

# Skeletal System

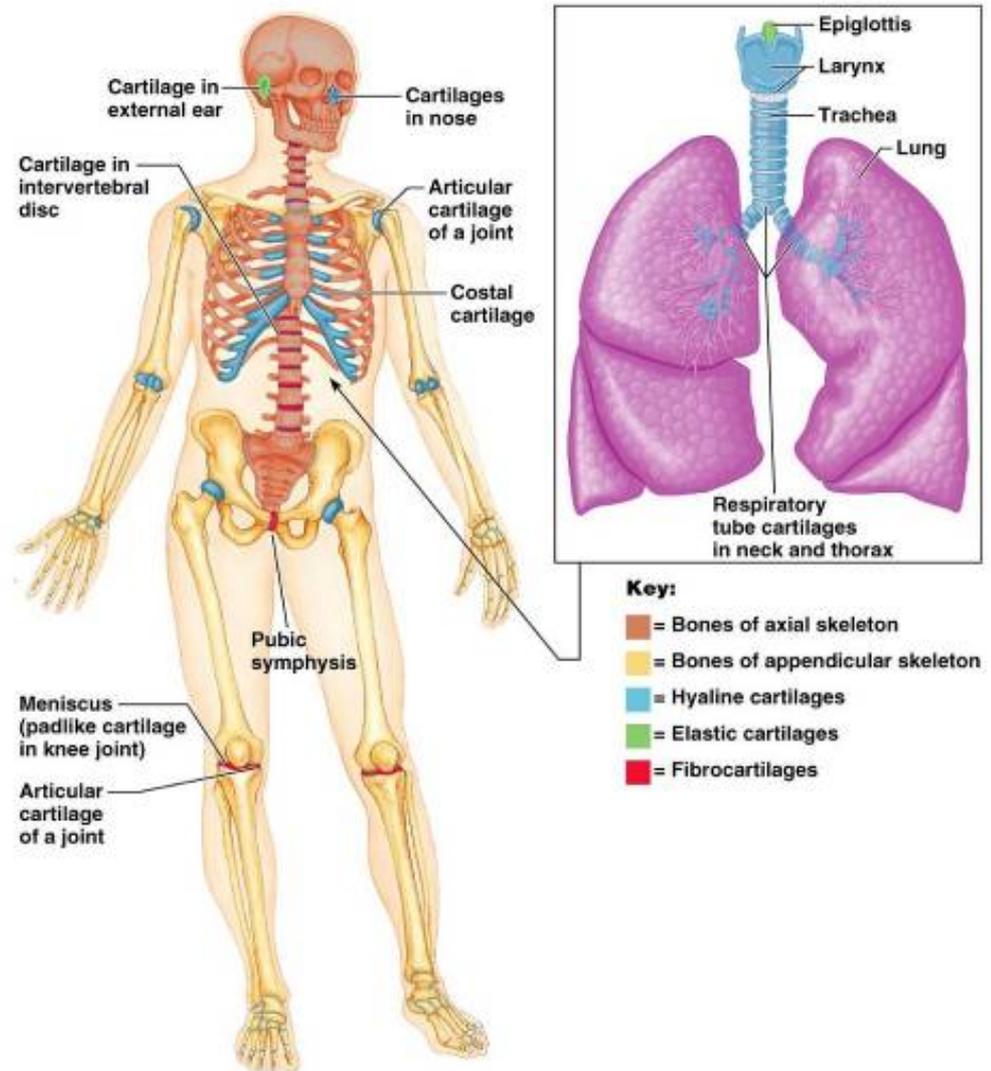
Structure, Function & Malfunction

# Functions of the Skeletal System

1. Support
2. Storage of minerals (e.g.  $\text{Ca}^{2+}$ )
3. Storage of lipids (e.g. **yellow marrow**)
4. Blood cell production (**red marrow**)
5. Protection (e.g. heart & lungs enclosed in rib cage)
6. Leverage (force of motion)

# Overview

- Components:
  - **Bones**
  - **Cartilages**
    - Shock absorber
  - **Ligaments**
    - Bind bone to bone
  - **Tendons**
    - Bind bone to muscle



# Skeletal system

- **All components are connective tissues (CT)**
- **Matrix** determines characteristic of **CT**
  - H<sub>2</sub>O
  - **Collagen** - tough, cordlike protein
  - **Proteoglycans** - polysaccharide “barbs” surrounding protein core
    - Trap H<sub>2</sub>O like a sponge.
  - **Minerals** - Ca<sup>2+</sup>, P, Mg<sup>2+</sup>, S

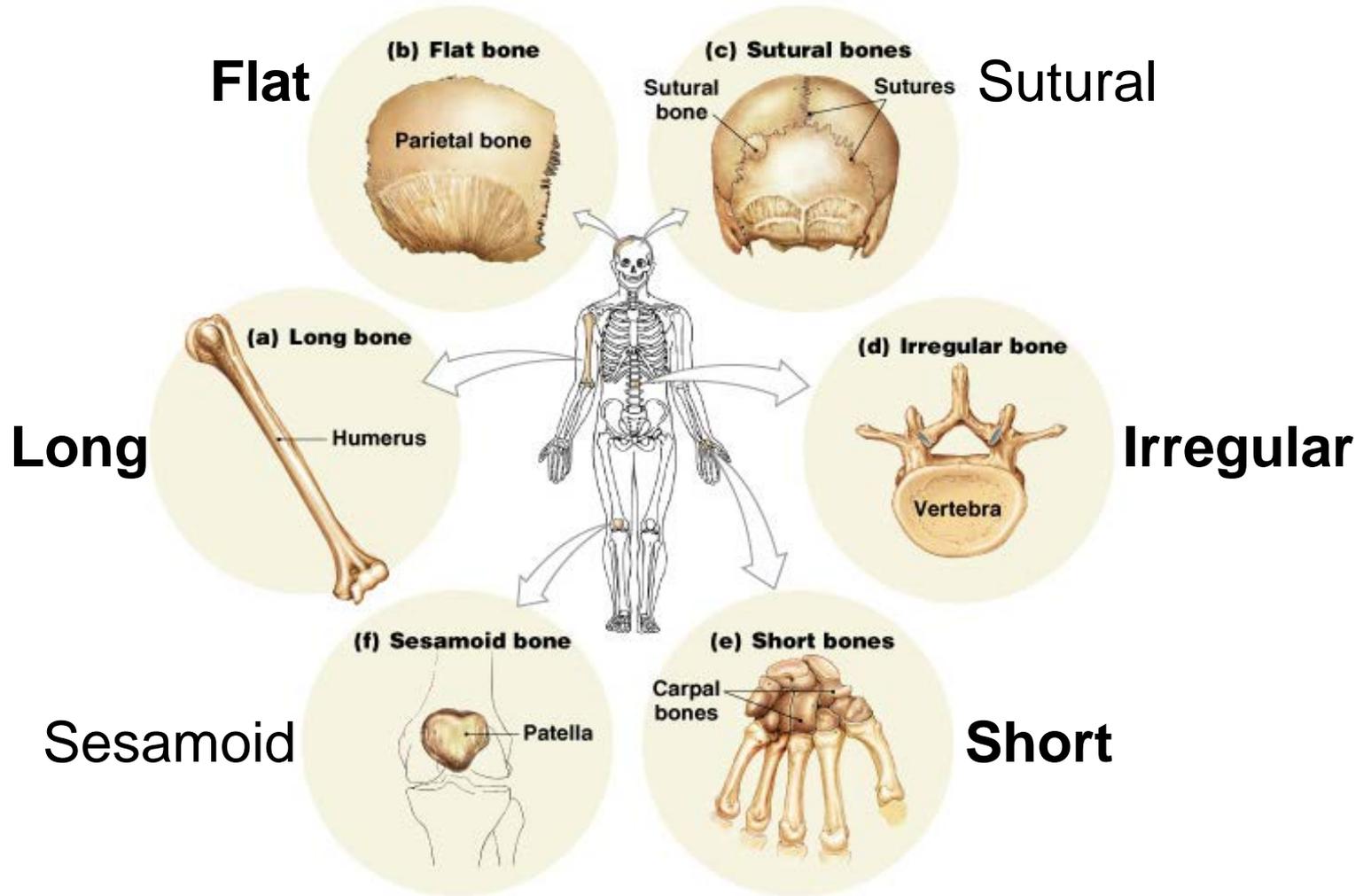
# Who's got what?

- **Tendons & ligaments** - mostly **collagen**; makes them tough; withstand tensile forces
- **Cartilage** - **Collagen** and **proteoglycans**; tough, but smooth and resilient
- **Bones** - **collagen** and **minerals** ( $\text{Ca}^{2+}$ , P; hydroxyapatite crystals) make it resistant to compression, but flexible

# Classification of Bones

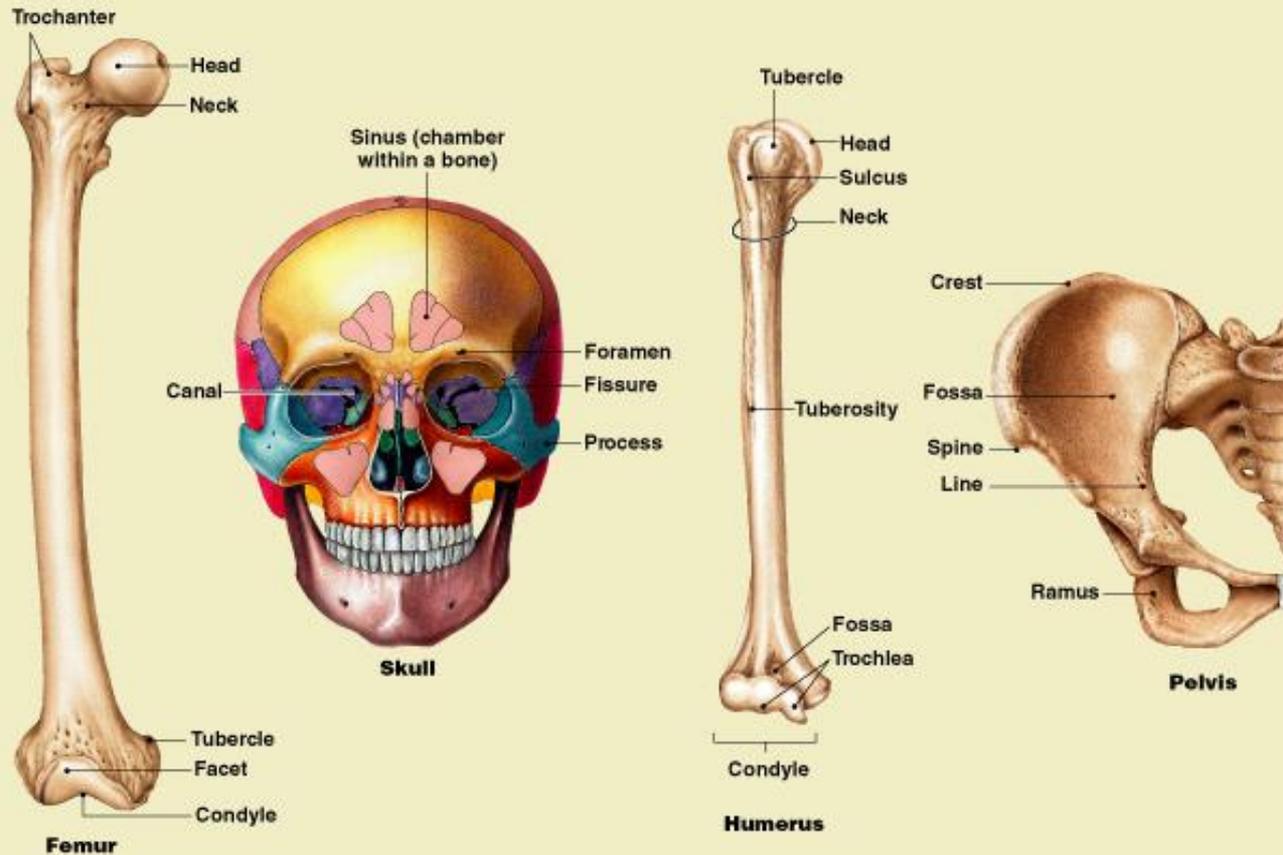
- Identified by:
  - Shape
  - Bone markings
  - Internal arrangement

# Bone Shapes



# Bone surface features

TABLE 6-1 An Introduction to Bone Surface Features



# Internal Arrangement: *Compact bone*

## *vs. spongy bone*

Arrangement

Location

Functions

# Structural types of Bone

## Compact

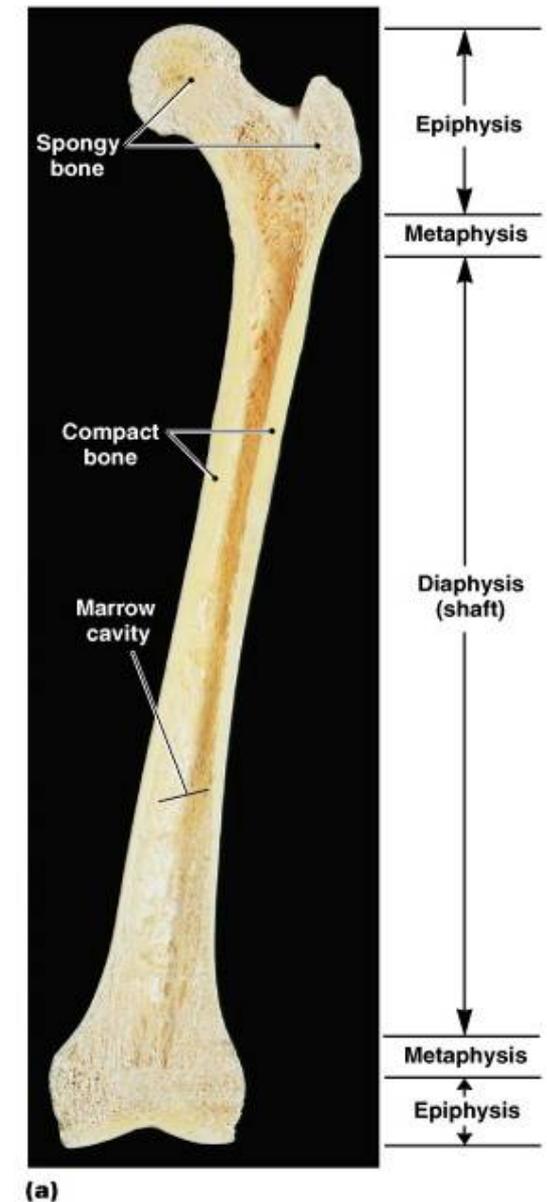
- Dense bone
- Relatively solid layer of matrix surrounding a central, **medullary cavity**
- *Parallel* structural elements withstand forces from one direction
- Heavily vascularized matrix

## Spongy

- Trabecular bone
- Open latticework of struts with a thin **cortex** of compact bone
- *Reticulate* structural elements withstand forces from multiple directions
- Avascular matrix
- Contains red or yellow marrow

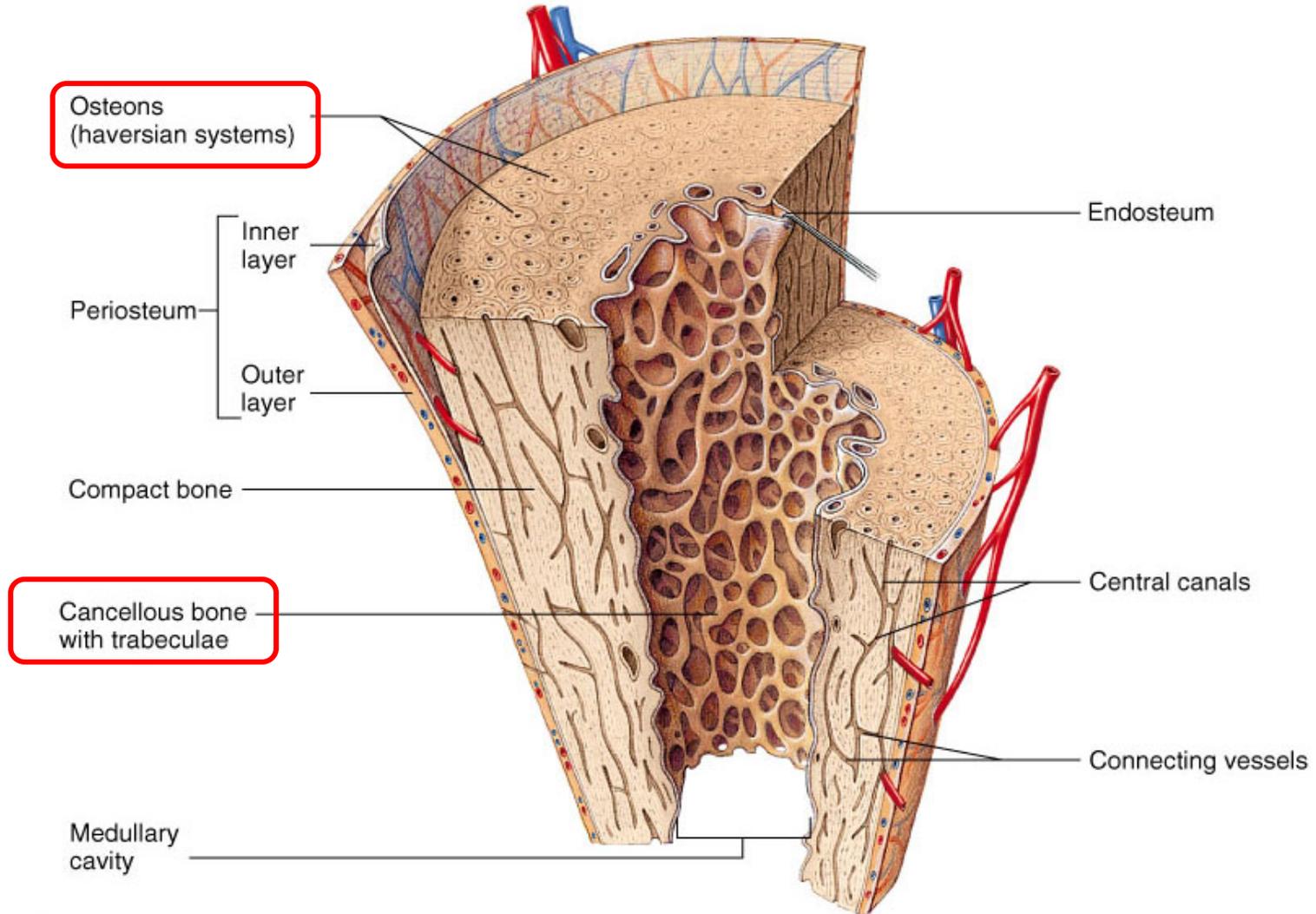
# Most bones have **both**

- **Diaphysis:** the shaft
  - **Thick** layer of **outer** compact bone, with *thin* layer of spongy bone facing medullary cavity
- **Epiphysis:** Articulating features at each end
  - *Thin* layer of *outer* compact bone with **thick** layer of spongy bone throughout **inside**



# Internal structure

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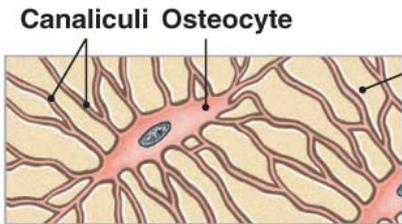
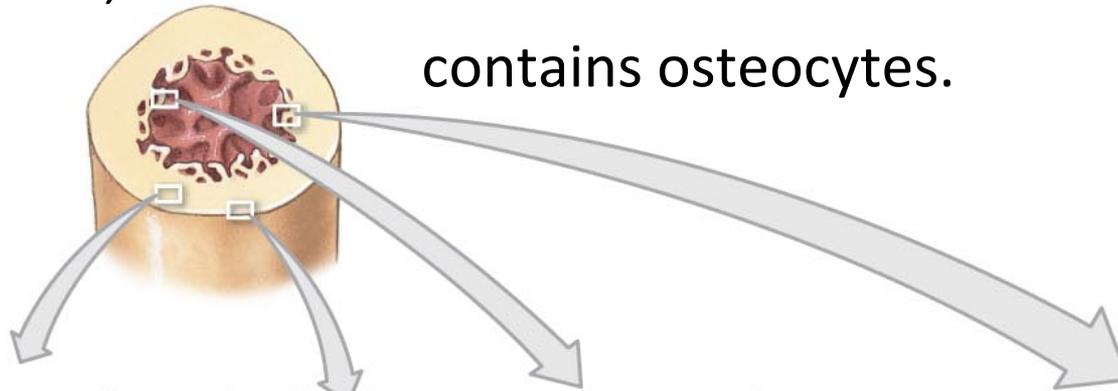
Adult bone

# Bone Cells make both types of bone

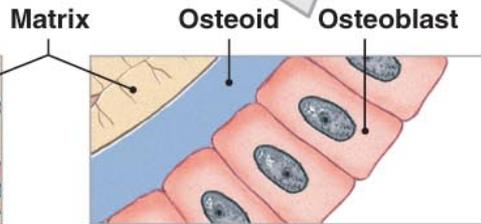
- Only **2%** of bone mass:
  - **Osteoprogenitor** (mesenchymal) cells - produce osteoblasts; fracture repair
  - **Osteoblasts** - produce *organic* products of matrix (**collagen**)
  - **Osteocytes** - mature cells; maintain matrix; stimulate deposition of hydroxyapatite
  - **Osteoclasts** - remove and recycle matrix; derived from germ cells

# Bone Cell locations

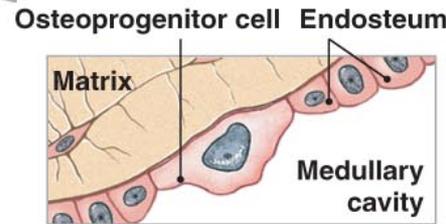
- Compact bone is covered with living membranes:
  - **Periosteum:** outer layer; contains osteoprogenitors & osteoblasts
  - **Endosteum:** inner layer; contains osteoprogenitors, osteoblasts; osteoclasts
  - Matrix: contains osteocytes.



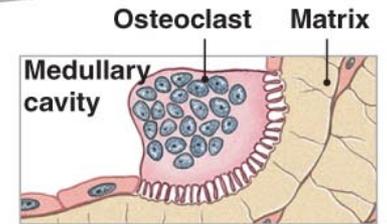
**Osteocyte:** Mature bone cell that maintains the bone matrix



**Osteoblast:** Immature bone cell that secretes organic components of matrix



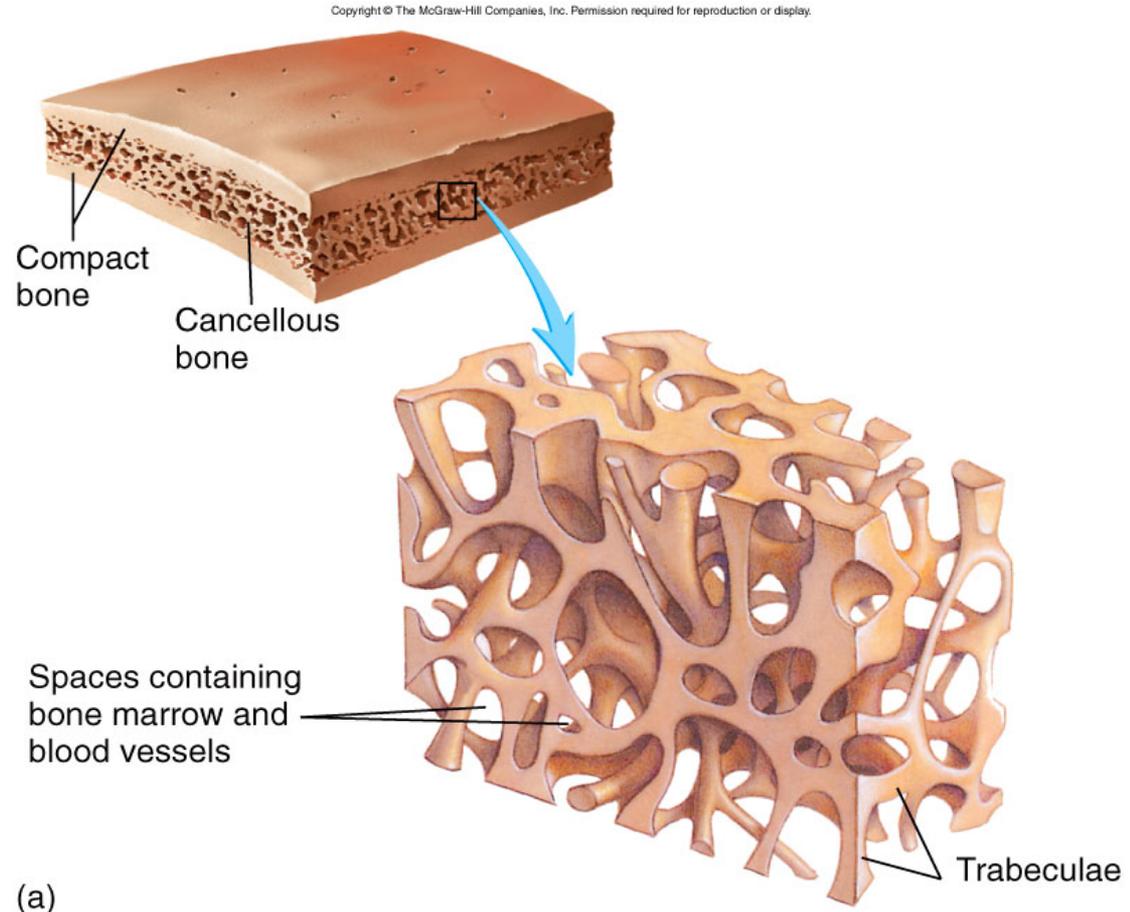
**Osteoprogenitor cell:** Stem cell whose divisions produce osteoblasts



**Osteoclast:** Multinucleate cell that secretes acids and enzymes to dissolve bone matrix

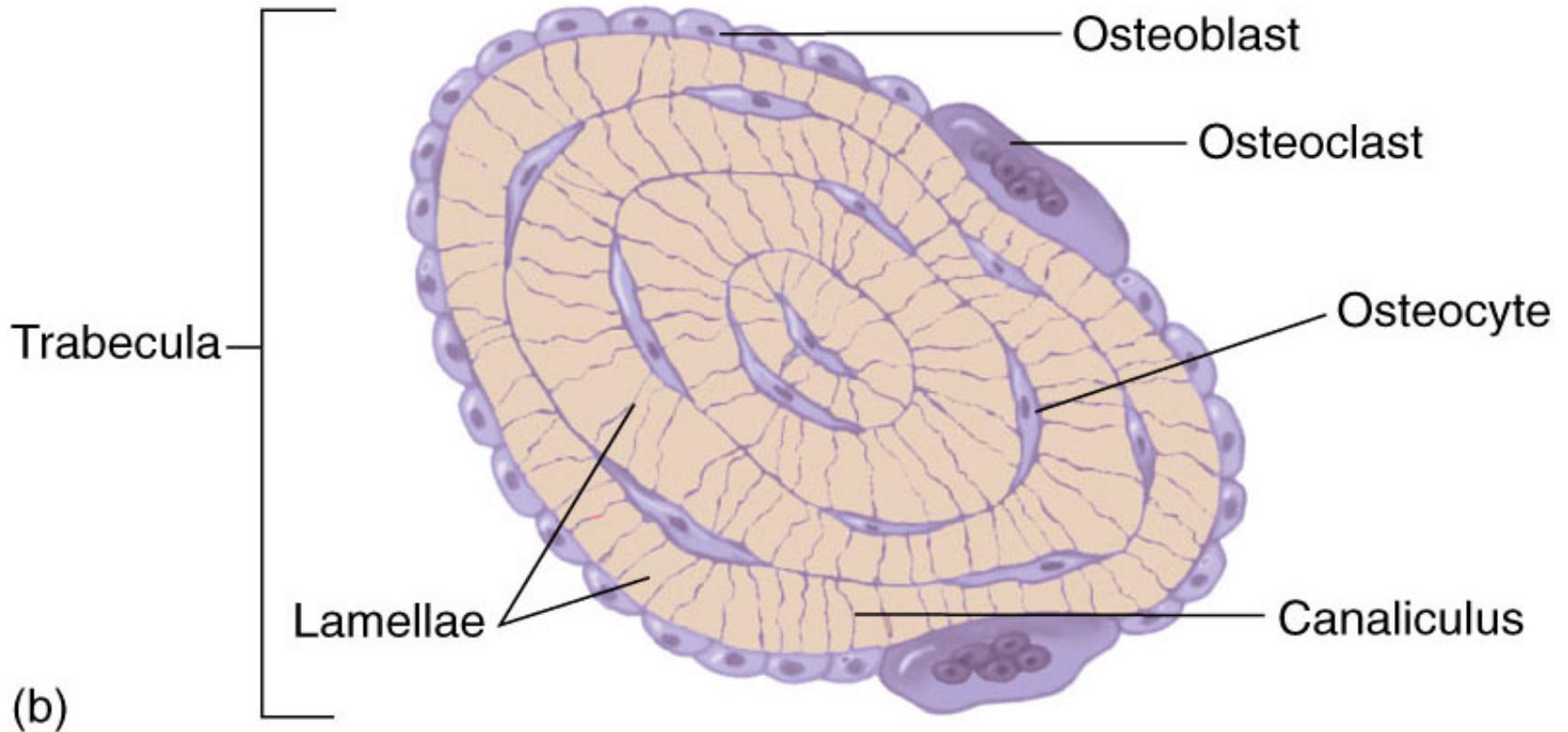
# Spongy (Cancellous) Bone

- NO osteons
- Matrix forms open network of **trabeculae**
- Trabeculae **NOT vascularized**



# Spongy (Cancellous) Bone

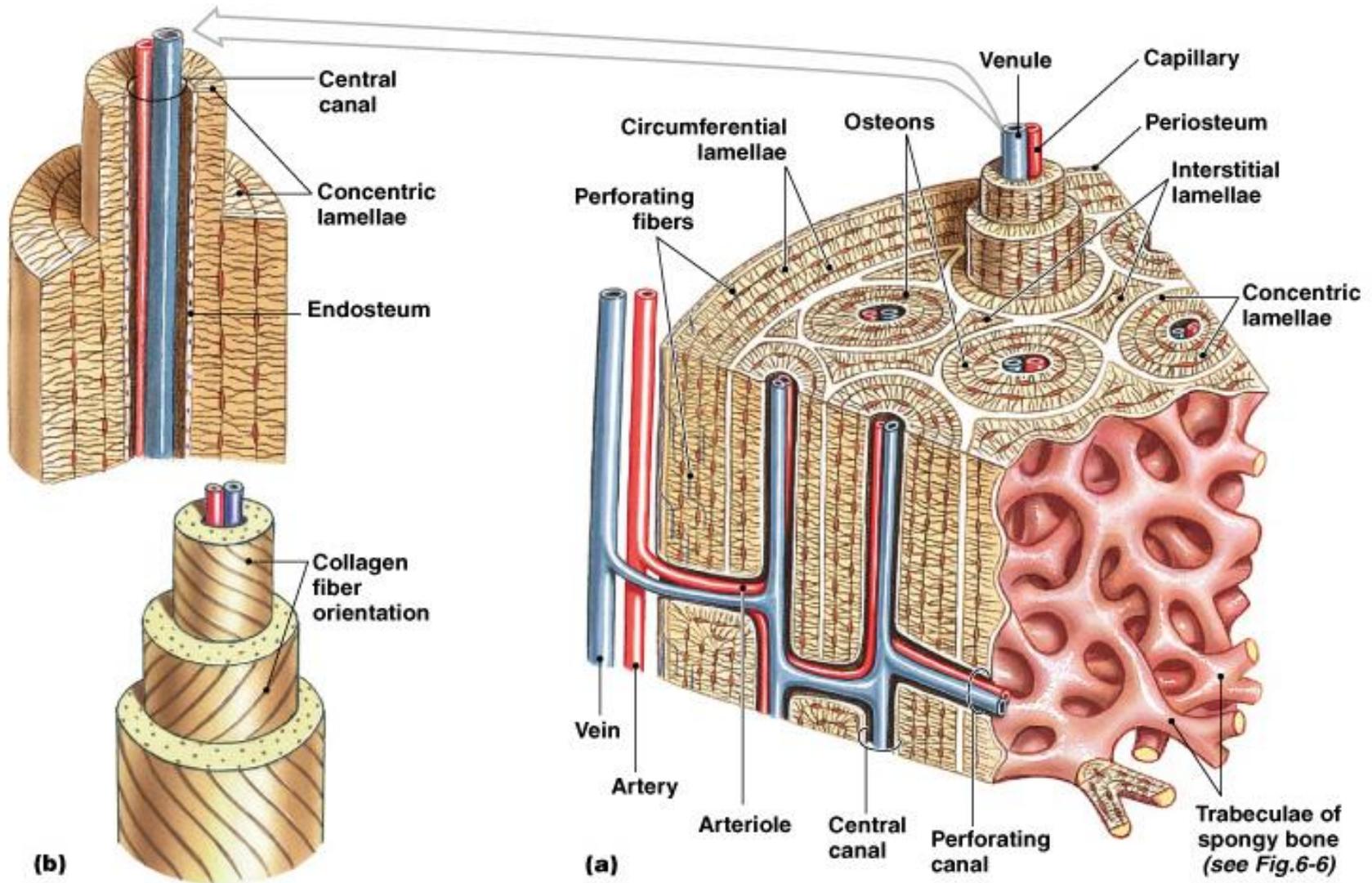
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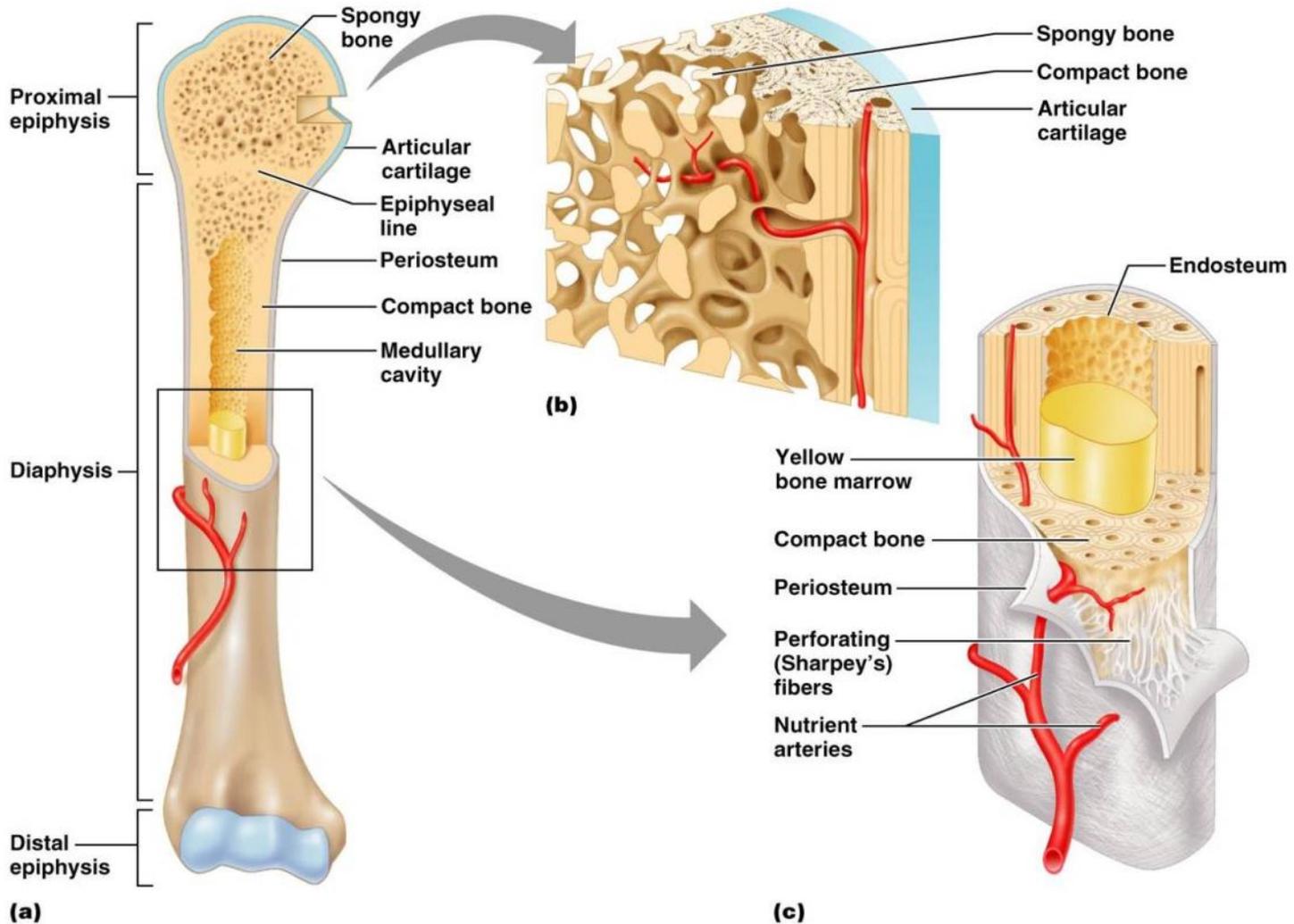
# Compact Bone

- Composed of **osteons (haversian system)**:  
Basic unit of mature compact bone
  - **Osteocytes** arranged in **concentric lamellae (layers)**
  - Each osteon surrounds a **central canal** containing blood vessels (deliver nutrients [like what?]; remove waste)
  - **Perforating canals** connect neighboring osteons
- **Circumferential lamellae** encases osteons
- Surrounded by **periosteum** (out) and **endosteum** (in)

# Compact Bone (x.s. & l.s.)

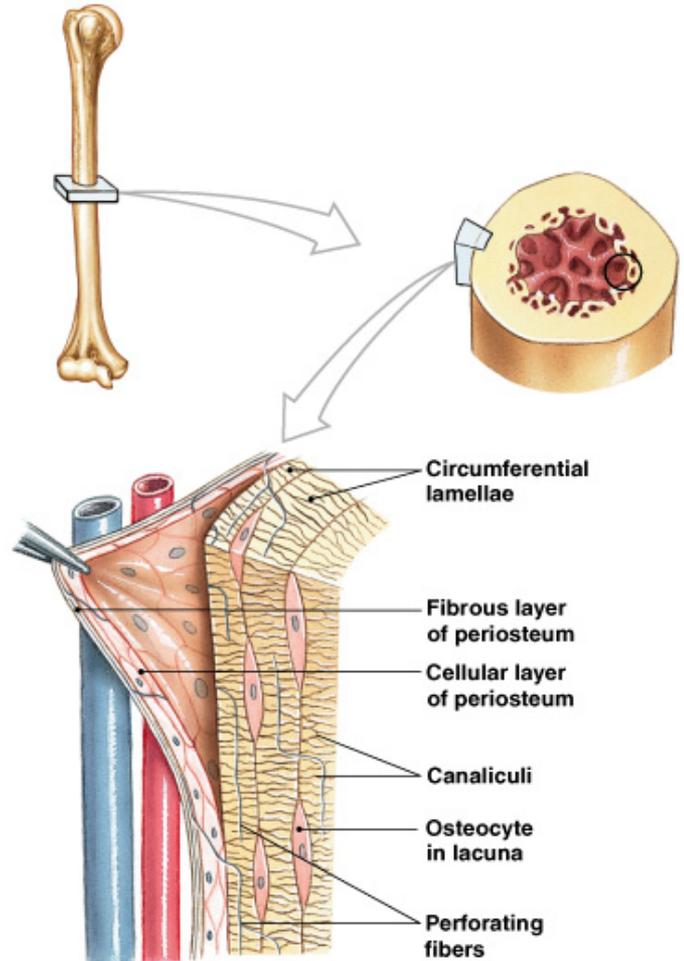


# Compact Bone (x.s. & l.s.)



# Arrangement

- Lamellae:
  - deposits of  $\text{Ca}^{2+}$  salts surrounding
  - Osteocytes within **lacunae** surrounding blood vessels
- **Canaliculi:**
  - Little canals through which osteocytes connect
- **Periosteum:**
  - covers **outer** surface of bone
  - Has an outer *fibrous* + inner *cellular* layer



(a) The periosteum contains outer (fibrous) and inner (cellular) layers. Collagen fibers of the periosteum are continuous with those of the bone, adjacent joint capsules, and attached tendons and ligaments.

# Matrix = Minerals + Proteins

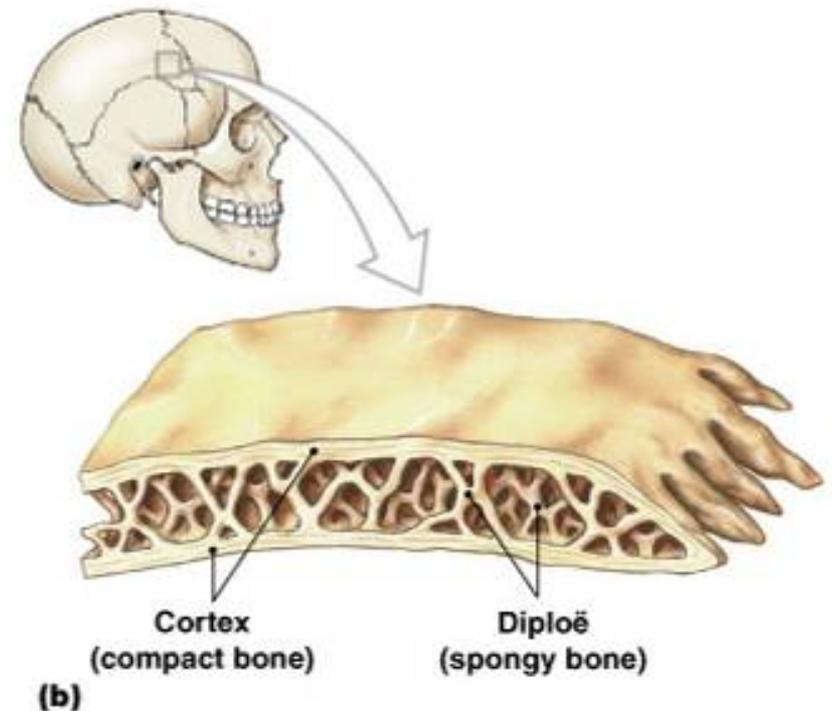
- 2/3 of bone *matrix* (by weight) is calcium phosphate,  $\text{Ca}_3(\text{PO}_4)_2$ 
  - calcium phosphate,  $\text{Ca}_3(\text{PO}_4)_2$  + calcium hydroxide,  $\text{Ca}(\text{OH})_2$  = hydroxyapatite,  $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$
  - Which adds other calcium salts and ions
- 1/3 of bone *matrix* is collagen fibers
- These two components make bone stronger and more flexible than steel-reinforced concrete.

# Red & Yellow Marrow

- Medullary cavity filled with **red bone marrow**:
  - has blood vessels
  - forms red blood cells (RBC)
  - supplies nutrients to osteocytes
- As we age, **yellow marrow** replaces most red marrow in distal bones:
  - stores FAT

# Flat Bones

- Ex: the parietal bone of the skull
- sandwich of spongy bone between 2 layers of compact bone



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# Homeostasis

- Bone building, by **osteocytes**, and bone recycling, by **osteoclasts**, must balance:
  - If more breakdown than building, then bones become weak
  - Exercise induces osteocytes to build bone
    - See article for more

***intramembranous vs.  
endochondral ossification***

# Ossification

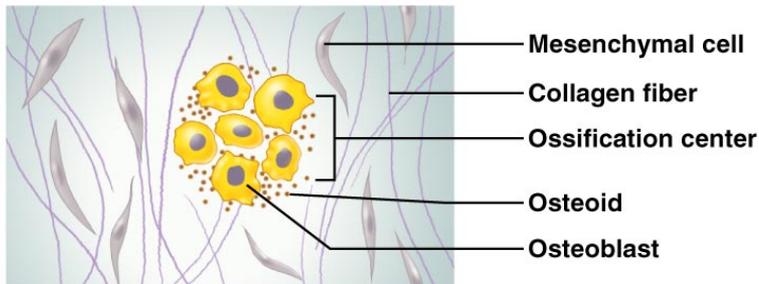
- Formation of bone by **osteoblasts**
- 2 main forms of ossification:
  - **intramembranous** ossification
  - **endochondral** ossification



# Intramembranous Ossification

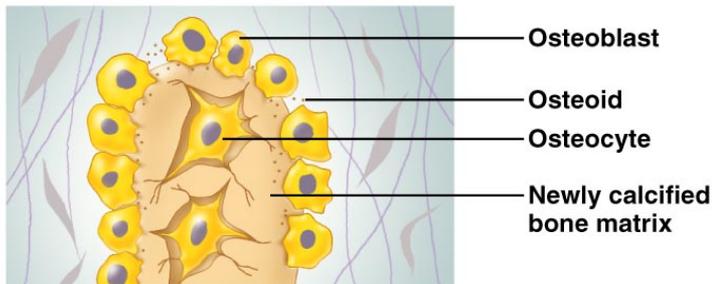
- Also called **dermal ossification**
  - produces **dermal bones** such as cranial bones and clavicle
- Forms bone within connective tissue membranes
  - Ex: bones of the skull
- 3 steps in intramembranous ossification

# Intramembranous Ossification



① **An ossification center appears in the fibrous connective tissue membrane.**

- Selected centrally located mesenchymal cells cluster and differentiate into osteoblasts, forming an ossification center.

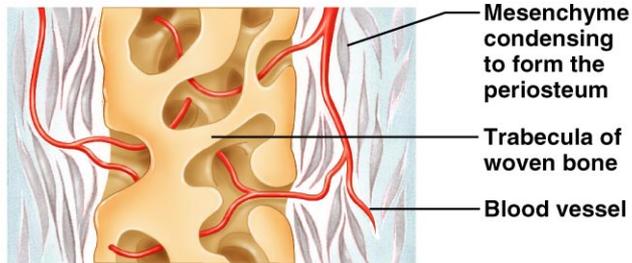


② **Bone matrix (osteoid) is secreted within the fibrous membrane.**

- Osteoblasts begin to secrete osteoid, which is mineralized within a few days.
- Trapped osteoblasts become osteocytes.

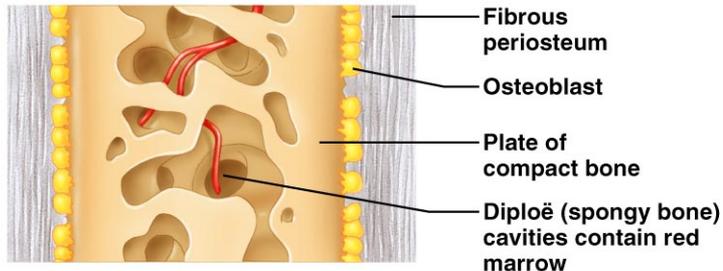
- Mesenchymal osteoprogenitor cells aggregate:
  - differentiate into osteoblasts (ossification center)
  - Osteoblasts secrete organic matrix (what is that?)
  - develop projections of trabeculae

# Intramembranous Ossification:



## ③ Woven bone and periosteum form.

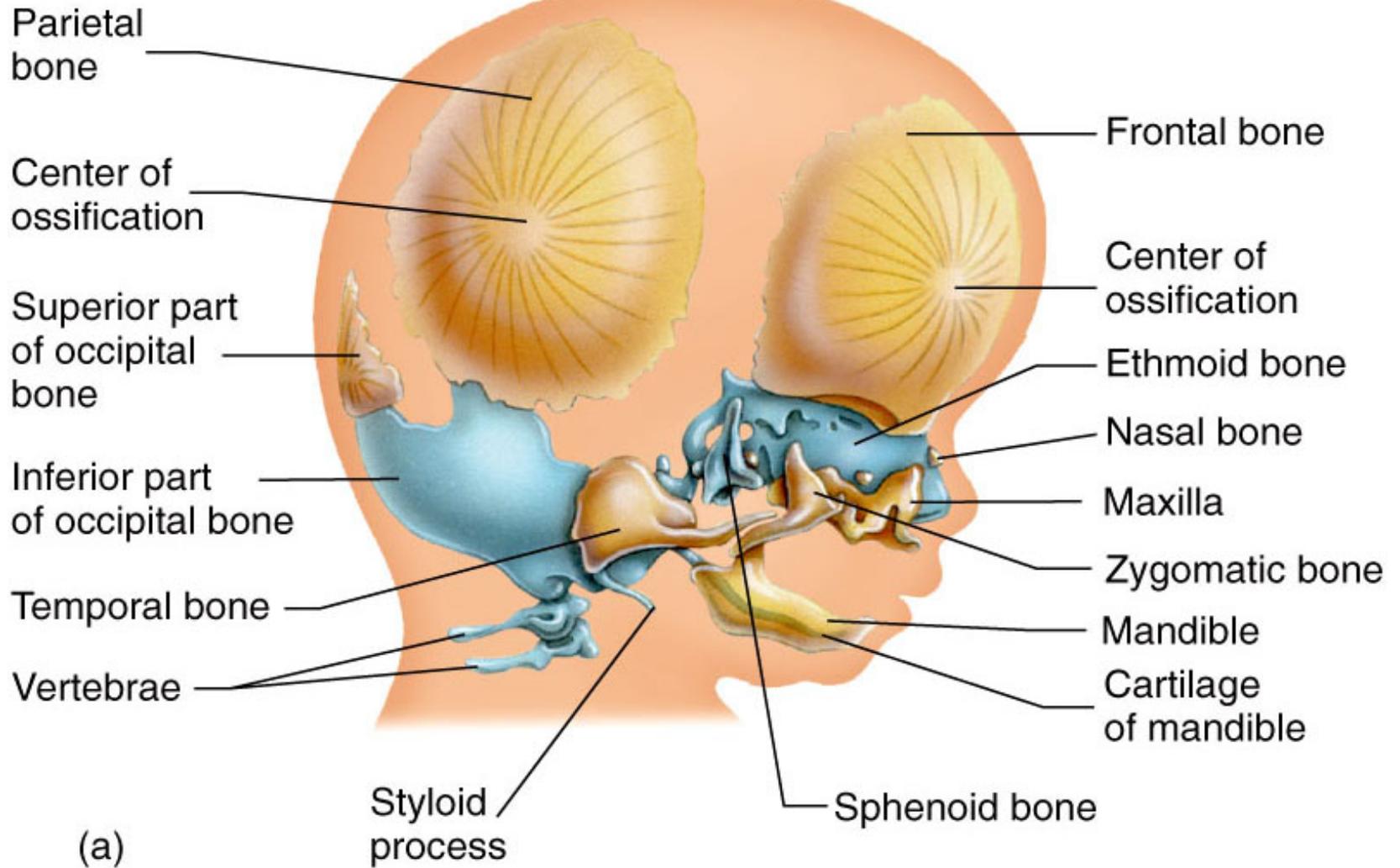
- Accumulating osteoid is laid down between embryonic blood vessels, which form a random network. The result is a network (instead of lamellae) of trabeculae.
- Vascularized mesenchyme condenses on the external face of the woven bone and becomes the periosteum.



## ④ Bone collar of compact bone forms and red marrow appears.

- Trabeculae just deep to the periosteum thicken, forming a woven bone collar that is later replaced with mature lamellar bone.
- Spongy bone (diploë), consisting of distinct trabeculae, persists internally and its vascular tissue becomes red marrow.

- Blood vessels invade area; supply osteoblasts with nutrients
- Trabeculae connect:
  - trap blood vessels inside bone
- Resulting spongy bone is remodeled into:
  - osteons of compact bone
  - periosteum
  - or marrow cavities



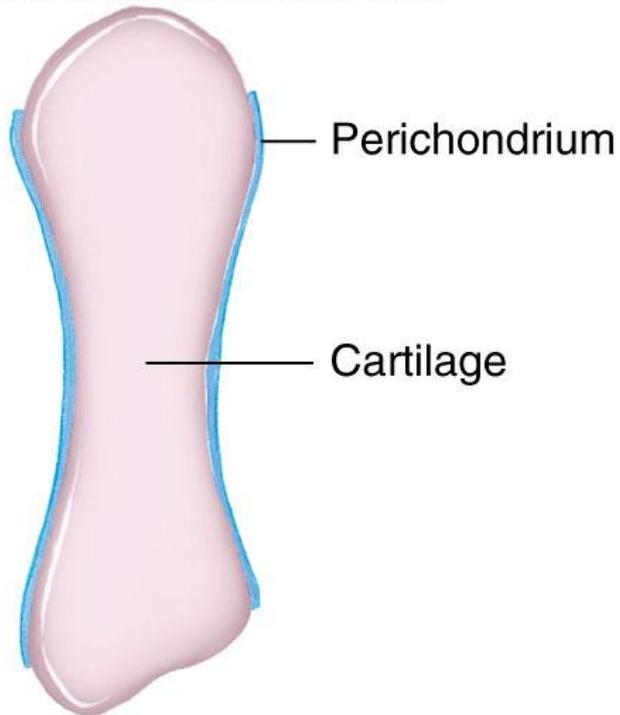
***How does bone form and grow?***

# Endochondral Ossification

- Growth and ossification of long bones
- Begins with *hyaline cartilage model*
- Proceeds via expansion of cartilage matrix (**interstitial growth**) and production of new cartilage at outer surface (**appositional growth**).

# Endochondral Ossification

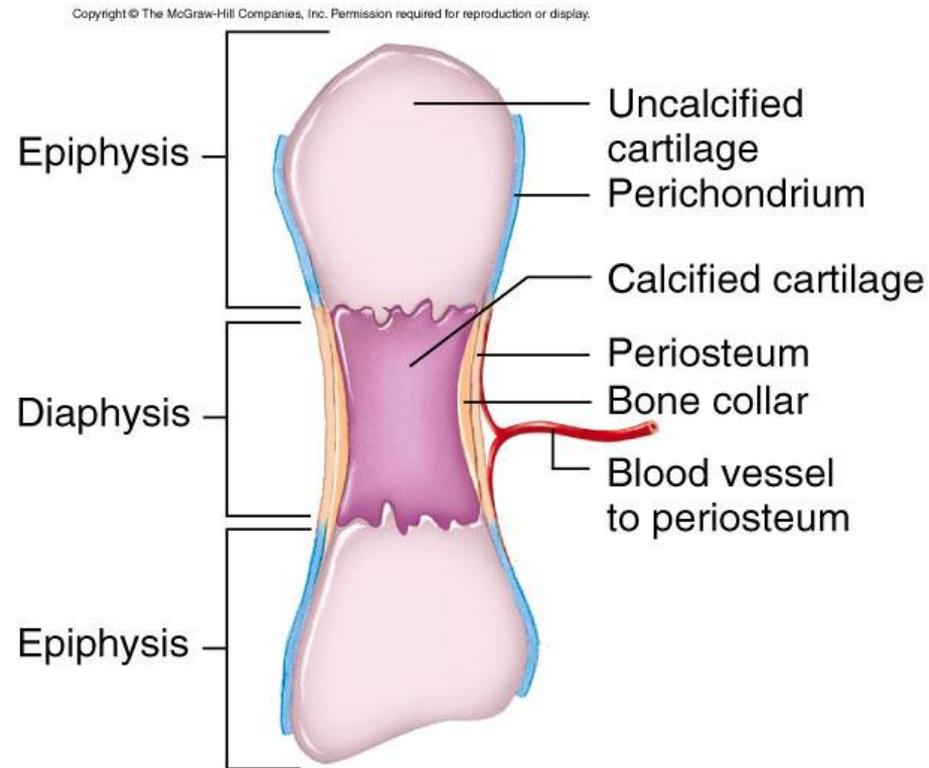
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- **Chondrocytes** in the center of hyaline cartilage:
  - enlarge
  - form struts & calcify
  - die, leaving cavities in cartilage

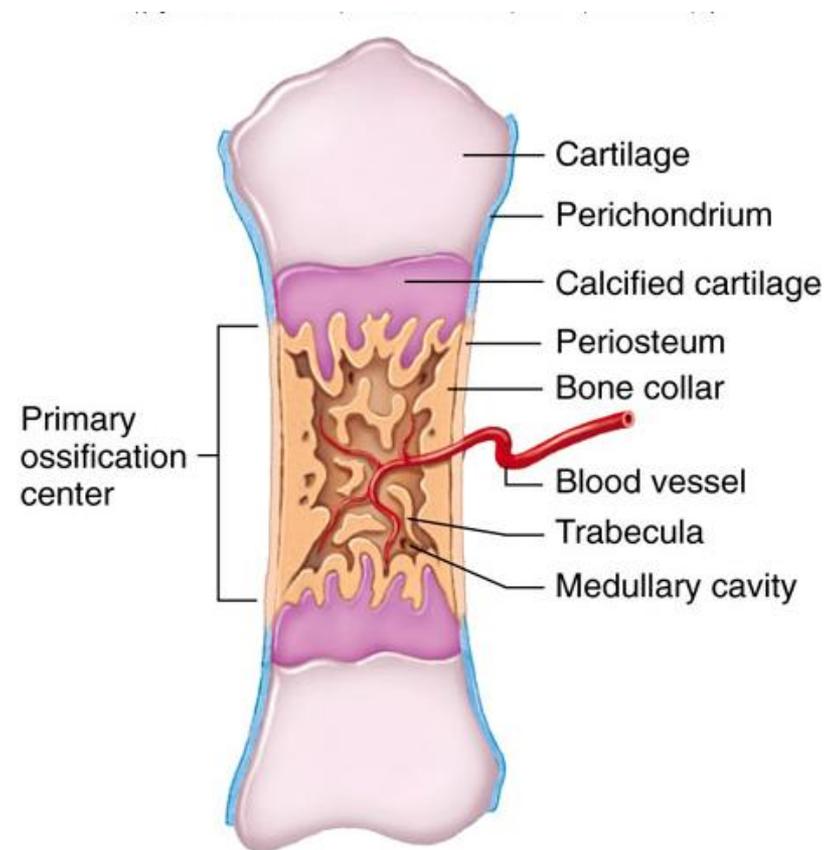
# Endochondral Ossification

- Blood vessels surround edges of cartilage
- Fibroblasts of perichondrium become osteoblasts:
  - Produce layer of superficial bone around shaft
  - Eventually becomes compact bone (appositional growth)



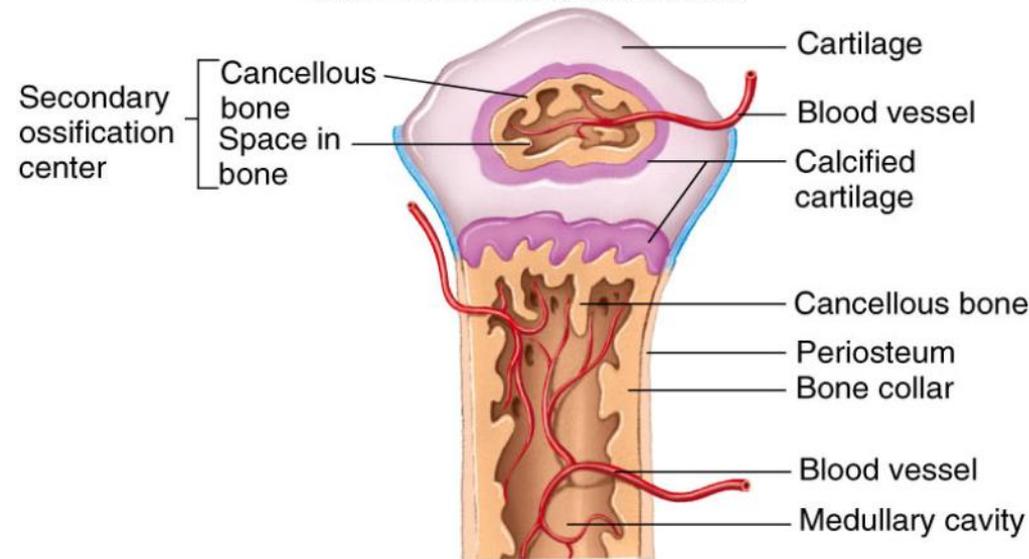
# Endochondral Ossification

- Blood vessels enter the cartilage:
  - bring fibroblasts that become osteoblasts
  - spongy bone develops at the **primary ossification center**



# Endochondral Ossification:

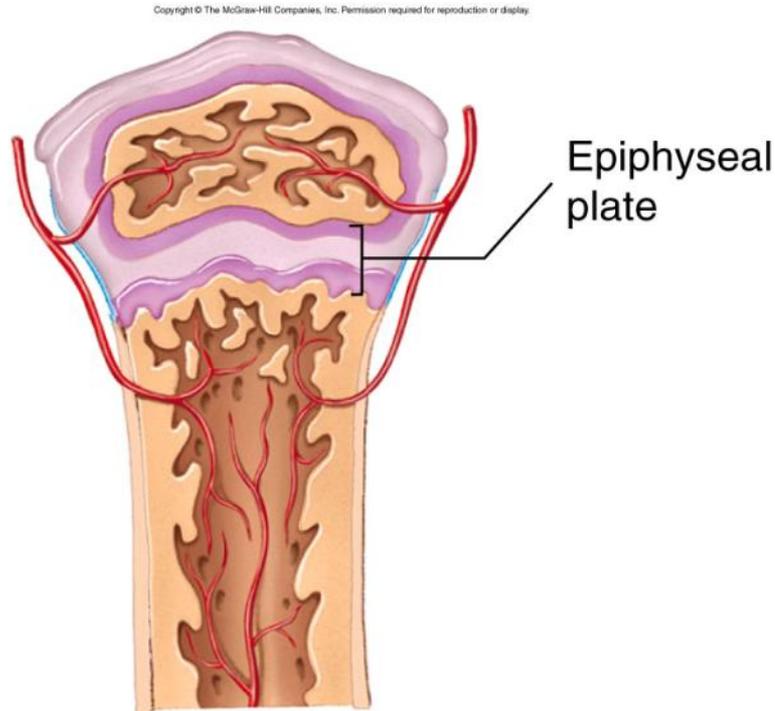
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- Remodeling creates a **marrow cavity**:
  - bone replaces cartilage at the **metaphyses**
- Capillaries and osteoblasts enter the epiphyses:
  - create **secondary ossification centers**

4. Secondary ossification centers form in the epiphyses of long bones.

# Endochondral Ossification:



- Epiphyses fill with spongy bone:
  - cartilage within joint cavity is **articular cartilage**
  - cartilage at metaphysis is **epiphyseal cartilage**

(a)

# Bones Grow via E.O.

1. New cartilage produced on epiphyseal side of plate
2. Chondrocytes mature & enlarge
3. Matrix calcifies; chondrocytes die
4. Cartilage on diaphyseal side replaced by bone

