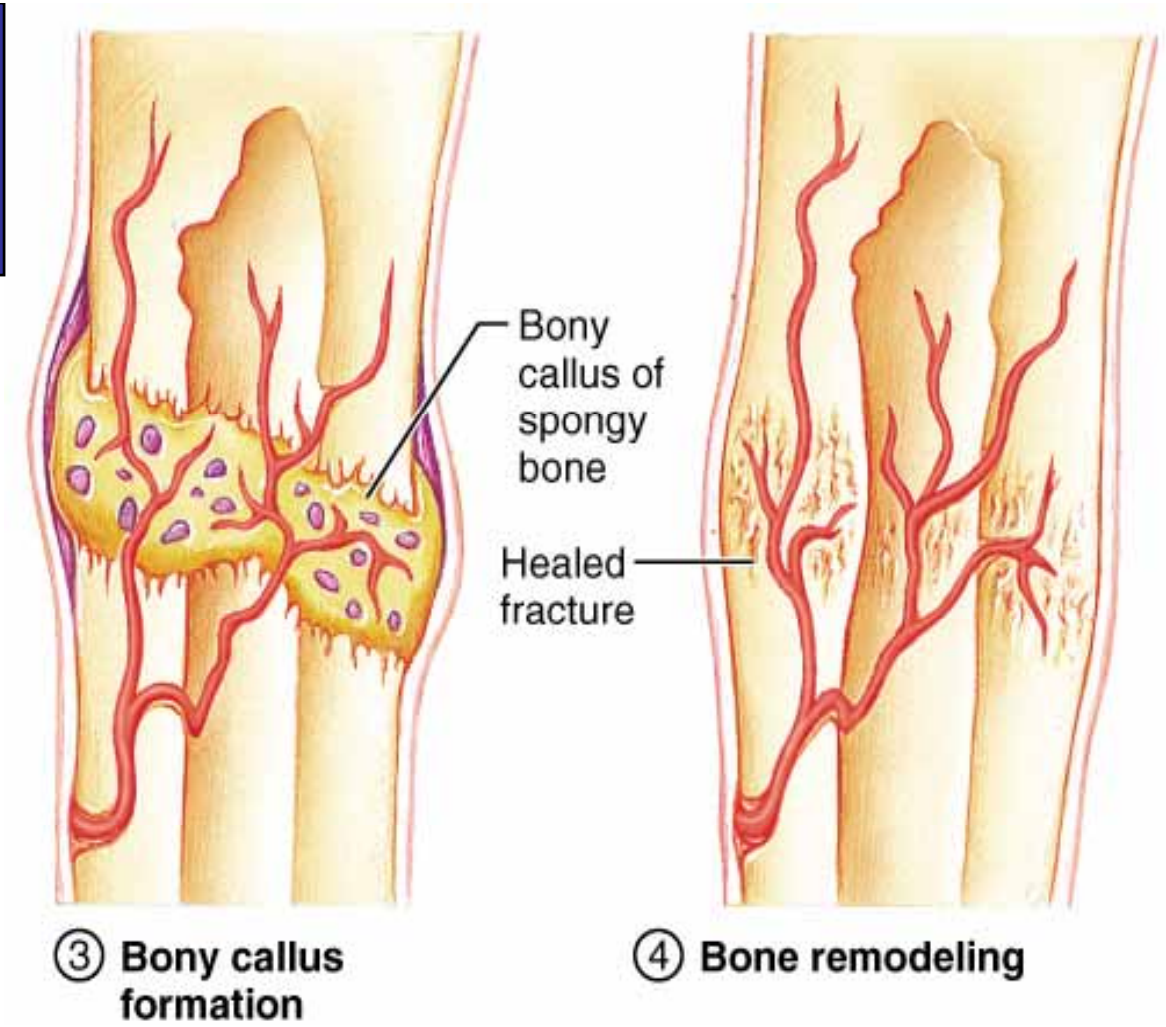

- Step 2:
  - A. Granulation tissue is formed as the hematoma is infiltrated by capillaries and macrophages, which begin to clean up the debris.
  - B. Some fibroblasts produce collagen fibers that span the break , while others differentiate into chondroblasts and begin secreting cartilage matrix.
  - C. Osteoblasts begin forming spongy bone.
  - D. This entire structure is known as a fibrocartilaginous callus and it splints the broken bone.



From: Imholtz

# Fracture Repair

- Step 3:
  - A. Bone trabeculae increase in number and convert the fibrocartilaginous callus into a bony callus of spongy bone. Typically takes about 6-8 weeks for this to occur.



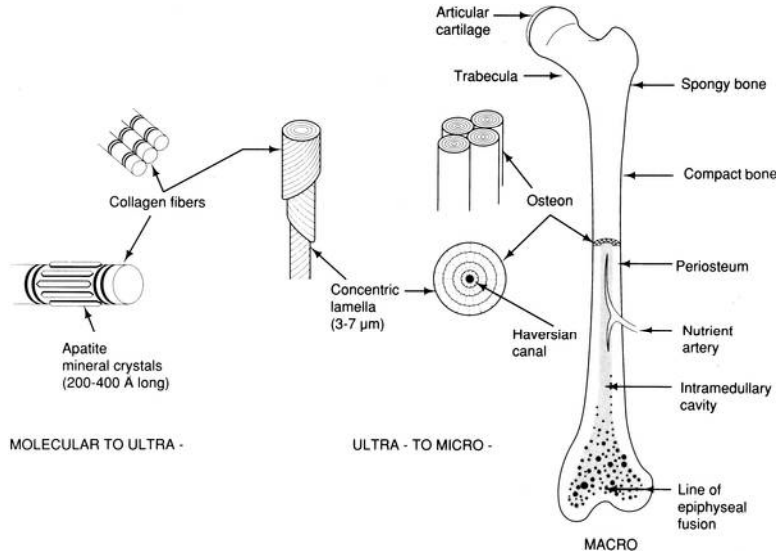

- Step 4:
  - A. During the next several months, the bony callus is continually remodeled.
  - B. Osteoclasts work to remove the temporary supportive structures while osteoblasts rebuild the compact bone and reconstruct the bone so it returns to its original shape/structure.

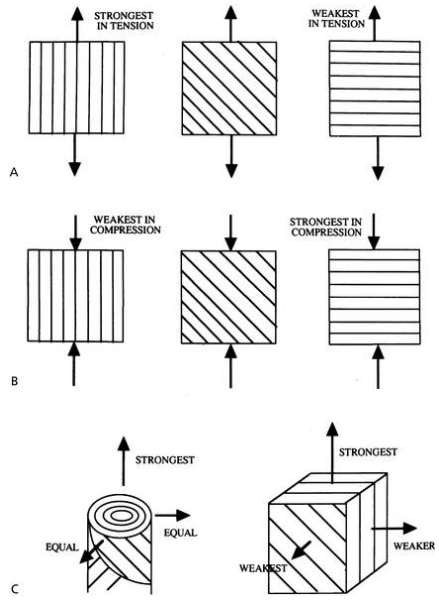


From: Imholtz

# Biomechanics Intact/Healing Bone

- Hierarchical structure
  - Collagen embedded with apatite
  - Decreased modulus with decreased apatite:collagen ratio
- Fibrils organized to resist force
  - Fibers organized into lamellae
  - Concentric Lemellae make an Osteon



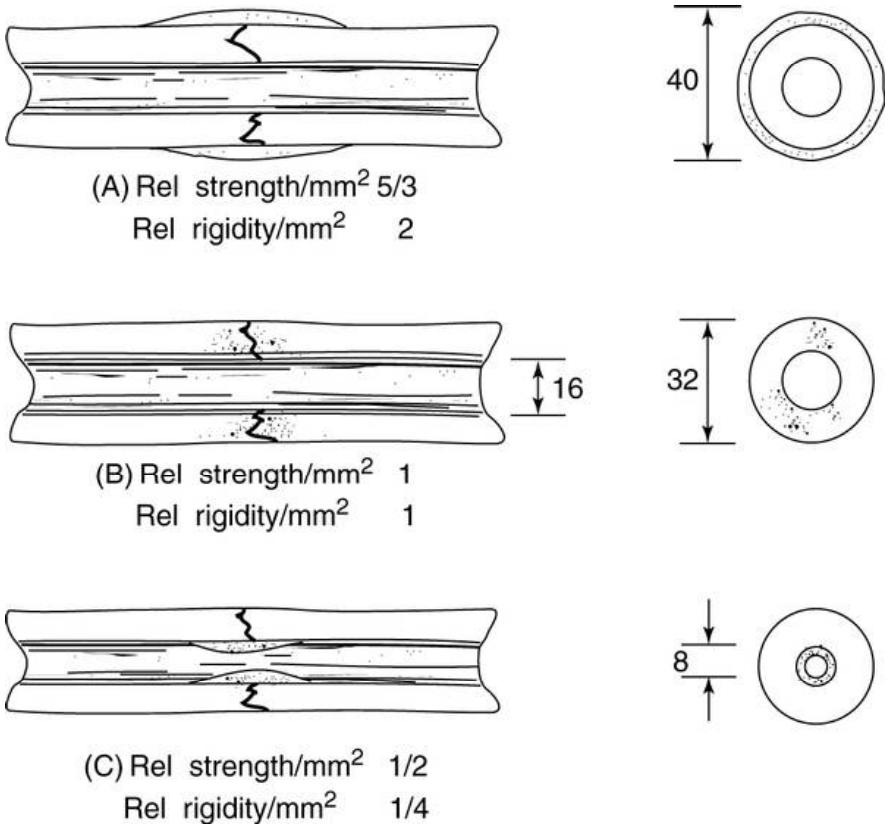






From: Justice

# Strength/Stiffness

- Strength proportional to **density$^2$**
- Modulus proportional to **density$^{(2\ to\ 3)}$**
- **Age**: increased modulus, bending strength from child to adult, then decrease
- **Holes/defects** weaken bone (round better than square)
- Strength proportional to **diameter$^4$**




From: Justice

# Fracture Mechanics

- Fracture Callus
  - Moment of inertia proportional to $r^4$
  - Increase in radius by callus greatly increases moment of inertia and stiffness

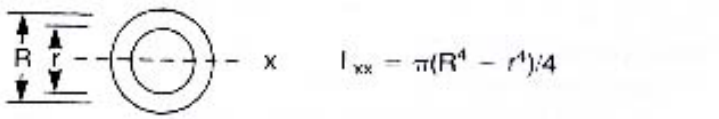
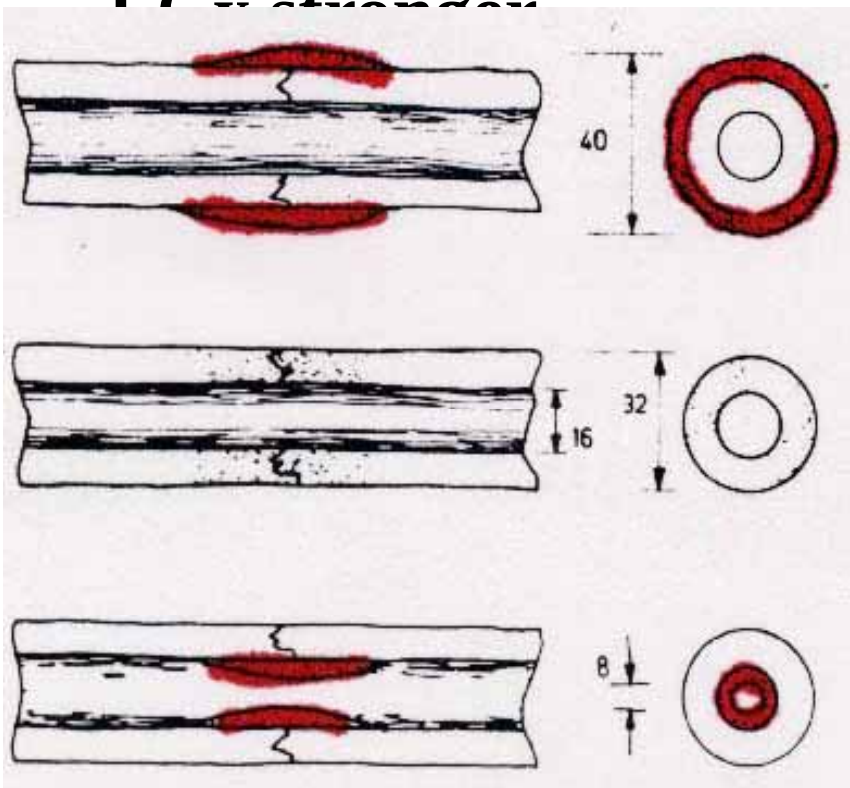



Figure from: Browner et al, Skeletal Trauma 2nd Ed, Saunders, 1998.

**1.6 x stronger**




**0.5 x weaker**

From: Le Figure from: Tencer et al: Biomechanics in Orthopaedic Trauma, Lippincott, 1994.

# Fracture Mechanics

- Time of Healing
  - Callus increases with time
  - Stiffness increases with time
  - Near normal stiffness at 27 days
  - Does not correspond to radiographs

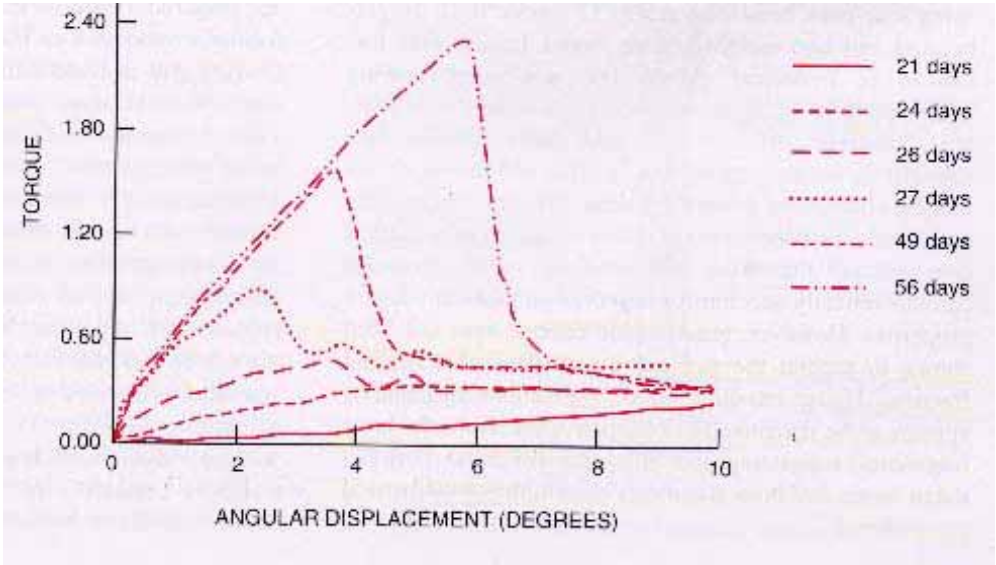



Figure from: Browner et al, Skeletal Trauma, 2nd Ed, Saunders, 1998.



From: Le

# Remodeling of Bone

- Wolff's Law
- Remodeling – balance between bone absorption of osteoclasts and bone formation by osteoblasts
  - osteoporosis –increase porosity of bone, decrease in density and strength, increase in vulnerability to fractures
  - piezoelectric effect – electric potential created when collagen fibers in bone slip relative to one another, facilitates bone growth
  - use of electric and magnetic stimulation to facilitate bone healing