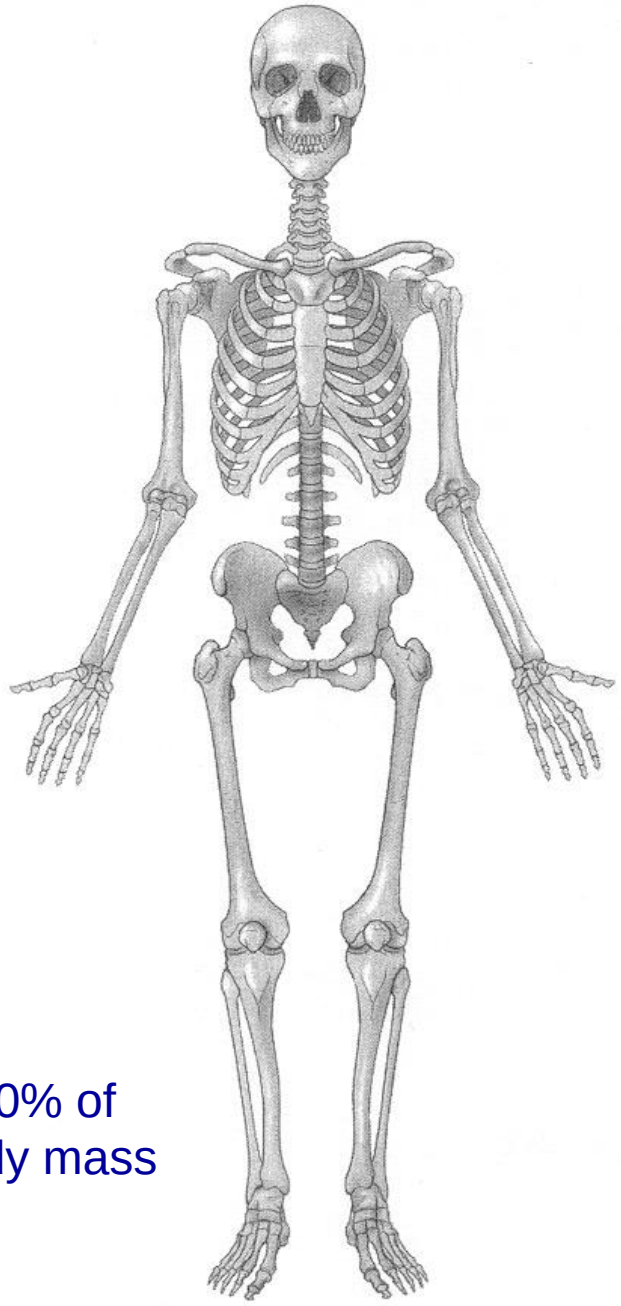
Chapter 6:
Skeletal System

The Skeleton ("Dried-up Body"):

Composed of:

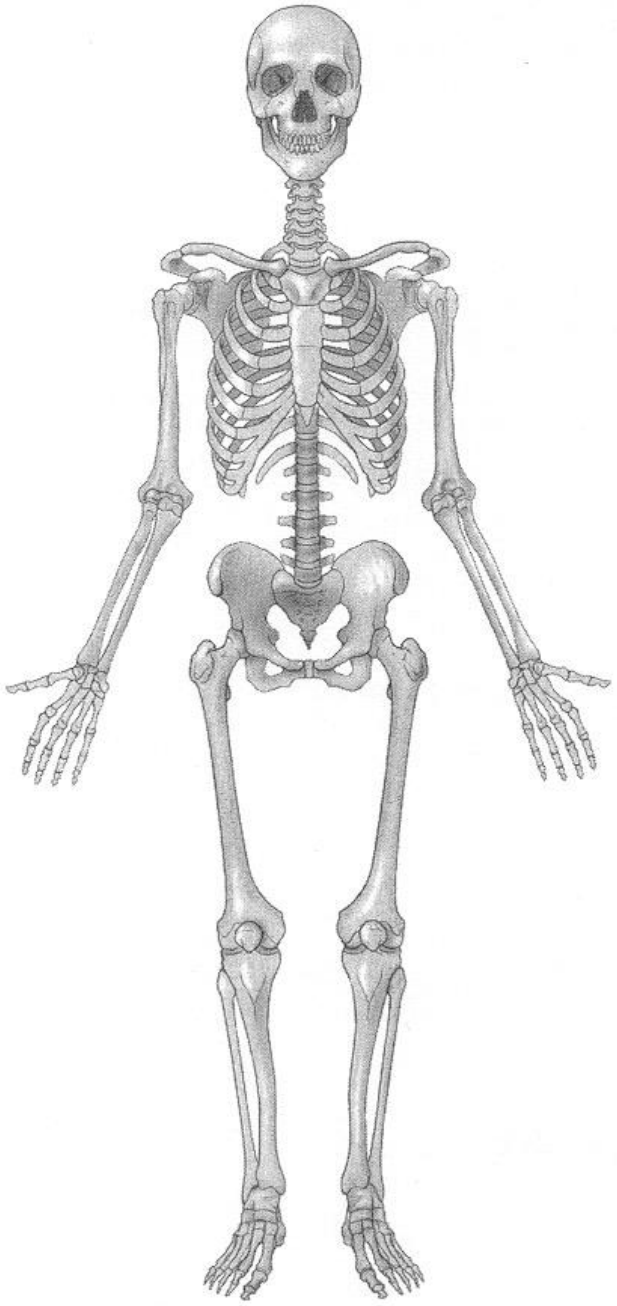
1) Bones (206 named bones)
   - Axial (skull, vertebral column, bony thorax)
   - Appendicular (upper / lower appendages)
2) Cartilage
   - Hyaline (most abundant)
     - Articular cartilage (joints)
     - Costal cartilage (ribs → sternum)
     - Respiratory cartilage (larynx / trachea)
     - Nasal cartilage (nose)
   - Elastic (external ear / epiglottis)
   - Fibrocartilage (intervertebral disks / menisci)
3) Ligaments
4) Joints



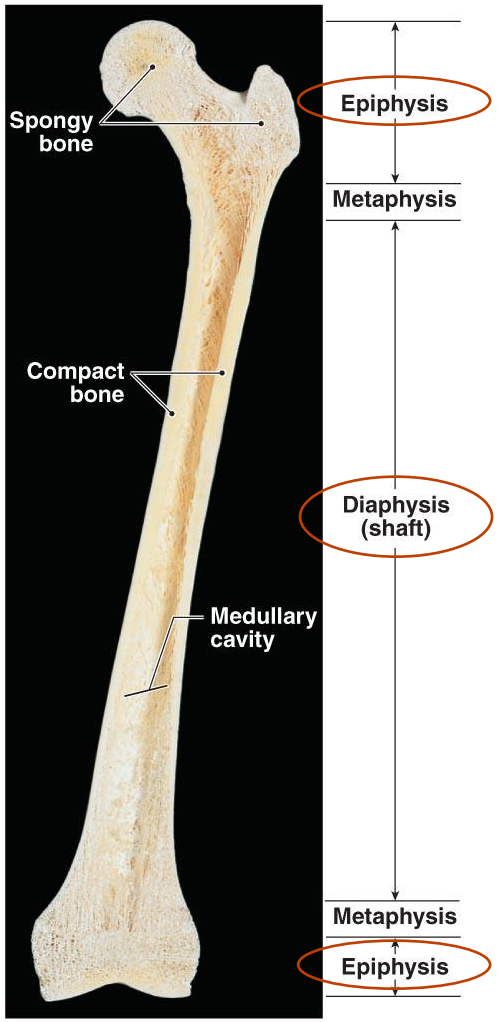
20% of body mass

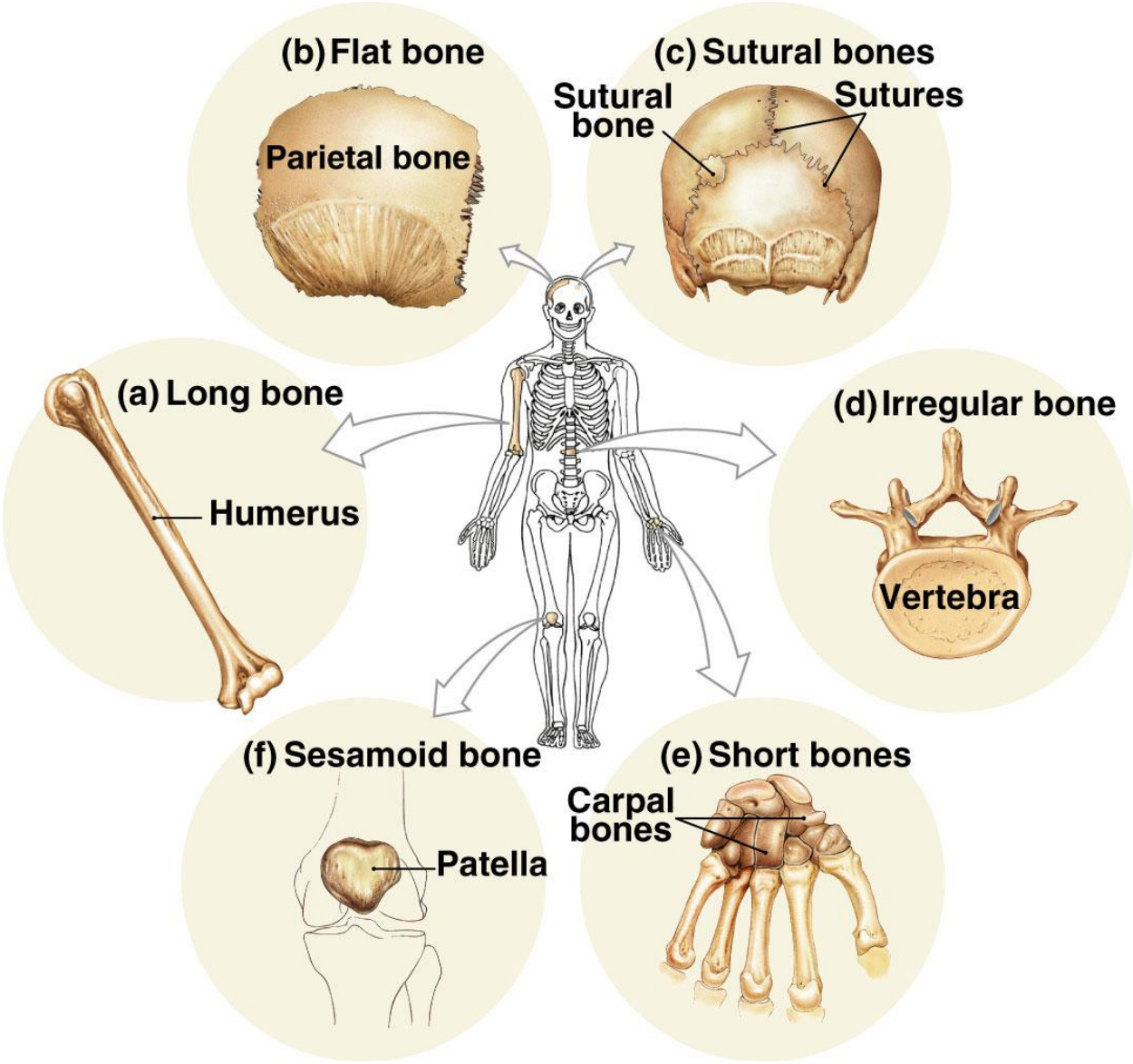
Functions of the Skeleton:

1) Support (solid framework):
   - Support body; cradle soft organs
2) Protection:
   - Provide snug enclosures for vital organs
3) Movement:
   - Work with muscles to move body and / or body parts
4) Storage:
   - Serve as reservoirs for minerals (e.g., calcium)
   - Serve as reservoirs for triglycerides (bone cavity)
5) Hematopoiesis:
   - Location of blood cell production



Macroanatomy of Bone:

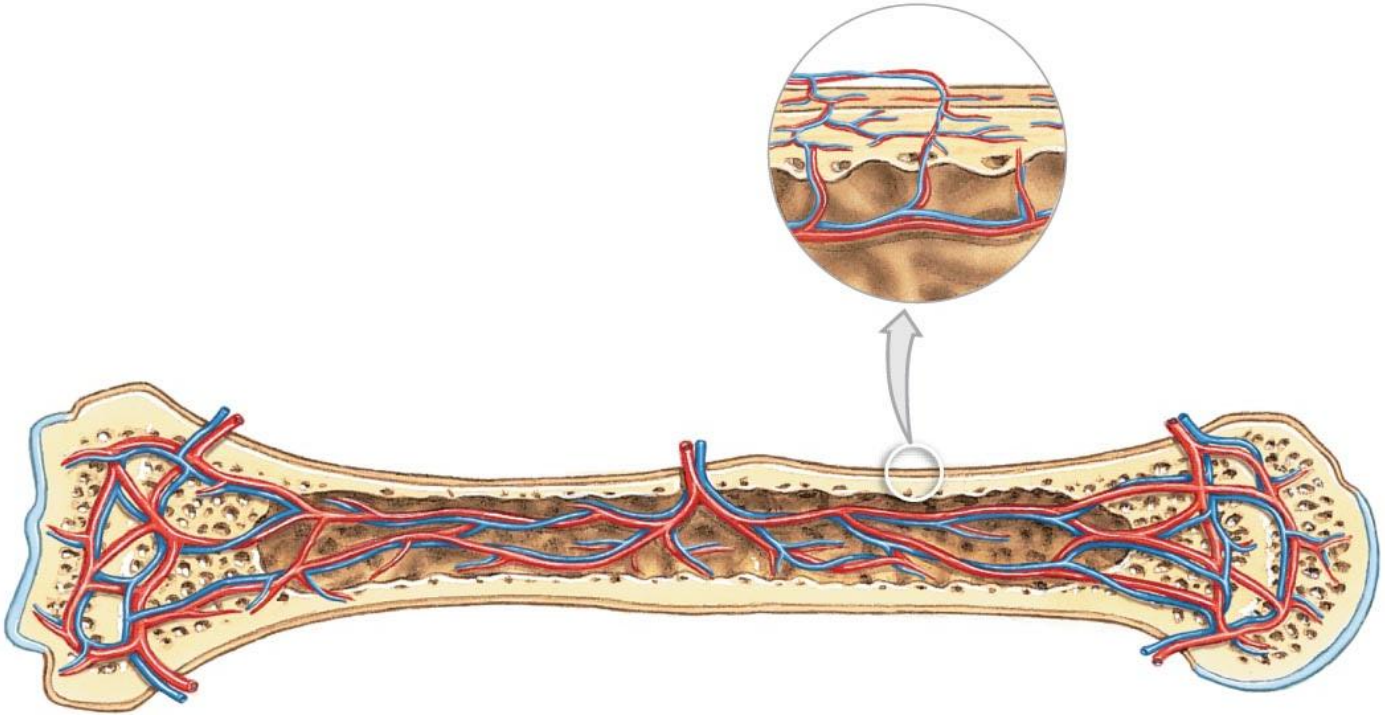




Bones are Organs that are Alive!

- Composed primarily of osseous connective tissue
- Also contains nervous, muscle, and epithelial tissue

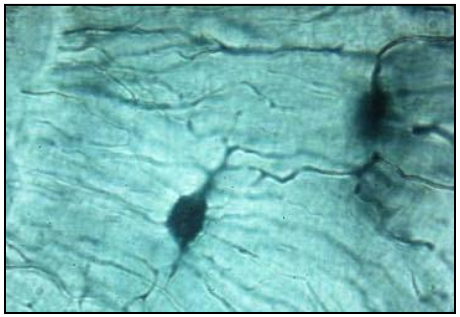
(nerves) (blood vessels)



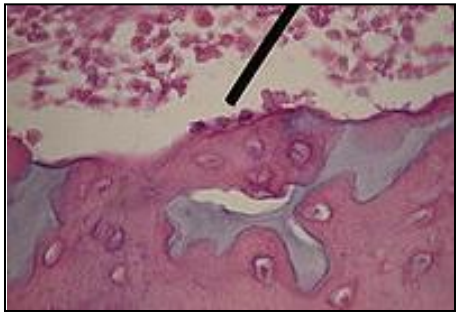
Composition of Bone - Cells:

Osteoprogenitor cells:
Stem cells that produce osteoblasts; located in periosteum / endosteum

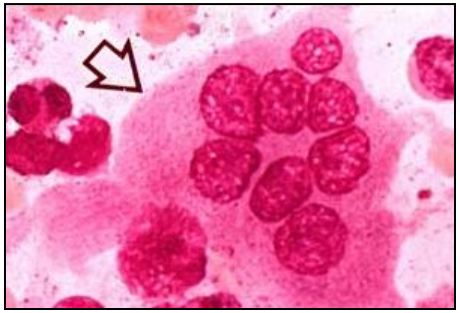
A) Osteocytes (most common present):
- Mature bone cell; can not divide
- Connect via passageways to neighboring cells
  - Communicate via gap junctions
- Function: 1) Maintain protein / mineral content of matrix
  2) Repair damaged bone (cell conversion)

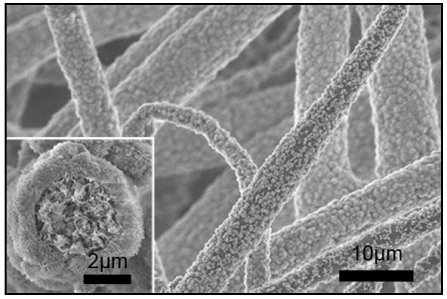


B) Osteoblasts:
- Produce new bone matrix (osteogenesis)
  - Collagen / proteoglycans / glycoproteins (osteoid)
- Located at surface of bone tissue; mature to osteocytes



C) Osteoclasts (large, multi-nucleated cells):
- Remove / recycle bone matrix (osteolysis)
  - Acids (dissolve inorganic crystals) ; Enzymes (digest collagen)

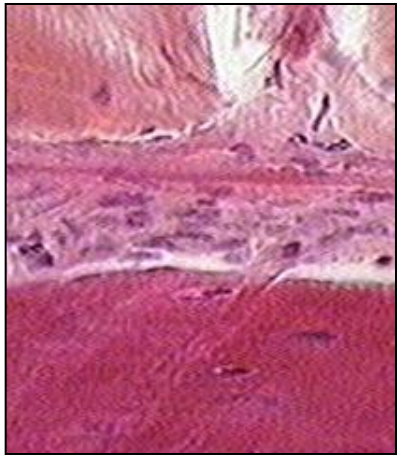




Composition of Bone - Matrix:

1) Calcium phosphate ($Ca_3(PO_4)_2$) ~ 2 / 3 of bone mass
   - Interacts with calcium hydroxide ($Ca(OH)_2$) to form crystals of hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$)
   - Hydration shell: Layer of water / ions forming around crystals
     - Facilitates exchange of ions between crystals / body fluid

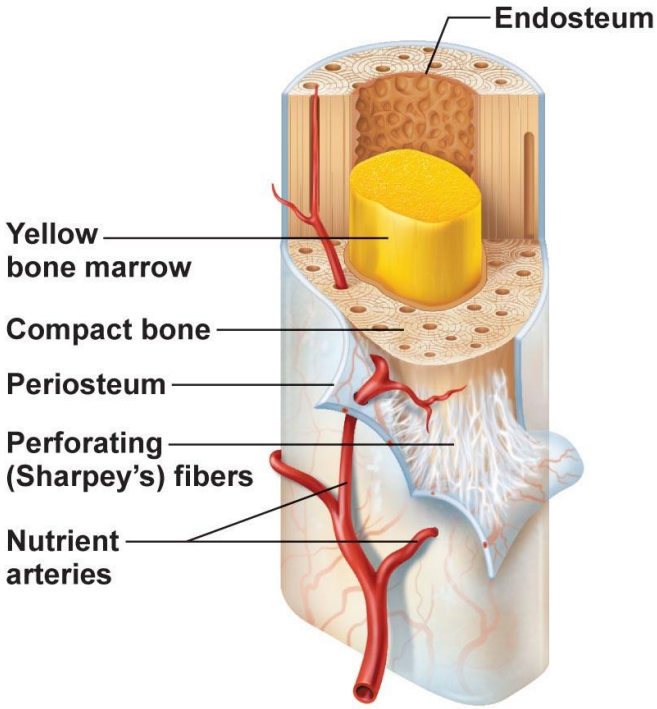
2) Collagen fibers ~ 1 / 3 of bone mass
   - Provide organic framework for hydroxyapatite crystals



Surface Coverings (Membranes) of Bone:

A) Periosteum: Superficial layer of bone (except joint regions)
- Fibrous outer layer (collagen fibers; fibroblasts)
  - Sharpey's Fibers = Collagen fibers; penetrate matrix
- Cellular inner layer (osteoprogenitor cells)

B) Endosteum: Internal layers lining all cavities within bone
- Single layer of osteoprogenitor cells; ↓ connective tissue



Marieb & Hoehn – Figure 6.3

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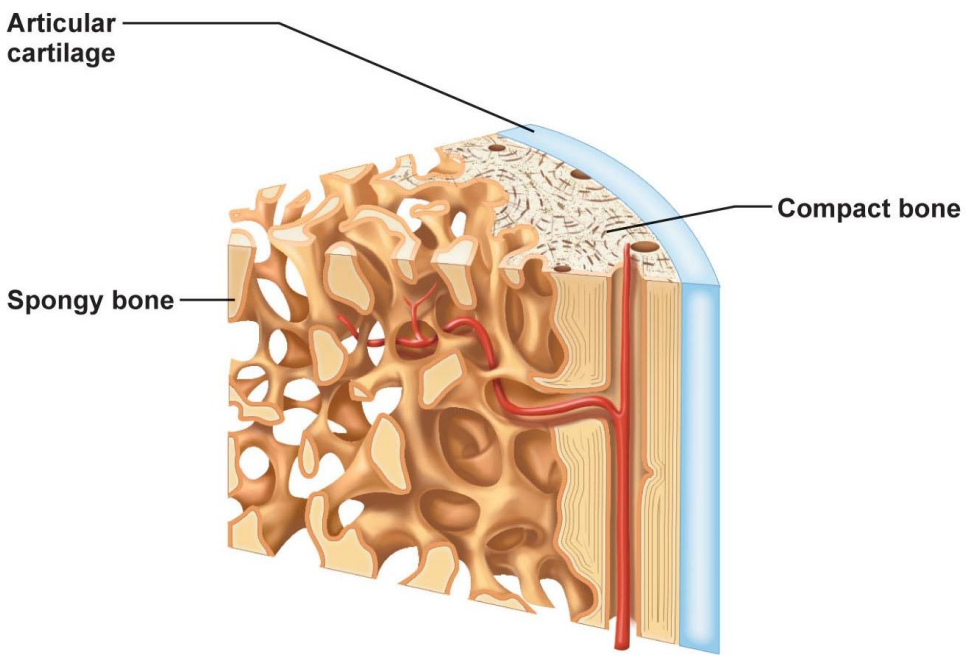
Types of Bone:

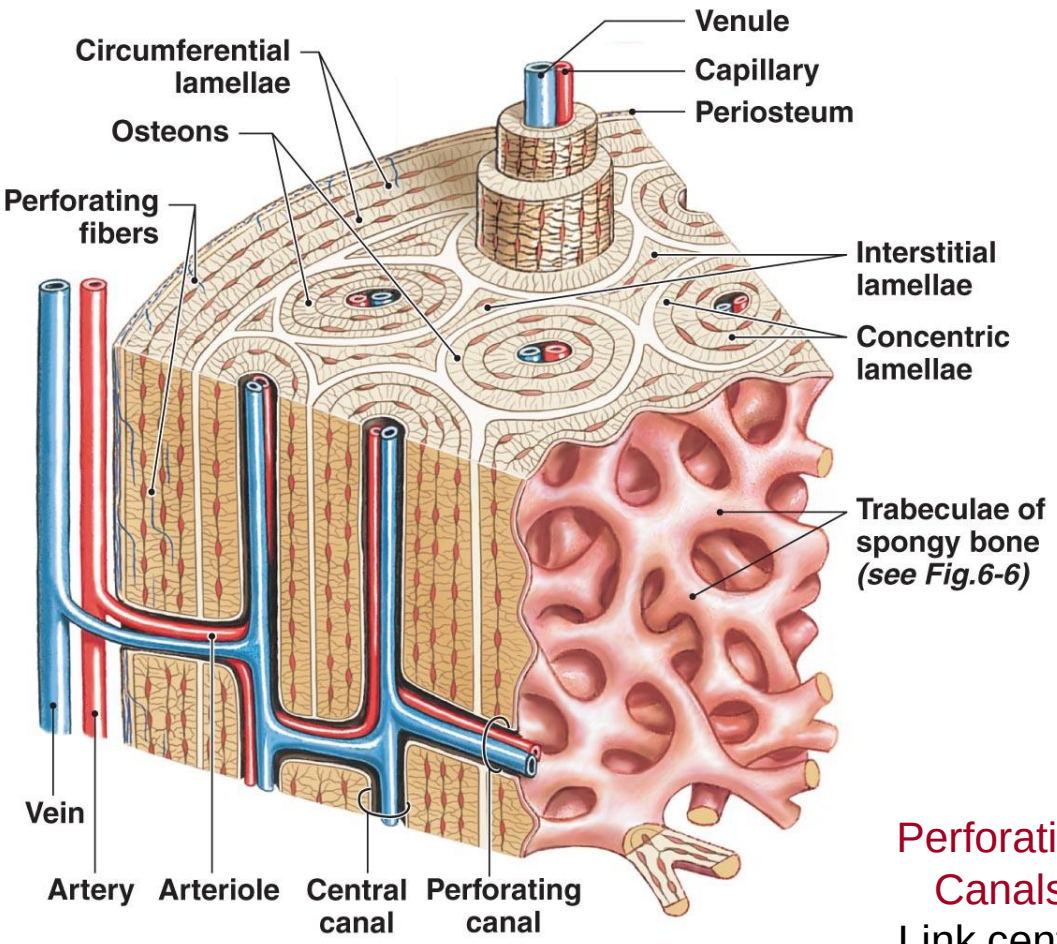
1) Compact Bone: Dense & solid
2) Spongy Bone: Air-filled pockets
   (Cancellous bone)



Marieb & Hoehn – Figure 6.3

Microanatomy of Compact Bone:

Osteon:
Structural unit of bone

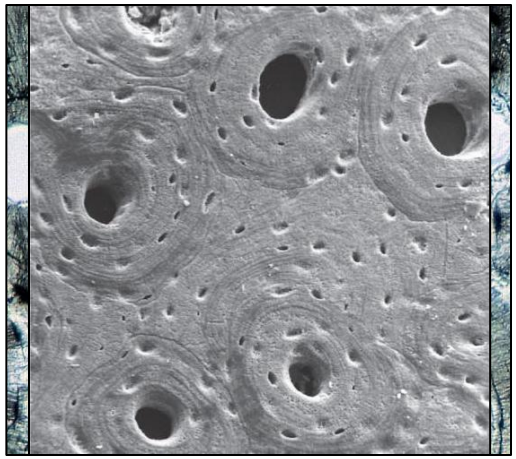


Martini & Nath – Figure 6.5

Osteon contains:

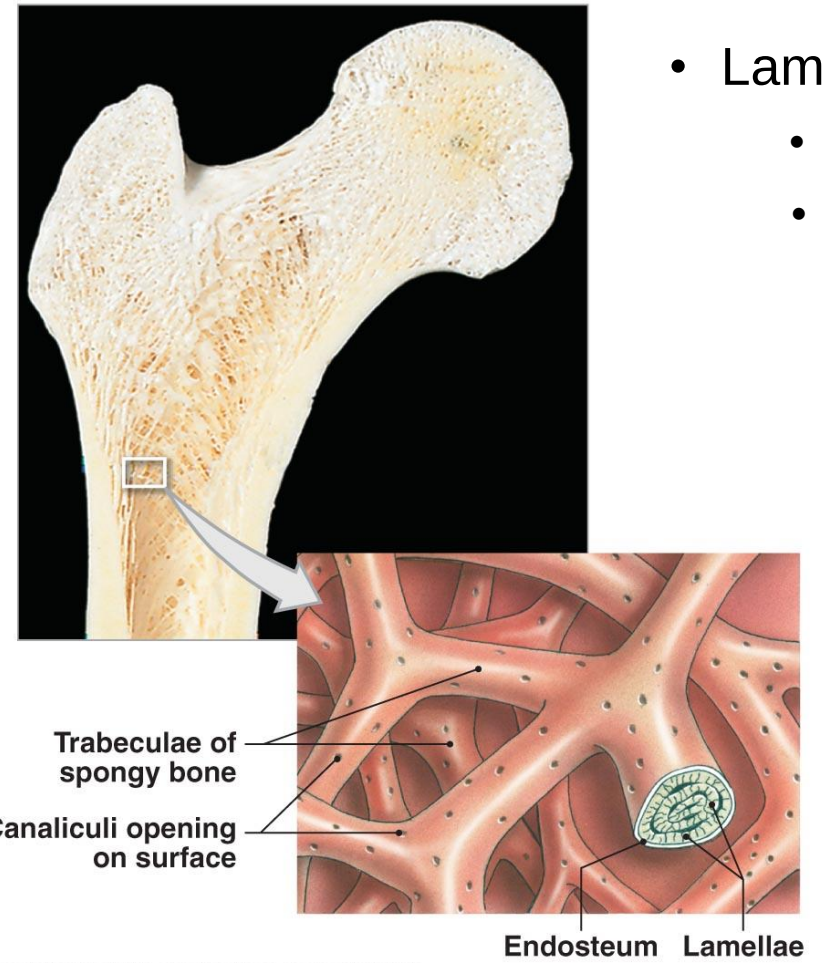
1) Central canal
   - Blood vessels
2) Lamellae
   - Calcified matrix sheets
   - Cylindrical arrangement
3) Osteocytes
   - Sit in small pockets (lacunae)
   - Connected via canaliculi

Perforating Canals:
Link central canals & blood supply

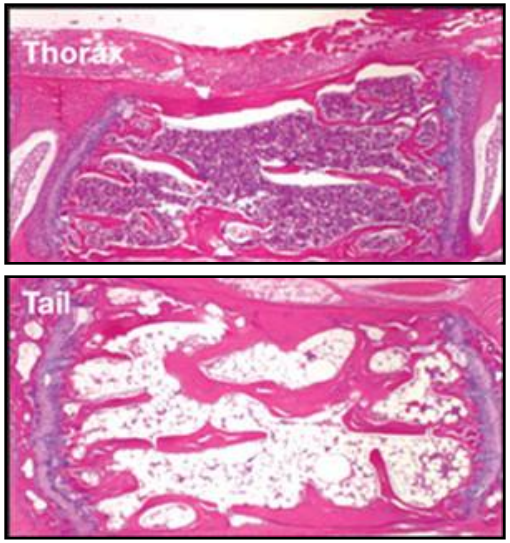


Microanatomy of Cancellous (Spongy) Bone:

Benefit:
Reduced bone weight



- Lamellae not arranged in osteons
  - Matrix forms struts / plates called trabeculae
  - Marrow located between trabeculae



Red Marrow:
Blood cell formation

Yellow Marrow:
Lipid storage

Martini & Nath – Figure 6.6

Mechanics of Bone:

- Bone needs to:
  a) be stiff (but not too stiff)
  b) be lightweight
  c) not break

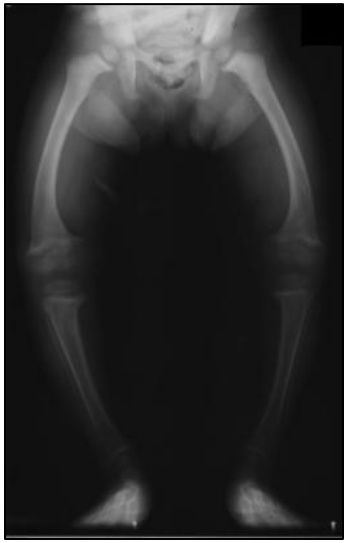
Mechanical Properties of Bone:

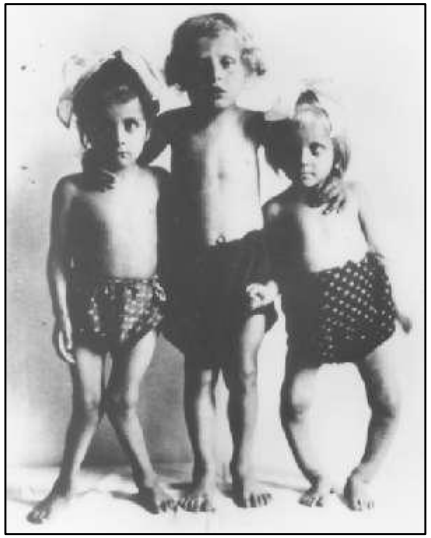
1) Bone is a composite:
   - Collagen fibers: strong (tension); flexible
   - Mineral crystals: strong (compression); stiff

} Must maintain balance

Heat

Vinegar





Rickets (osteomalacia):

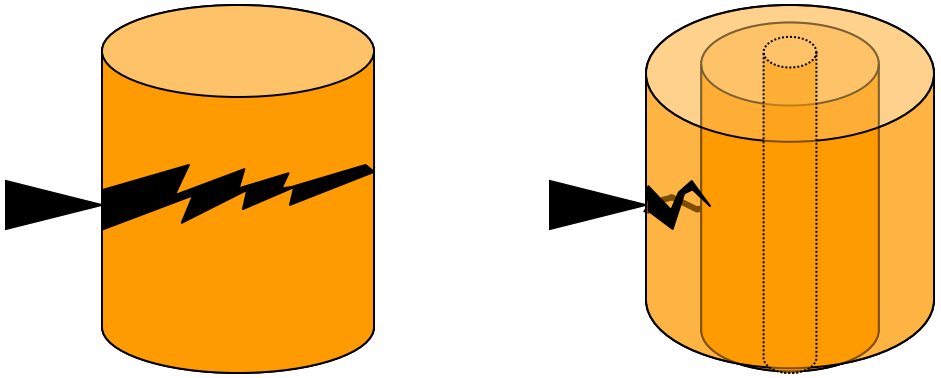
Softening of bone (loss of mineralization)

Cause: Calcium / Vitamin D_3 deficiency

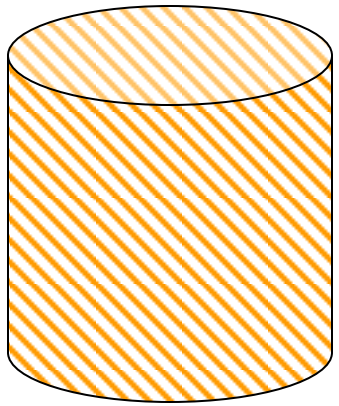
Mechanical Properties of Bone:

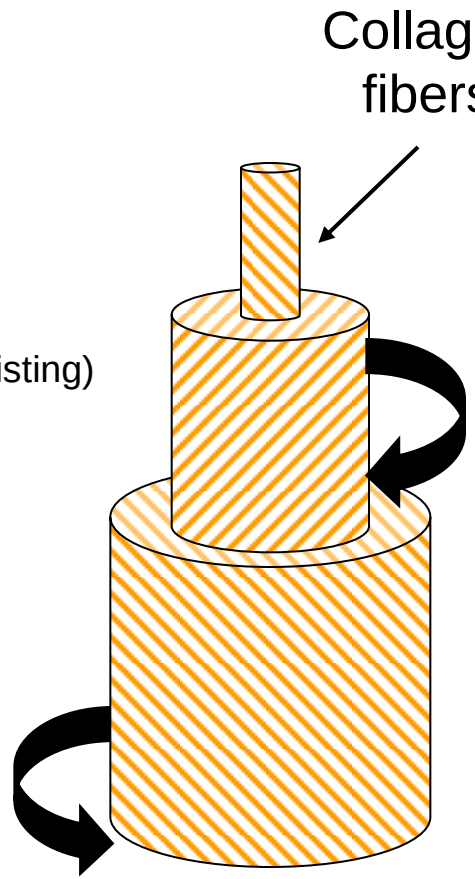
2) Bone is arranged in layers (compact bone):

- Concentric layers (lamellae) inhibit crack propagation



- Alternating orientation of collagen fibers resist torsion (twisting)





Classification of Fractures:

1) Position of bone after fracture
   - Nondisplaced fracture: Bone ends retain normal position
   - Displaced fracture: Bone ends out of normal alignment
2) Completeness of break
   - Complete fracture: Bone is broken through
   - Incomplete fracture: Bone is not broken through
3) Orientation of the break (relative to long axis of bone)
   - Linear fracture: Break parallel to long axis
   - Transverse fracture: Break is perpendicular to long axis
4) Penetration of break (relative to skin)
   - Closed fracture: Bone ends do not exit skin
   - Open (Compound) fracture: Bone ends exit skin

Displaced fracture
Complete fracture

Transverse fracture
Open fracture

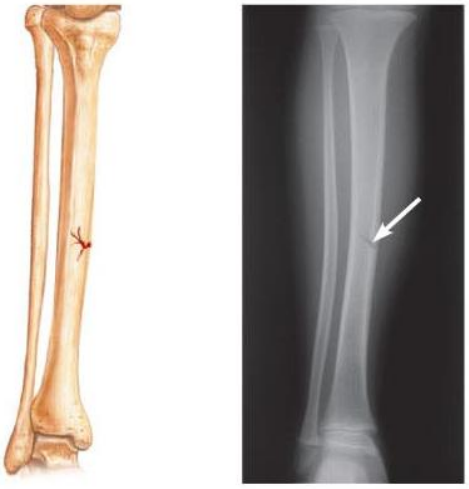
Classification of Fractures:

Comminuted Fracture

Bone is broken into
≥ 3 fragments

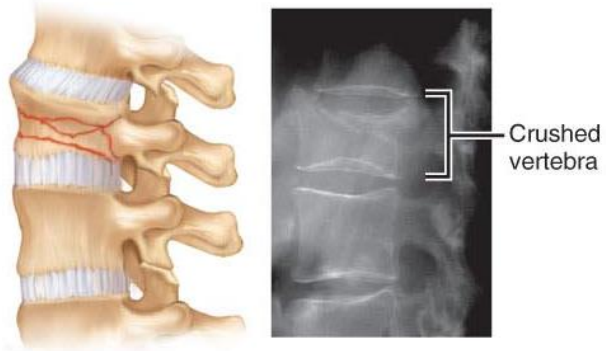
Epiphyseal Fracture

Epiphysis / diaphysis
separation



Greenstick Fracture

Incomplete break;
common in children

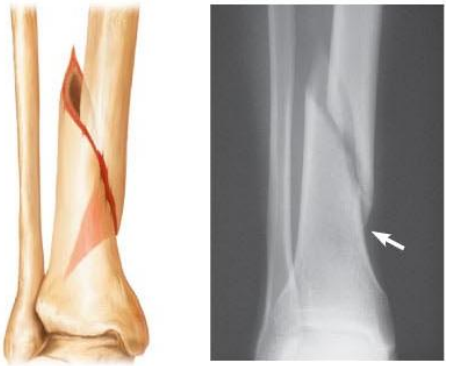


Compression Fracture

Bone is crushed under
extreme forces

Depressed Fracture

Broken bone portion
pressed inward



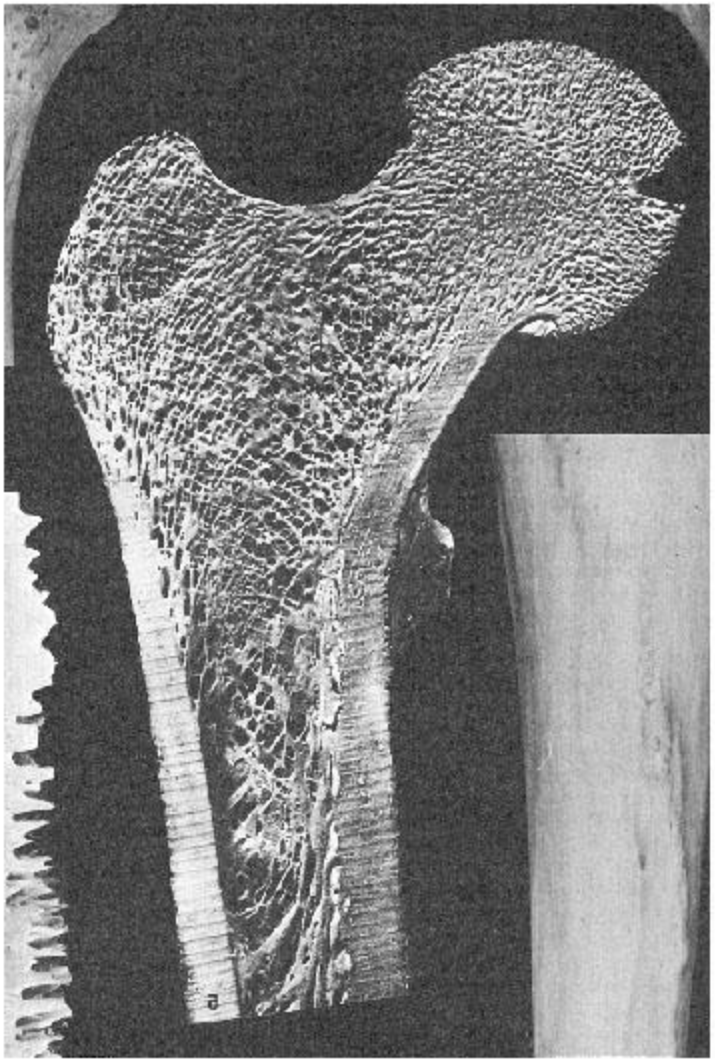
Spiral Fracture

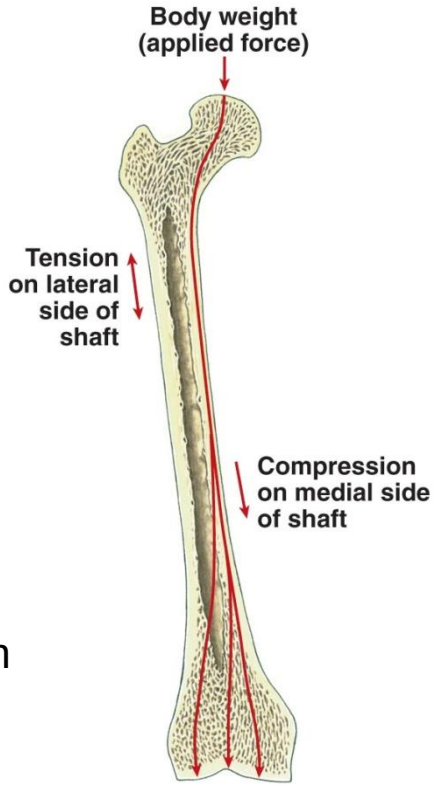
Ragged break due to
twisting forces

Martini & Nath – Figure 6.7

Mechanical Properties of Bone:

3) Trabeculae arranged along lines of stress (spongy bone):





Spongy bone:

Stress from many directions

compared to

Compact bone:

Stress from a single direction

4) Long bones are hollow:

- Reduced weight
- Increased strength

Hollow cylinders are stronger
than solid cylinders (of same mass…)

Bone Development:

1) Intramembranous Ossification (dermal ossification):

- Bone develops from fibrous connective tissue
- Relatively uncommon (e.g., skull / clavicles)

Osteoblasts develop in dermal layer

↓

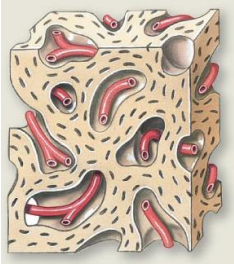
Osteoblasts cluster and secrete osteoid (ossification center)

↓

Osteoblasts trapped; convert to osteocytes

(compact bone)
Bone collar forms; periosteum forms

↑



Trabeculae form

↑

Spicules form; trap blood vessels

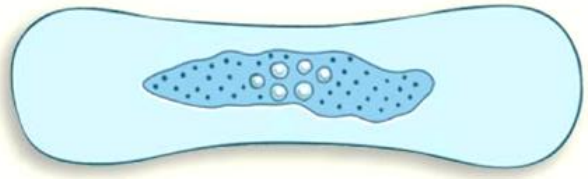
Epiphyseal Plate:
Line of cartilage separating epiphysis from diaphysis

Bone Development:

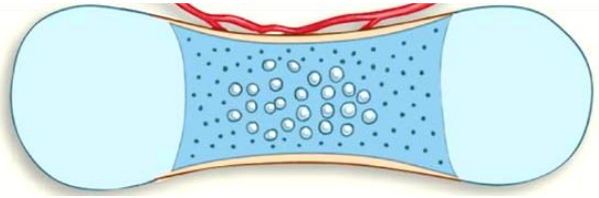
2) Endochondral Ossification:

- Bone develops from hyaline cartilage
- Most common (e.g., all bones from skull down (sans clavicles))

Hyaline cartilage template forms

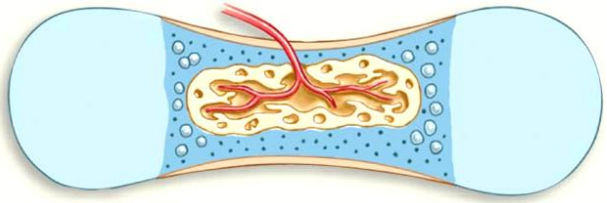


Osteoblasts form in periosteum; build bone collar (diaphysis)

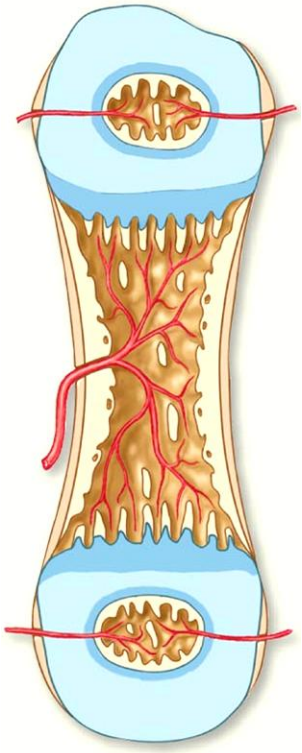


(primary ossification center)

Diaphysis center calcifies; blood vessels invade cavity



(secondary ossification centers)

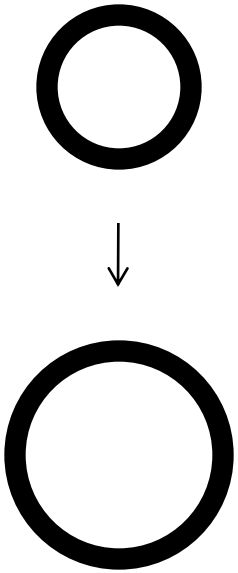


Diaphysis elongates; epiphyses ossify

Bone Growth:

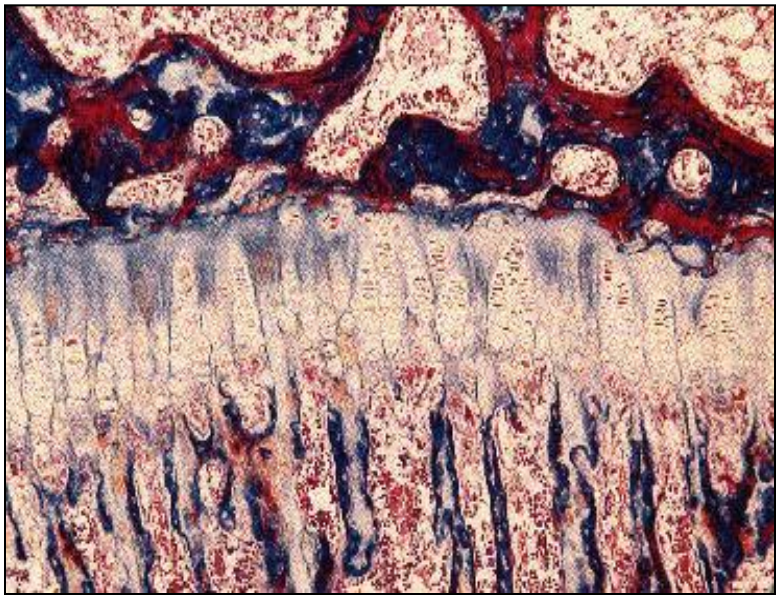
1) Appositional Growth: Increases bone width
   - Osteoblasts (periosteum) form bone
   - Osteoclasts (endosteum) resorb bone

} Cortical size / shape maintained



2) Interstitial Growth: Increases bone length
   - Growth occurs at epiphyseal plates

Epiphyseal side



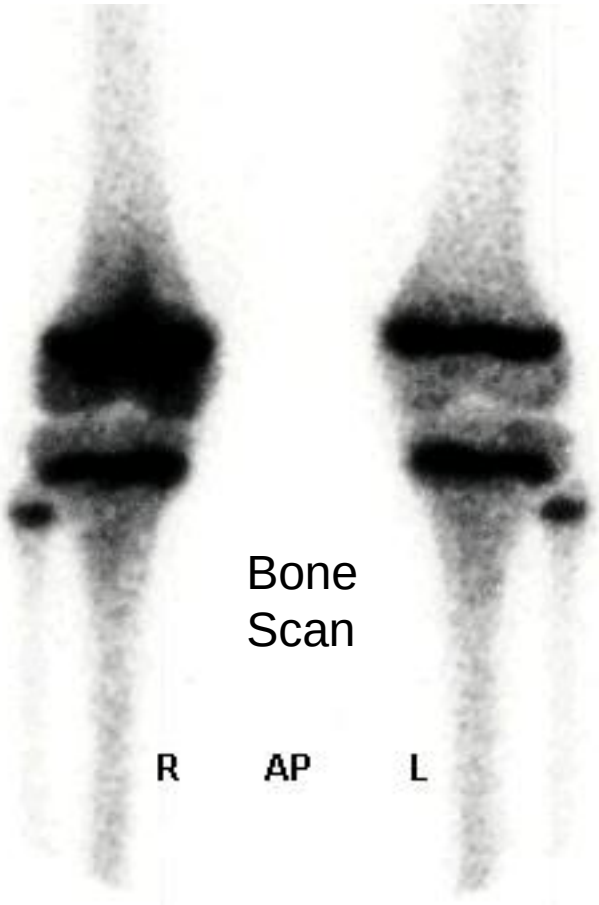
Diaphyseal side

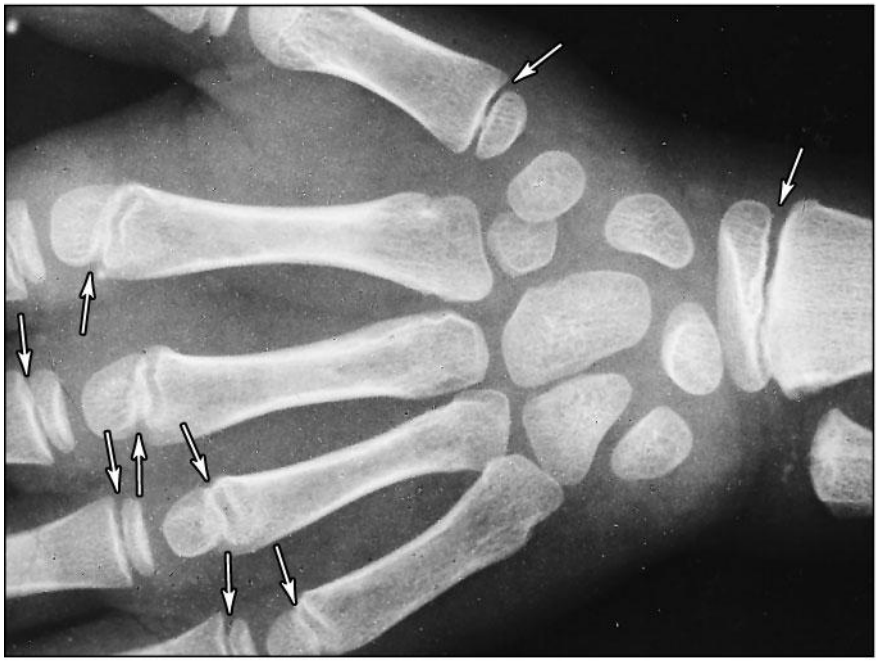
Epiphyseal side: Cartilage cells rapidly divide

Diaphyseal side: Osteoblasts convert cartilage to bone

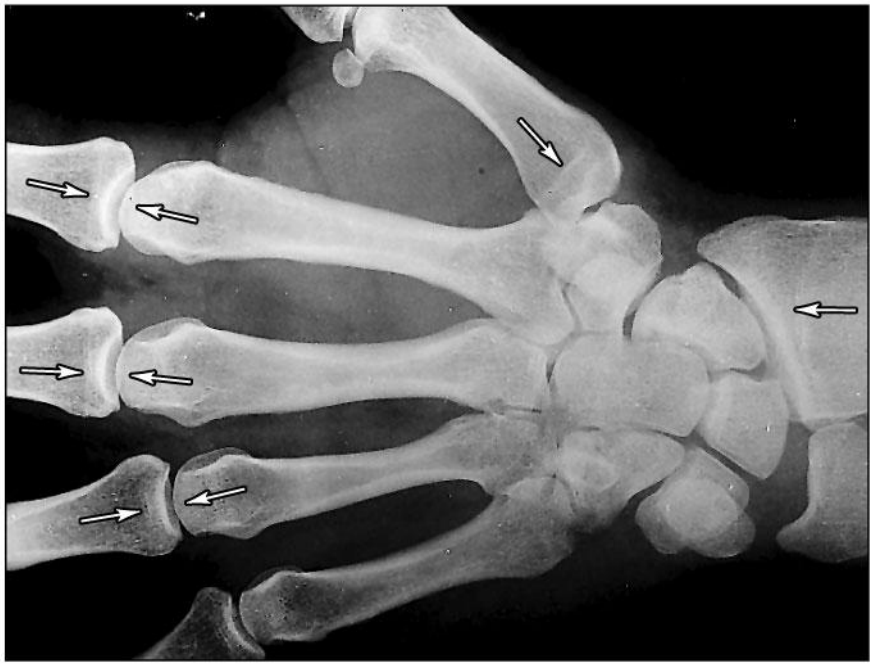
Epiphyseal plate eventually ossifies:
- Female = ~ 18 years
- Male = ~ 21 years

9 year old child:





(a) Epiphyseal cartilages



(b) Epiphyseal lines

When Things Go Very Wrong:

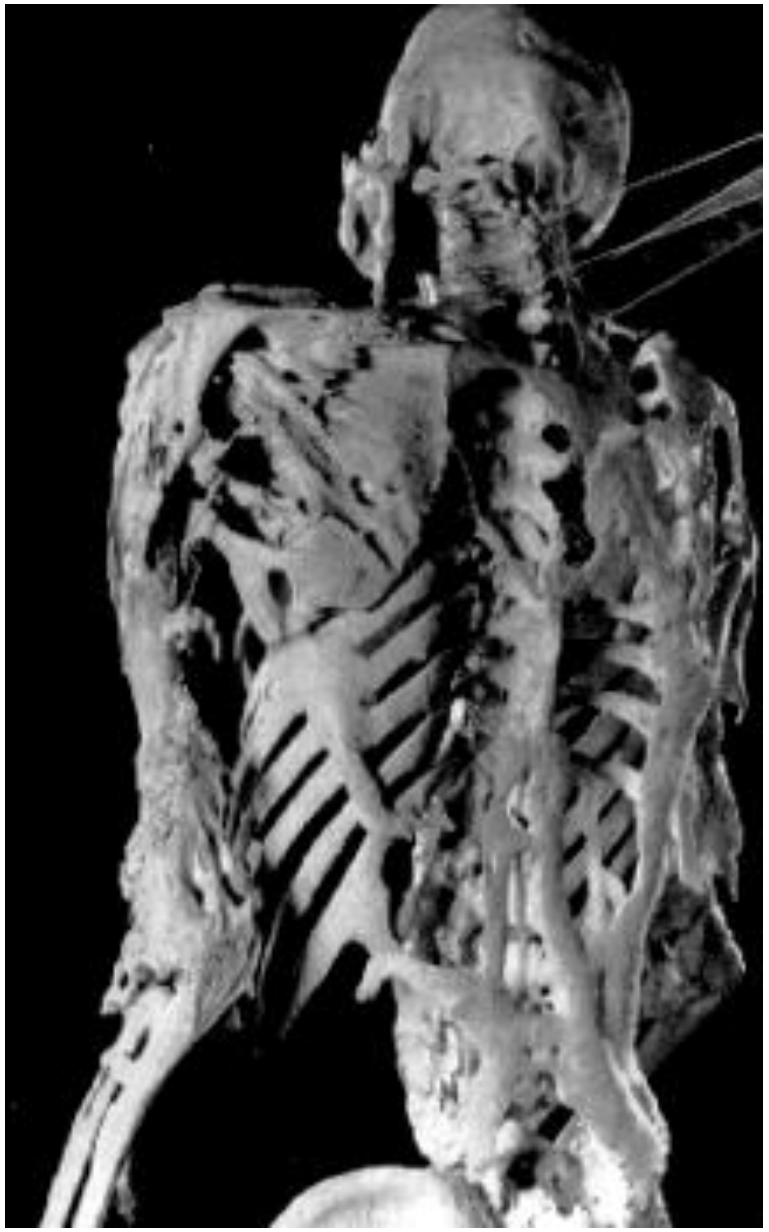
Fibrodysplasia Ossificans Progressiva

(Uncontrolled bone growth)

Fibrous tissue (e.g., muscle / tendon / ligament) ossifies when damaged

Genetic Disorder:

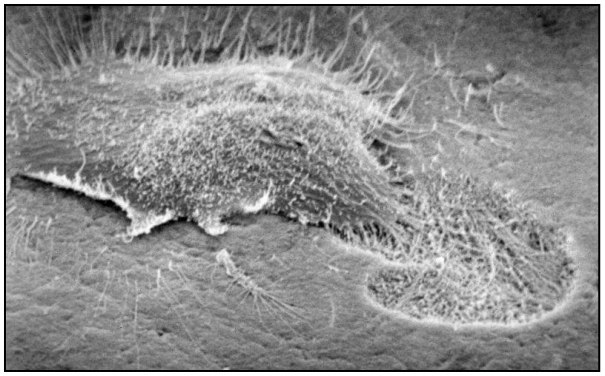
Extremely Rare: 1 / 2,000,000 births



Heavy-metal ions can be incorporated into bone matrix

Bone Remodeling:

- 5 - 7% of bone mass recycled each year



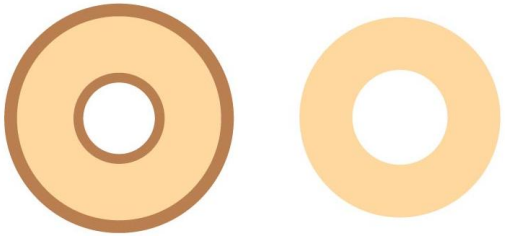
A) Bone Deposition (Osteoblasts)

- Secretion of osteoid and collagen fibers

B) Bone Resorption (Osteoclasts)

- Acid secretion = Inorganic matrix digestion
- Enzyme secretion = Organic matrix digestion

Functions of Bone Remodeling:



1) Maintenance (normal growth)
2) Reshape Bones
   - Wolff's Law: Bones remodel in response to forces placed on them

Mechanical Stress → Micro-cracks in bone → ↑ Osteoblast / osteoclast activity

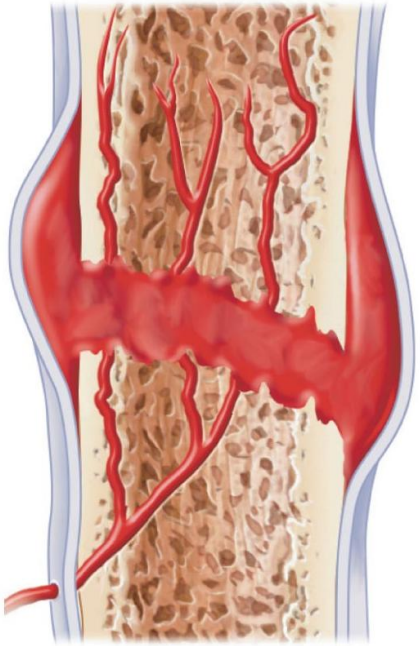
Electrical signals suggested to direct remodeling

Functions of Bone Remodeling:

3) Repair Bones:

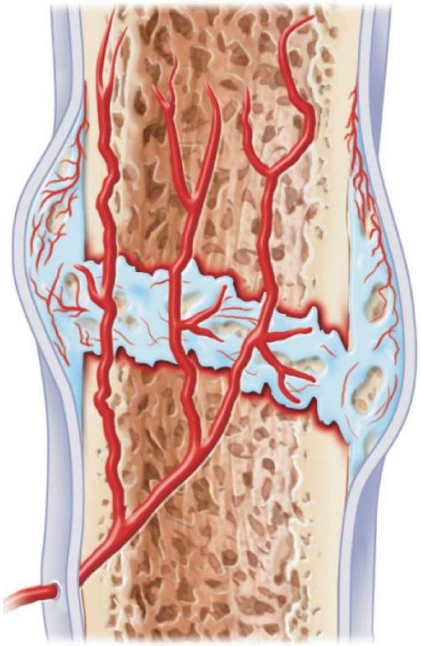
Hematoma Formation:

Clotting seals injured blood vessels



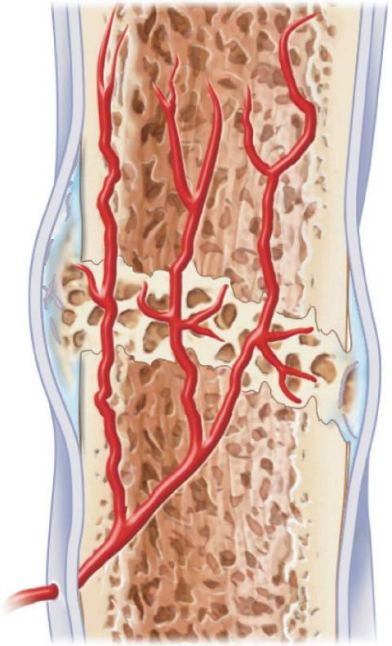
Cartilaginous Callus Formation:

Cartilage fills in damaged area



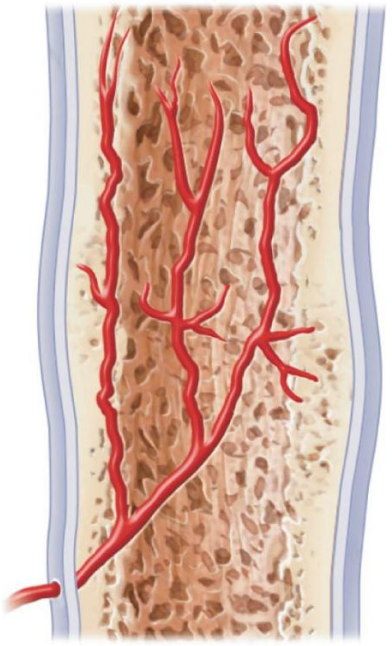
Bony Callus Formation:

Spongy bone replaces cartilage



Bone Remodel:

Compact bone Lines shaft wall

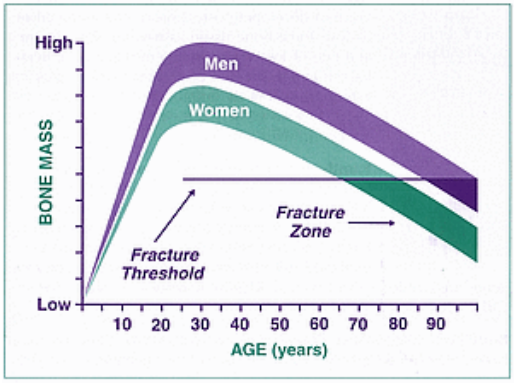


Typical human body
~ 2 kg of Ca^{++}
(99% deposited in bone)

Functions of Bone Remodeling:

4) Maintain Blood Calcium Levels:

- Regulation via negative feedback loops (endocrine system):
  - A) Calcitonin (Thyroid gland):
    - Decrease blood Ca^{++} levels (increase bone deposition)
  - B) Parathyroid Hormone (Parathyroid gland):
    - Increase blood Ca^{++} levels (increase bone resorption)
- Hormones inhibit / stimulate osteoclast activity



Aging of the Skeletal System:

Osteopenia: Inadequate ossification

- Normal aging process (decreased osteoblast activity)
  - Peak bone mass ~ 35 – 40 years of age
    - Males ~ 3% loss / decade; Females ~ 8% loss / decade

Osteoporosis: Porous & fragile bone (spongy bone)

- Frequent in elderly; especially post-menopausal women

Influencing Factors:

1) ↓ sex hormones
2) Calcium deficiency
3) Vitamin D deficiency
4) Inactivity

Marieb & Hoehn – Figure 6.16