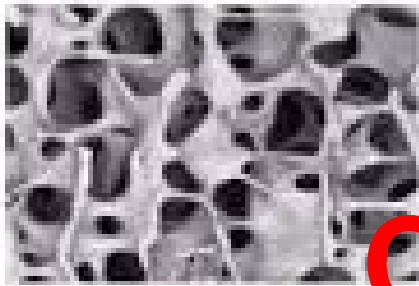
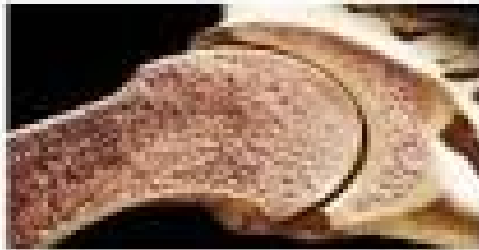


# Bone Tissue



## CHAPTER 6



# Functions of Bone and the Skeletal System

- Support
- Protection
- Assistance in movement
- Mineral storage and release
- Blood cell production
- Triglyceride storage

# Functions of Bone and the Skeletal System

- **1. Support.**
- Body's structural framework: supports soft tissue, provides attachment for tendons of most skeletal muscles.
- **2. Protection.**
- protects most important internal organs from injury. (cranial bones protect the brain, vertebrae (backbones) protect the spinal cord, rib cage protects heart and lungs.
- **3. Assistance in movement.**
- Most skeletal muscles attach to bones; when they contract, they pull on bone to produce movement.
- **4. Mineral storage and release.**
- Bone tissue makes up about **18 percent of the weight of the human body** and stores several minerals, especially **calcium (99% of total body) and phosphorus**, which contribute to the strength of bone. On demand, bone releases minerals into the blood to maintain critical mineral balances and to distribute the minerals to other parts of the body.

# Functions of Bone and the Skeletal System

- **5. Blood cell production.**
- Within certain bones, a connective tissue called **red bone marrow**
  - **Red bone marrow** produces red blood cells, white blood cells, and platelets in a process called **hemopoiesis/hematopoiesis**
    - consists of developing blood cells, adipocytes, fibroblasts, and macrophages within a network of reticular fibers.
    - present in developing bones of the fetus and in some adult bones (pelvic bones, ribs, sternum, vertebrae, skull, and ends of the humerus and femur.
    - *Newborn*: all bone marrow is red and is involved in hemopoiesis.
    - *Adult*: much of the bone marrow changes from red to yellow.
- **6. Triglyceride storage.**
  - **Yellow bone marrow** consists mainly of adipose cells, which store triglycerides. The stored triglycerides are a potential chemical energy reserve

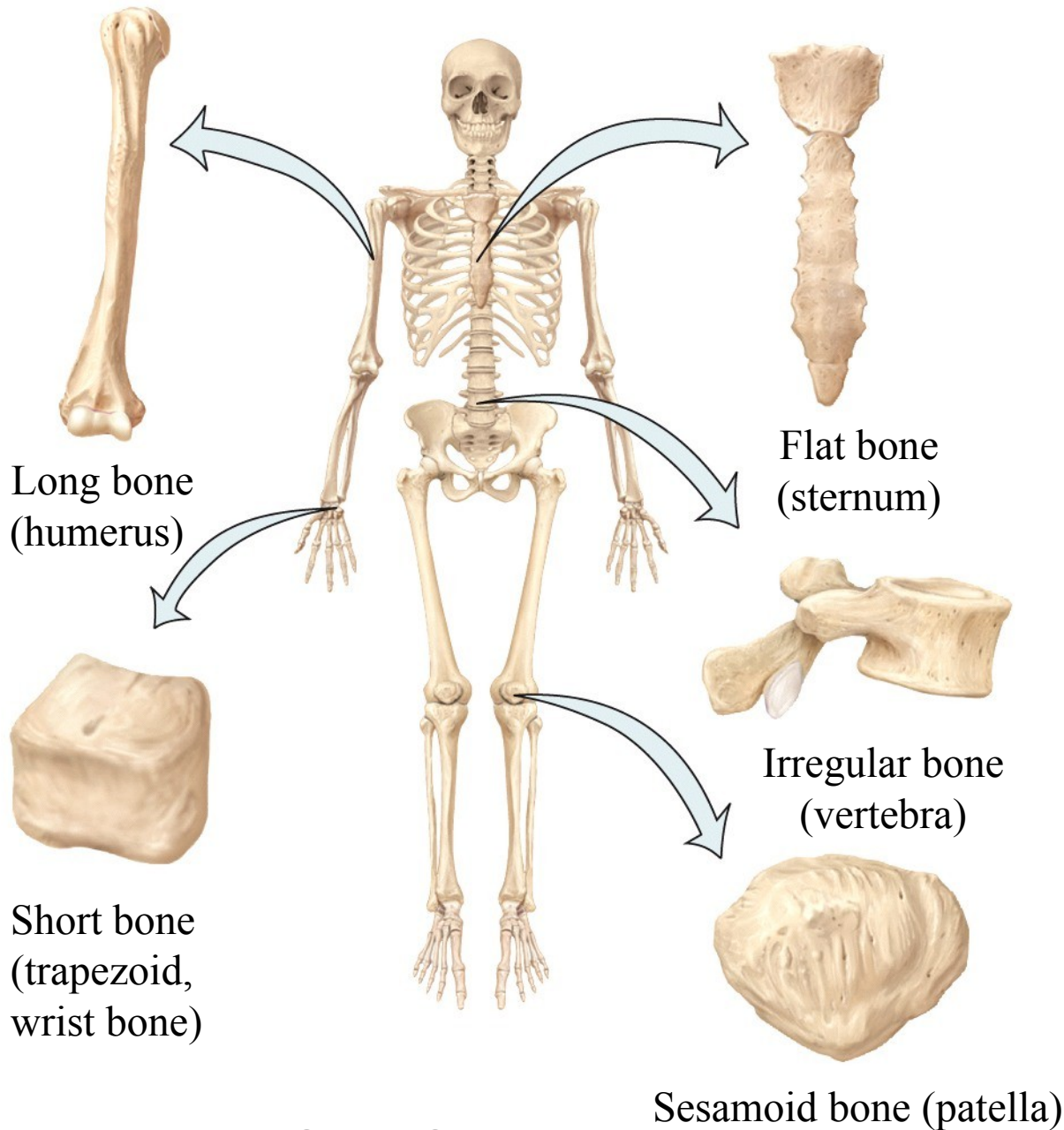
# Anatomy Overview:

- Bone Structure and Tissues

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# 5 Types of Bones

**206 individual bones in an adult skeleton come in a variety of sizes and shapes range in size from the small ear bones in the skull to the nearly two-foot-long femur of an adult**

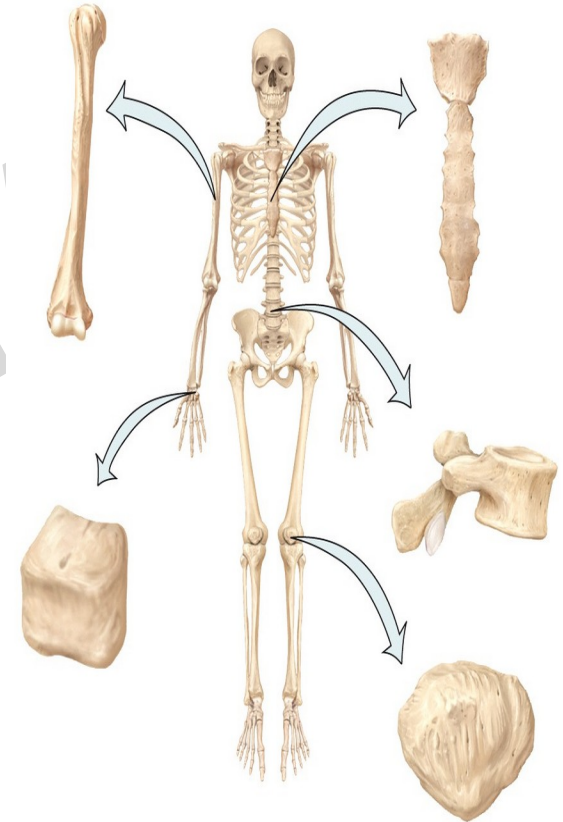


# Types of Bones

- Long bones
- Short bones
- Flat bones
- Irregular bones
- Sesamoid bones

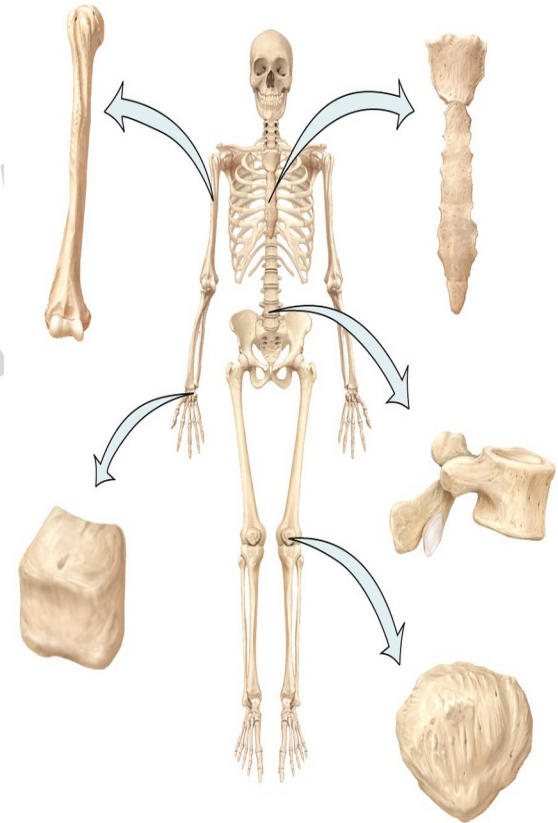
# Types of Bones

- **Long bones:** humerus, ulna and radius, femur, tibia and fibula, metacarpals, metatarsals, and phalanges
- greater length than width, tubular design provides maximum strength with minimum weight
- consist of a *diaphysis* (shaft) and a variable number of *epiphyses* or extremities (ends)
- are slightly curved for strength.
- consist mostly of *compact bone tissue*
- **Short bone:** most carpal (wrist) bones and most tarsal (ankle) bones.
- cube-shaped and nearly equal in length, width, and depth
- consist of spongy bone except at the surface, where there is a thin layer of compact bone



# Types of Bones

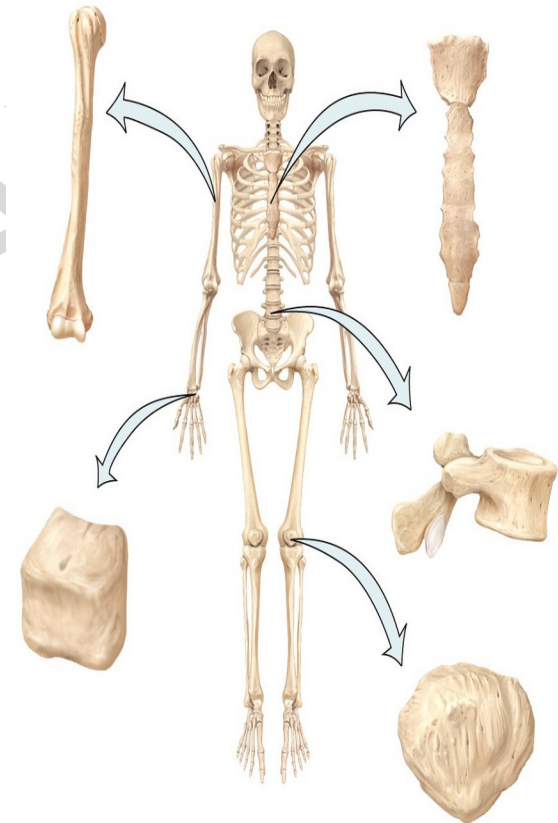
- **Flat bones:** cranial, which protect the brain; sternum and ribs, which protect organs in the thorax; and the scapulae
- generally thin
- composed of two nearly parallel plates of compact bone (external and internal *tables*) enclosing a layer of spongy bone (cranial -spongy bone = **diploë** (DIP-lō-ē))
- afford considerable protection and provide extensive areas for muscle attachment
- **Irregular bones:** vertebrae, certain facial bones, and calcaneus
- have complex shapes and cannot be grouped into other categories
- vary in the amounts of spongy and compact bone they contain
- **Not classified by shape, but rather by location:**
- **Sutural bones** *wormian bones (named after a Danish anatomist, O. Worm, who lived from 1588 to 1654)*
- are small bones located within the sutures (joints) of certain cranial bones (see Figure 7.5a).
- number varies greatly from person to person



# Types of Bones

## Sesamoid bones

- develop in certain tendons where there is considerable friction, compression, and physical stress. Functionally, protect tendons from excessive wear and tear, and they can alter the direction of pull of a tendon, which improves the mechanical advantage at a joint.
- not always completely ossified and measure only a few millimeters to centimeters in diameter except for the two patellae (largest sesamoid bones)
- vary in number from person to person except for the patellae, which are located in the quadriceps femoris tendon (normally present in all individuals). In the upper limbs, sesamoid bones usually occur only in the joints of the palmar surface of the hands.
- Two common = tendons of the adductor pollicis and flexor pollicis brevis muscles at the metacarpophalangeal joint of the thumb
- In the lower limbs, there are two constant sesamoid bones in addition to the patellae; these occur on the plantar surface of each foot in the tendons of the flexor hallucis brevis muscle at the metatarsophalangeal joint of the great (big) toe



# Anatomy of a Bone

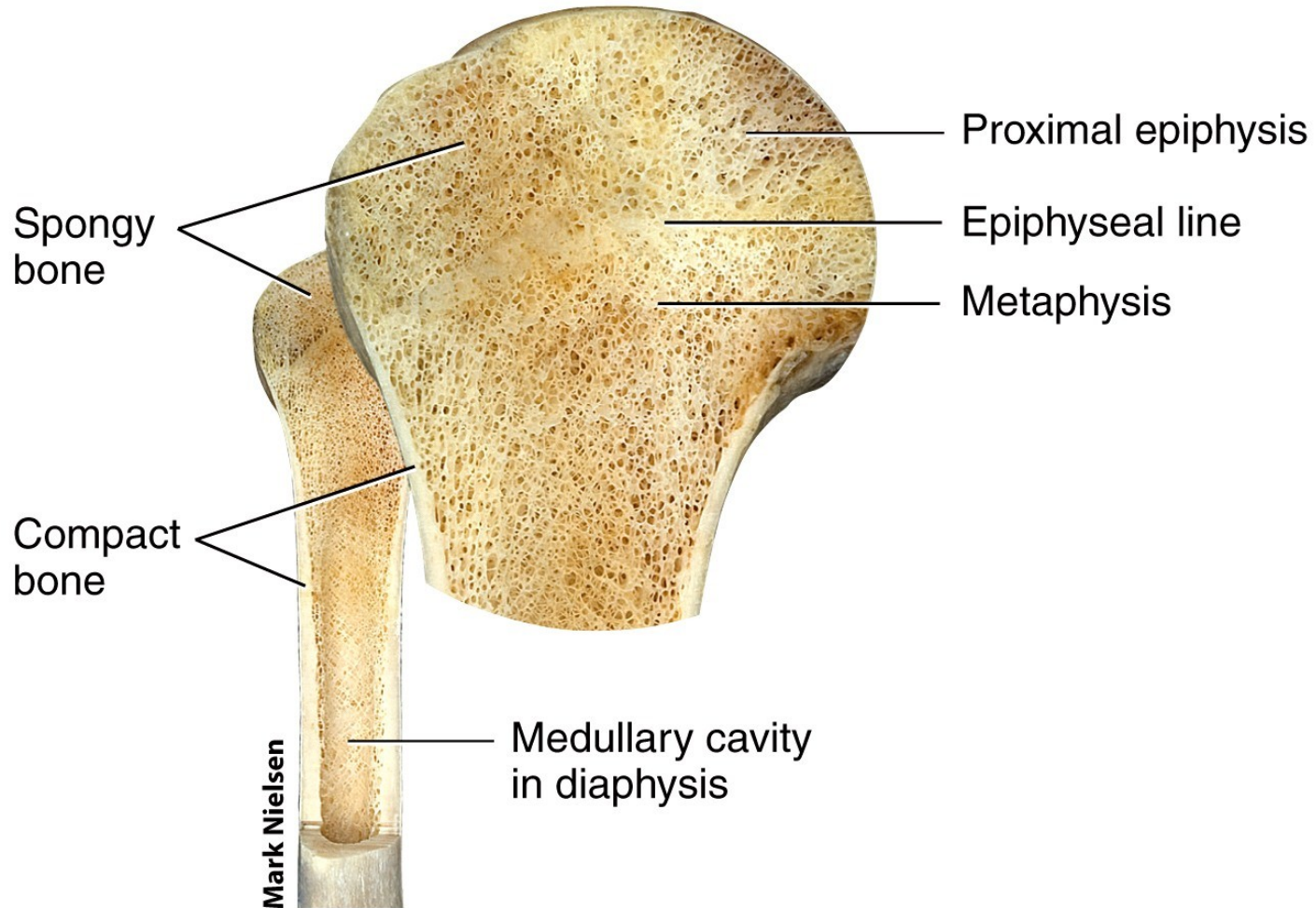
- Diaphysis
- Epiphyses
- Metaphysis
- Articular cartilage
- Periosteum
- Medullary cavity
- Endosteum

# Anatomy Overview:

- Bone Structure and Tissues

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# Anatomy of a Long Bone



(b) Partially sectioned humerus

# Anatomy of a Long Bone

**Diaphysis** bone's shaft, or body—the long, cylindrical, main portion of the bone

**Epiphyses** or *extremities* are the proximal and distal ends of the bone.

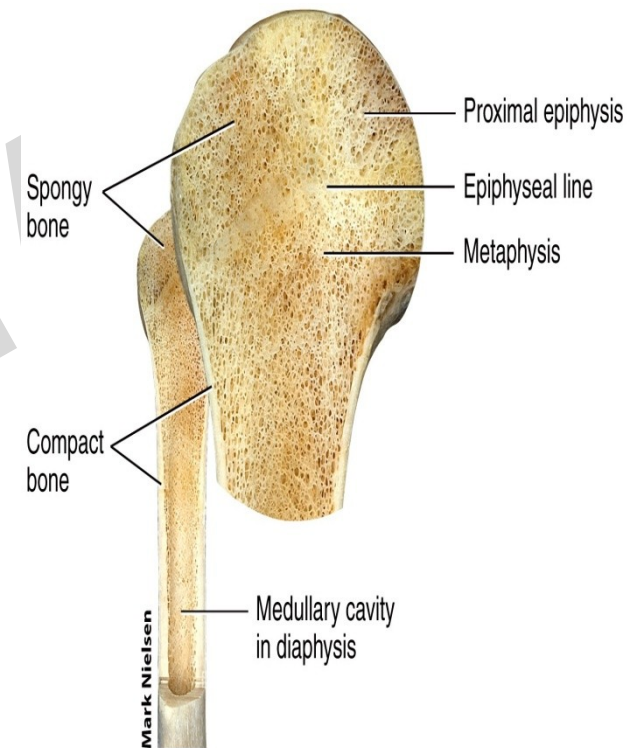
## **Metaphyses**

regions between the diaphysis and the epiphyses.

- In *growing bone*, each metaphysis contains an **epiphyseal (growth) plate** a layer of hyalin cartilage that allows the diaphysis of the bone to grow in length. When bone growth in length stops somewhere between the **ages of 14 and 24**, the cartilage in the epiphyseal plate is replaced by bone and the resulting bony structure is known as the **epiphyseal medullary cavity/marrow cavity**

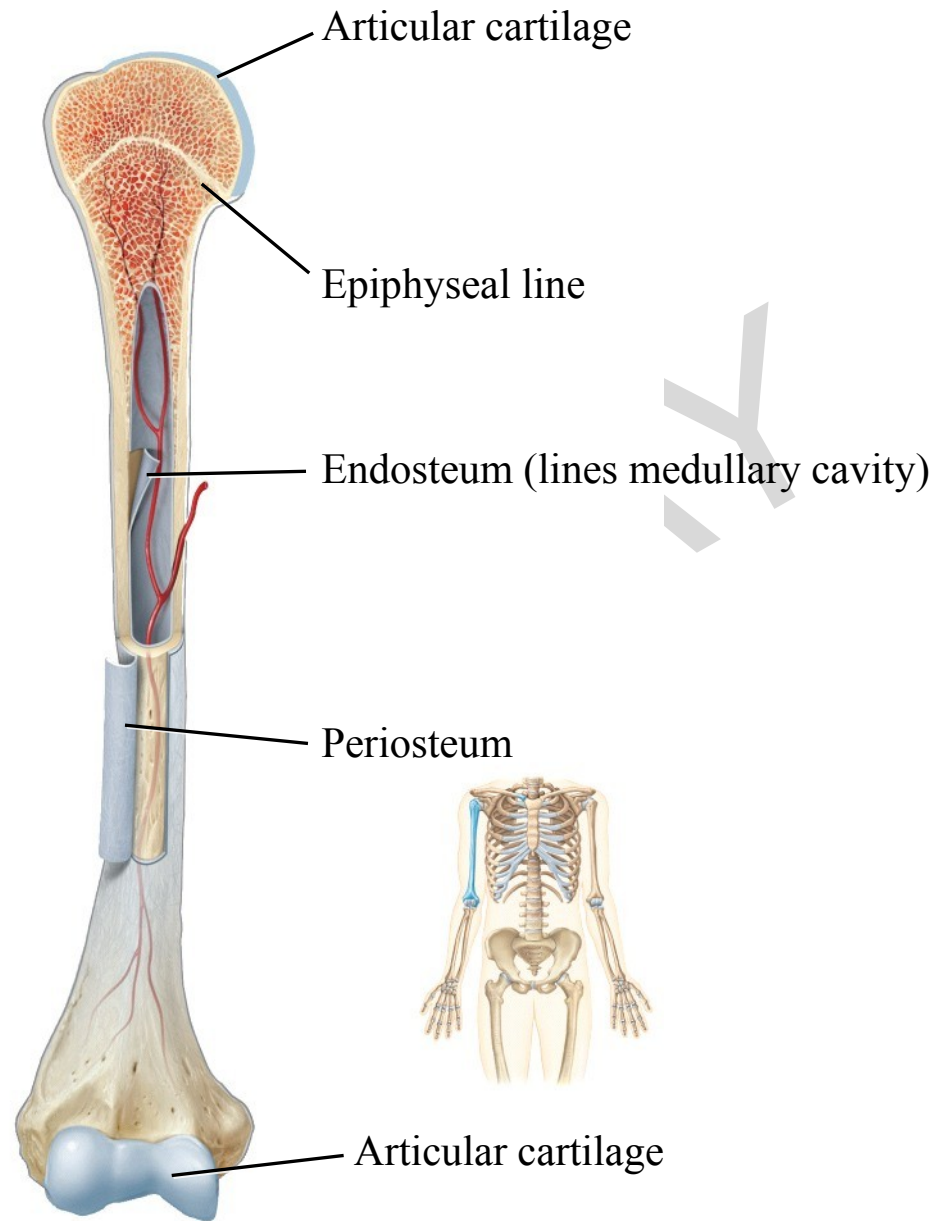
- hollow, cylindrical space within the diaphysis that contains fatty yellow bone marrow and numerous blood vessels in adults

- minimizes the weight of the bone by reducing the dense bony material where it is least needed. The long bones' tubular design provides maximum strength with minimum weight



(b) Partially sectioned humerus

# Anatomy of a Long Bone



(a) Partially sectioned humerus (arm bone)

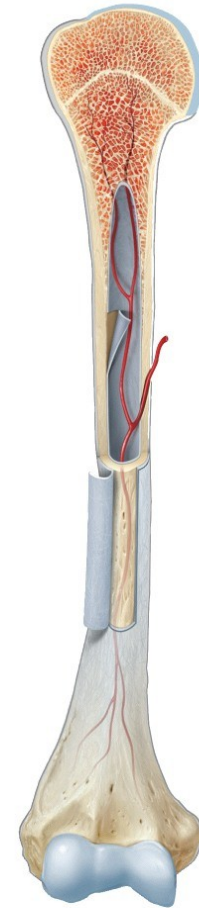
A long bone is covered by articular cartilage at the articular surfaces of its proximal and distal epiphyses and by periosteum around all other parts of the bone.

### **Articular cartilage**

thin layer of hyalin cartilage covering the part of the epiphysis where the bone forms an articulation (joint) with another bone  
reduces friction and absorbs shock at freely movable joints  
lacks a perichondrium and lacks blood vessels, repair of damage is limited

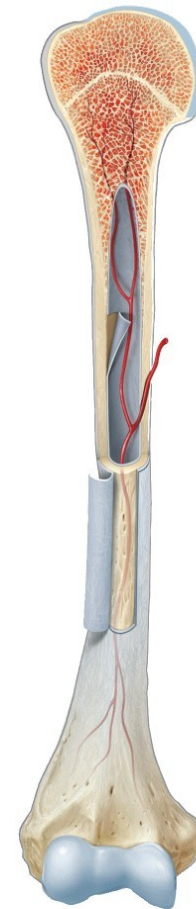
### **Periosteum**

tough connective tissue sheath and its associated blood supply that surrounds the bone surface wherever it is not covered by articular cartilage  
•composed of:



- *outer fibrous layer* of dense irregular connective tissue
- *inner osteogenic layer* of cells. Some cells enable bone to grow in thickness, but not in length.
- protects the bone, assists in fracture repair, helps nourish bone tissue, and serves as an attachment point for ligaments and tendons
- is attached to the underlying bone by **perforating (Sharpey's) fibers**, thick bundles of collagen that extend from the periosteum into the bone extracellular matrix.

**endosteum** (end-OS-tē-um; *endo*=within) is a thin membrane that lines the medullary cavity. It contains a single layer of bone-forming cells and a small amount of connective tissue.



Long bones are the only bones with a diaphysis and a medullary cavity.

Each of the other bone types—short, flat, irregular, and sesamoid—have designs that closely resemble the epiphysis of a long bone.

They have outer plates of compact bone covering an inner core of spongy bone.

# Bone Surface Markings

Are structural features adapted for specific functions.

- most not present at birth
- develop later in response to certain forces, most prominent during adulthood

- Two major types of surface markings:

- 

- (1) ***depressions and openings***

- form joints

- allow the passage of soft tissues (such as blood vessels and nerves)

- (2) ***processes***, projections or outgrowths that either

- form joints

- serve as attachment points for connective tissue (such as ligaments and tendons).

# Bone Surface Markings

- Depressions and openings
  - **Fossa:** Shallow depression
  - **Sulcus:** Furrow along a bone surface that accommodates a blood vessel, nerve, or tendon
  - **Fissure:** Narrow slit between adjacent parts of bones through which blood vessels or nerves pass
  - **Foramen:** Opening through which blood vessels, nerves, or ligaments pass
  - **Meatus:** Tubelike opening

# Bone Surface Markings

- Processes that form joints
  - **Condyle:** Large, round protuberance with a smooth articular surface at the end of a bone
  - **Facet:** Smooth, flat, slightly concave or convex articular surface
  - **Head :** Usually rounded articular projection supported on the neck (constricted portion) of a bone

# Bone Surface Markings

- Processes that form attachment points for connective tissues
  - **Crest:** Prominent ridge or elongated projection
  - **Epicondyle:** Typically roughened projection above a condyle
  - **Line:** Long, narrow ridge or border (less prominent than a crest)
  - **Spinous process:** Sharp, slender projection
  - **Trochanter:** Very large projection
  - **Tubercle:** Variable sized rounded projection
  - **Tuberosity :** Variable sized projection that has a rough, bumpy surface

TABLE 6.1

## Bone Surface Markings

| MARKING                                                                                                                                        | DESCRIPTION                                                                                | EXAMPLE                                                                          |
|------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| <b>DEPRESSIONS AND OPENINGS: Sites allowing the passage of soft tissue (nerves, blood vessels, ligaments, tendons) or formation of joints</b>  |                                                                                            |                                                                                  |
| <b>Fissure</b> (FISH-ur)                                                                                                                       | Narrow slit between adjacent parts of bones through which blood vessels or nerves pass     | Superior orbital fissure of the sphenoid bone (Figure 7.6f and 7.10b)            |
| <b>Foramen</b> (fō-RĀ-men=hole; plural is <i>foramina</i> )                                                                                    | Opening through which blood vessels, nerves, or ligaments pass                             | Optic foramen (canal) of the sphenoid bone (Figure 7.6f and 7.10b)               |
| <b>Fossa</b> (FOS-a=trench; plural is <i>fossae</i> , FOS-ē)                                                                                   | Shallow depression ( <i>fossa</i> =trench)                                                 | Coronoid fossa of the humerus (Figure 8.4a)                                      |
| <b>Sulcus</b> (SUL-kus=groove; plural is <i>sulci</i> , SUL-sī)                                                                                | Furrow along a bone surface that accommodates a blood vessel, nerve, or tendon             | Intertubercular sulcus (groove) of the humerus (Figure 8.4a)                     |
| <b>Meatus</b> (mē-Ā-tus=passageway; plural is <i>meati</i> , me-Ā-tī)                                                                          | Tubelike opening                                                                           | External and internal auditory meati of the temporal bone (Figure 7.3c and 7.4a) |
| <b>PROCESSES: Projections or outgrowths on bone that form joints or attachment points for connective tissue, such as ligaments and tendons</b> |                                                                                            |                                                                                  |
| <i>Processes that form joints:</i>                                                                                                             |                                                                                            |                                                                                  |
| <b>Condyle</b> (KON-dil; <i>condylus</i> =knuckle)                                                                                             | Large, round protuberance with a smooth articular surface at the end of a bone             | Lateral condyle of the femur (Figure 8.11a)                                      |
| <b>Facet</b> (FAS-et or fa-SET)                                                                                                                | Smooth, flat, slightly concave or convex articular surface                                 | Superior articular facet of a vertebra (Figure 7.16a)                            |
| <b>Head</b>                                                                                                                                    | Usually rounded articular projection supported on the neck (constricted portion) of a bone | Head of the femur (Figure 8.11a)                                                 |
| <i>Processes that form attachment points for connective tissue:</i>                                                                            |                                                                                            |                                                                                  |
| <b>Crest</b>                                                                                                                                   | Prominent ridge or elongated projection                                                    | Iliac crest of the hip bone (Figure 8.9b)                                        |
| <b>Epicondyle</b> ( <i>epi</i> =above)                                                                                                         | Typically roughened projection above a condyle                                             | Medial epicondyle of the femur (Figure 8.11a)                                    |
| <b>Line</b>                                                                                                                                    | Long, narrow ridge or border (less prominent than a crest)                                 | Linea aspera of the femur (Figure 8.11b)                                         |
| <b>Spinous process</b>                                                                                                                         | Sharp, slender projection                                                                  | Spinous process of a vertebra (Figure 7.16a)                                     |
| <b>Trochanter</b> (trō-KAN-ter)                                                                                                                | Very large projection                                                                      | Greater trochanter of the femur (Figure 8.11a)                                   |
| <b>Tubercle</b> (TOO-ber-kul; <i>tuber</i> =knob)                                                                                              | Variable sized rounded projection                                                          | Greater tubercle of the humerus (Figure 8.4a)                                    |
| <b>Tuberosity</b>                                                                                                                              | Variable sized projection that has a rough, bumpy surface                                  | Ischial tuberosity of the hip bone (Figure 8.9b)                                 |

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# Animation:

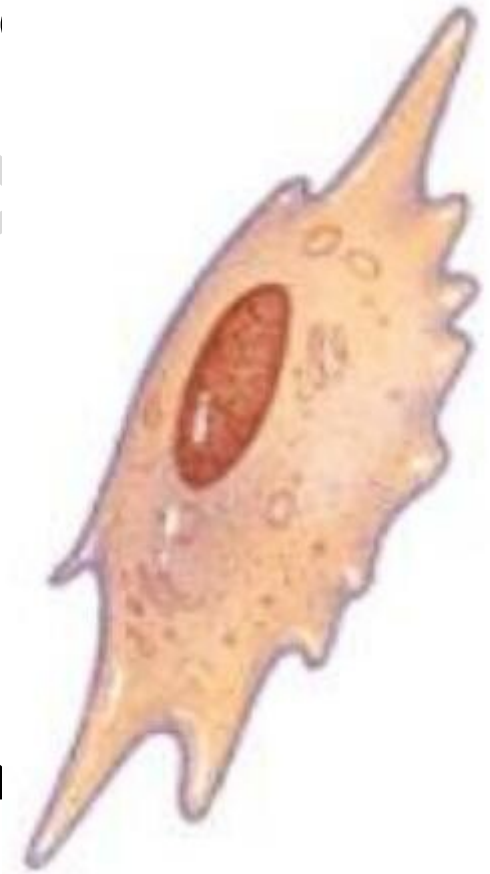
- Bone Dynamics and Tissue

# Histology of Bone

- Osteogenic cells
- Osteoblasts
- Osteocytes
- Osteoclasts

# Osteogenic/Osteoprogenitor cells

- unspecialized bone stem cells derive from mesenchyme, the tissue from which almost all connective tissues are formed.
- only bone cells to undergo cell division; the resulting cells develop into osteoblasts.
- found along the inner portion of the periosteum, in the endosteum, and in the canals within bone that contain blood vessels.



# Osteoblasts

- bone-building cells
- synthesize and secrete collagen fibers and other organic components needed to build the extracellular matrix of bone tissue
- initiate calcification (as osteoblasts surround themselves with extracellular matrix, they become trapped in their secretions and become osteocytes)



# Osteocytes

- mature bone cells
- main cells in bone tissue and maintain its daily metabolism, such as the exchange of nutrients and wastes with the blood
- osteocytes do not undergo cell division.



# Osteoclasts

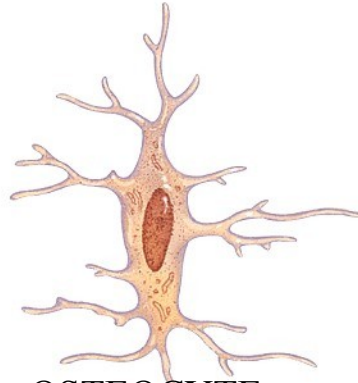
- huge cells derived from the fusion of as many as 50 monocytes (a type of white blood cell)
- found concentrated in the endosteum
- plasma membrane is deeply folded into a *ruffled border* on the side of the cell that faces the bone surface: RESORPTION
- help regulate blood calcium level in response to certain hormones
- target cells for drug therapy used to treat osteoporosis
- **Resorption:**
- cell releases powerful lysosomal enzymes and acids that digest the protein and mineral components of the underlying extracellular matrix of bone.
- is part of the normal development, growth, maintenance, and repair of bone.



# Types of Cells in Bone Tissue

From bone cell lineage

From white blood cell lineage



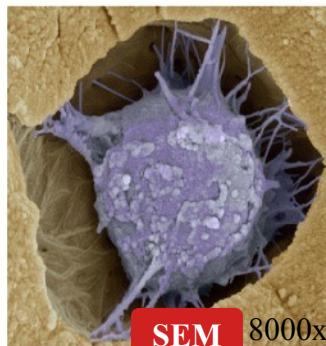
Ruffled border

**OSTEOPROGENITOR CELL** (develops into an osteoblast)

**OSTEOBLAST** (forms bone extracellular matrix)

**OSTEOCYTE** (maintains bone tissue)

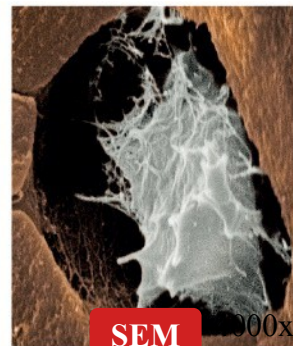
**OSTEOCLAST** (functions in resorption, the breakdown of bone extracellular matrix)



**SEM**

8000x

Steve Gschmeissner/  
Science Source Images



**SEM**

1000x

SPL/Science Source/Photo  
Researchers, Inc.



**SEM**

2700x

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# Animation:

- Bone Dynamics and Tissue

# Histology of Compact Bone

- Osteons
  - Central canal
  - Concentric lamellae
  - Lacunae
  - Canaliculi

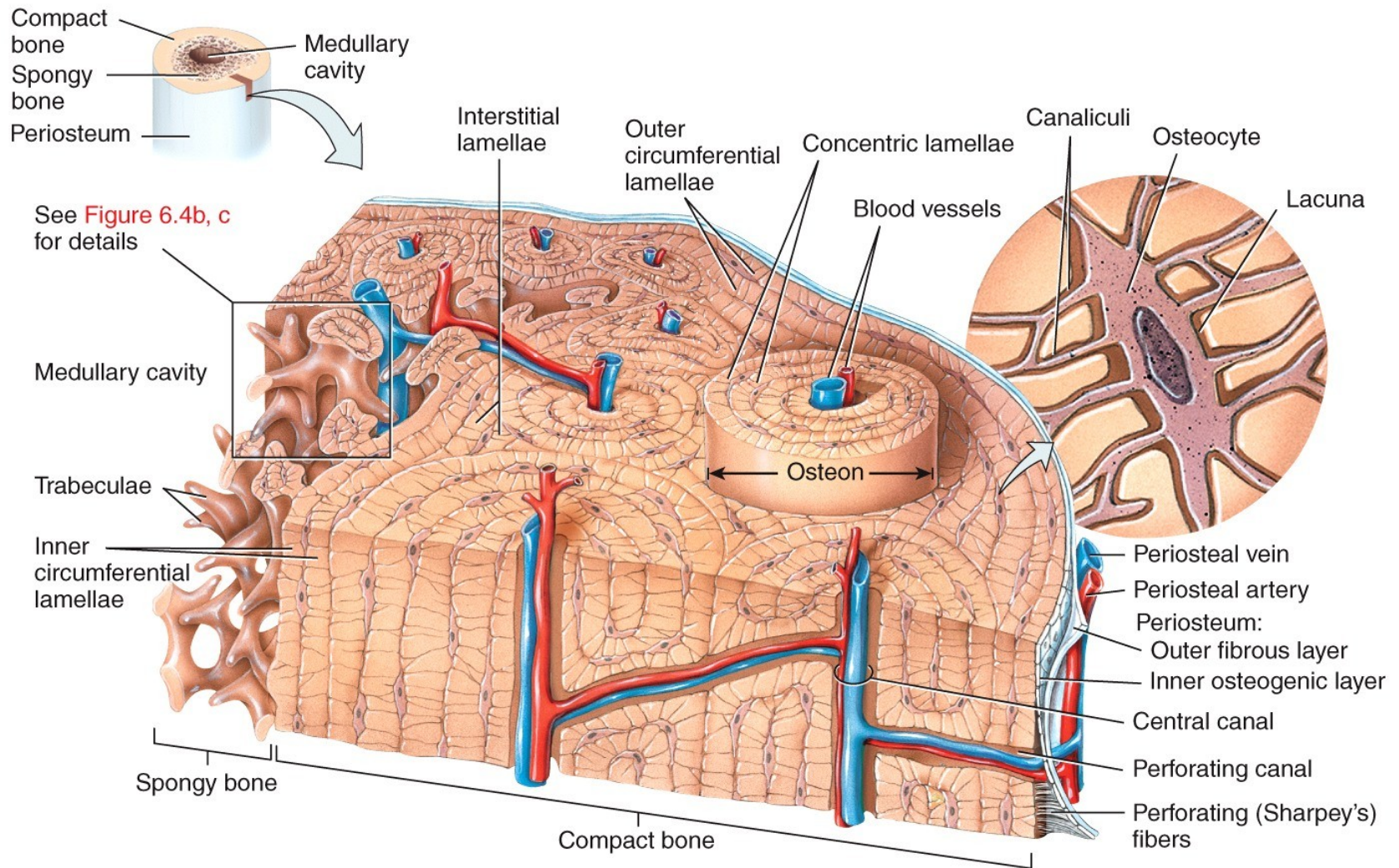
# Histology of Compact Bone

- **Compact bone / cortical / dense bone**
- surface of a bone, but it also can extend deeper into the bone tissue
- makes up the bulk of the diaphyses of long bones
- compact bone is quite porous, with an abundance of microscopic spaces and canals
- provides protection and support and resists the stresses produced by weight and movement
- are aligned in the same direction and are parallel to the length of the diaphysis. As a result, the shaft of a long bone resists bending or fracturing even when considerable force is applied from either end. Compact bone tissue tends to be thickest in those parts of a bone where stresses are applied in relatively few directions. The lines of stress in a bone are not static. They change as a person learns to walk and in response to repeated strenuous physical activity, such as weight training. The lines of stress in a bone also can change because of fractures or physical deformity. Thus, the organization of osteons is not static but changes over time in response to the physical demands placed on the skeleton.

# Histology of Compact Bone

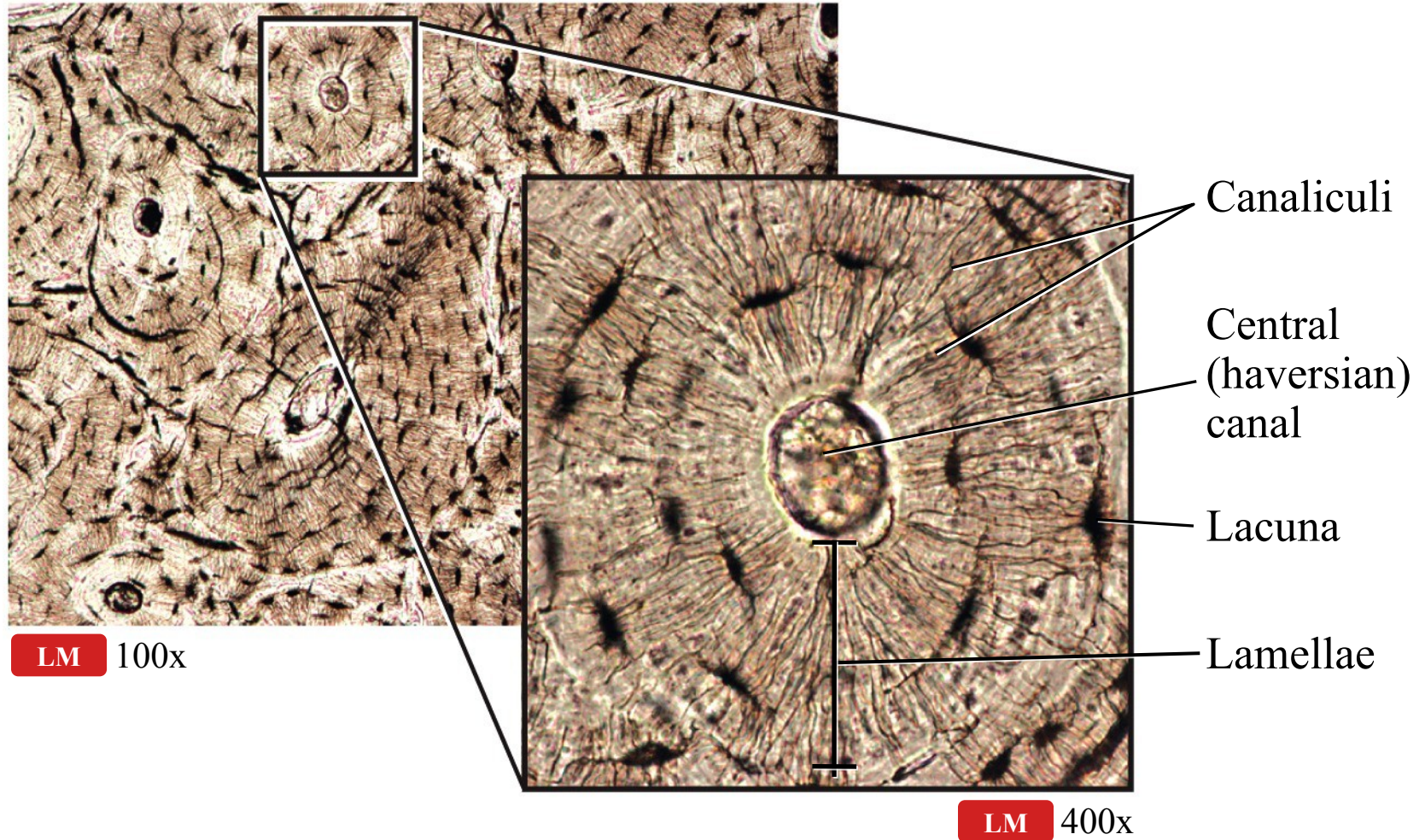
- **COMPOSED OF osteons**, or **haversian systems**
- consists of concentric lamellae arranged around a **central (haversian) canal**.
- Resembling the growth rings of a tree, the **concentric lamellae** are circular plates of mineralized extracellular matrix of increasing diameter, surrounding a small network of blood vessels and nerves located in the central canal
- These tube-like units of bone generally form a series of parallel cylinders that, in long bones, tend to run parallel to the long axis of the bone.
- Between the concentric lamellae are small spaces called **lacunae** which contain osteocytes.
- Radiating in all directions from the lacunae are tiny **canaliculi** (small channels), which are filled with extracellular fluid. Inside the canaliculi are slender fingerlike processes of osteocytes
- Neighboring osteocytes communicate via gap junctions
- The canaliculi connect lacunae with one another and with the central canals, forming an intricate, miniature system of interconnected canals throughout the bone. This system provides many routes for nutrients and oxygen to reach the osteocytes and for the removal of wastes.

# Histology of Compact Bone



(a) Osteons (haversian systems) in compact bone and trabeculae in spongy bone

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(d) Sectional view of several osteons (haversian systems) of femur (thigh bone) and details of one osteon

# Histology of Compact Bone

- **Interstitial lamellae:** The areas between neighboring osteons contain lamellae called interstitial lamellae which also have lacunae with osteocytes and canaliculi. Interstitial lamellae are fragments of older osteons that have been partially destroyed during bone rebuilding or growth.
- **Circumferential lamellae:**
  - Outer circumferential lamellae
    - Sharpey's fibers
  - Inner circumferential lamellae

# Histology of Compact Bone

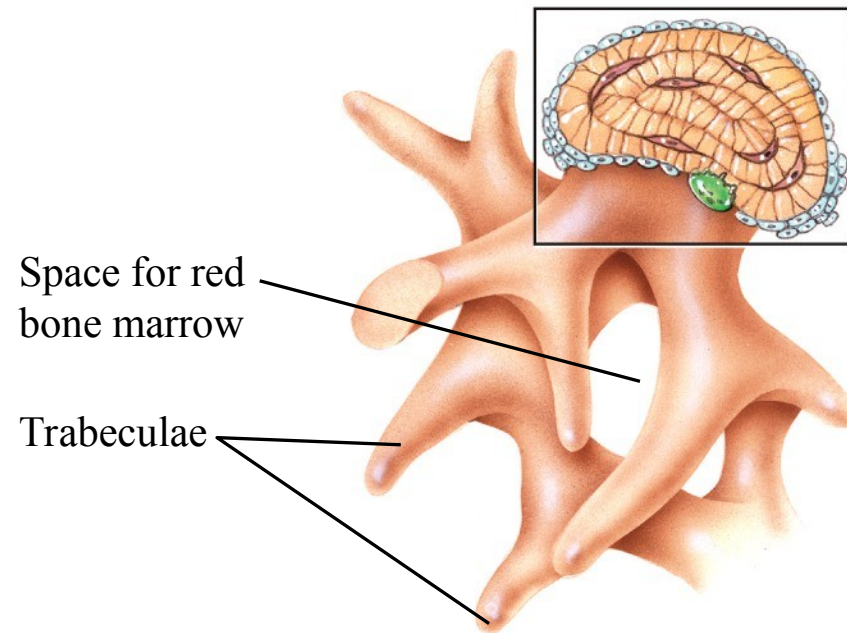
- Arranged around the entire outer and inner circumference of the shaft of a long bone are lamellae called **circumferential lamellae**
- They develop during initial bone formation.
- The circumferential lamellae directly deep to the periosteum are called *outer circumferential lamellae*. They are connected to the periosteum by **perforating fibers** or **Sharpey's fibers**.
- The circumferential lamellae that line the medullary cavity are called *inner circumferential lamellae*
- **Blood vessels and nerves** from the periosteum penetrate the compact bone through transverse **perforating canals** or *Volkman canals* (FOLK-man).
- The vessels and nerves of the perforating canals connect with those of the medullary cavity, periosteum, and central canals.

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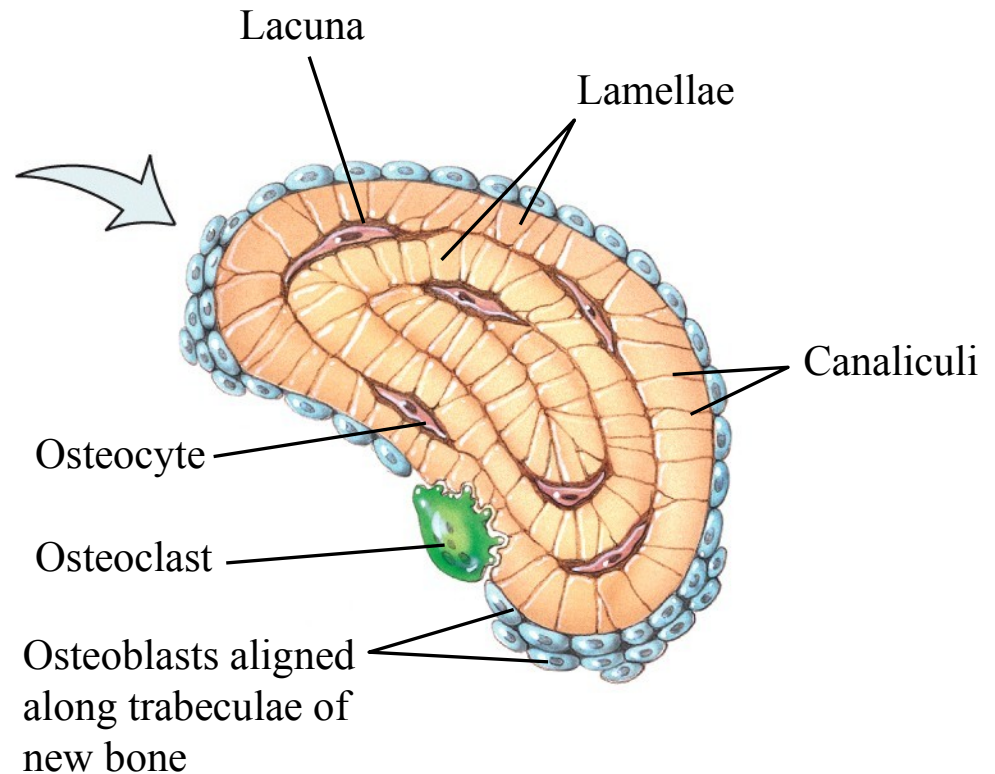
# Animation:

- Bone Dynamics and Tissue

# Histology of Spongy Bone



**(b) Enlarged aspect of spongy bone trabeculae**



**(c) Details of a section of a trabecula**

# Histology of Spongy Bone

## Spongy Bone Tissue/trabecular/cancellous bone tissue

- always located in the *interior* of a bone, protected by a covering of compact bone
- makes up most of the interior bone tissue of short, flat, sesamoid, and irregularly shaped bones
- long bones it forms the core of the epiphyses beneath the paper-thin layer of compact bone, and forms a variable narrow rim bordering the medullary cavity of the diaphysis
- CONSISTS of lamellae that are arranged in an irregular pattern of thin columns called **trabeculae**
  - concentric lamellae
  - osteocytes that lie in lacunae
  - canaliculi that radiate outward from the lacunae
  - precisely oriented along lines of stress, a characteristic that helps bones resist stresses and transfer force without breaking. Spongy bone tissue tends to be located where bones are not heavily stressed or where stresses are applied from many directions. The trabeculae do not achieve their final arrangement until **locomotion is completely learned**. In fact, the **arrangement can even be altered as lines of stress change** due to a poorly healed fracture or a deformity.

# Histology of Spongy Bone

- macroscopic spaces in between trabeculae are filled with
  - red bone marrow in bones that produce blood cells
  - yellow bone marrow (adipose tissue) in other bones
  - Both types of bone marrow contain numerous small blood vessels that provide nourishment to the osteocytes.

Spongy bone tissue is different from compact bone tissue in two respects. First, spongy bone tissue is light, which reduces the overall weight of a bone. This reduction in weight allows the bone to move more readily when pulled by a skeletal muscle. Second, the trabeculae of spongy bone tissue support and protect the red bone marrow. Spongy bone in the hip bones, ribs, sternum (breastbone), vertebrae, and the proximal ends of the humerus and femur is the only site where red bone marrow is stored and, thus, the site where hemopoiesis (blood cell production) occurs in adults.

# Clinical Connection

## **Rickets**

Children new bone formed at the epiphyseal (growth) plates fails to ossify

- growing bones become “soft” or rubbery and are easily deformed
- bowed legs and deformities of the skull, rib cage, and pelvis are common.

## **Osteomalacia**

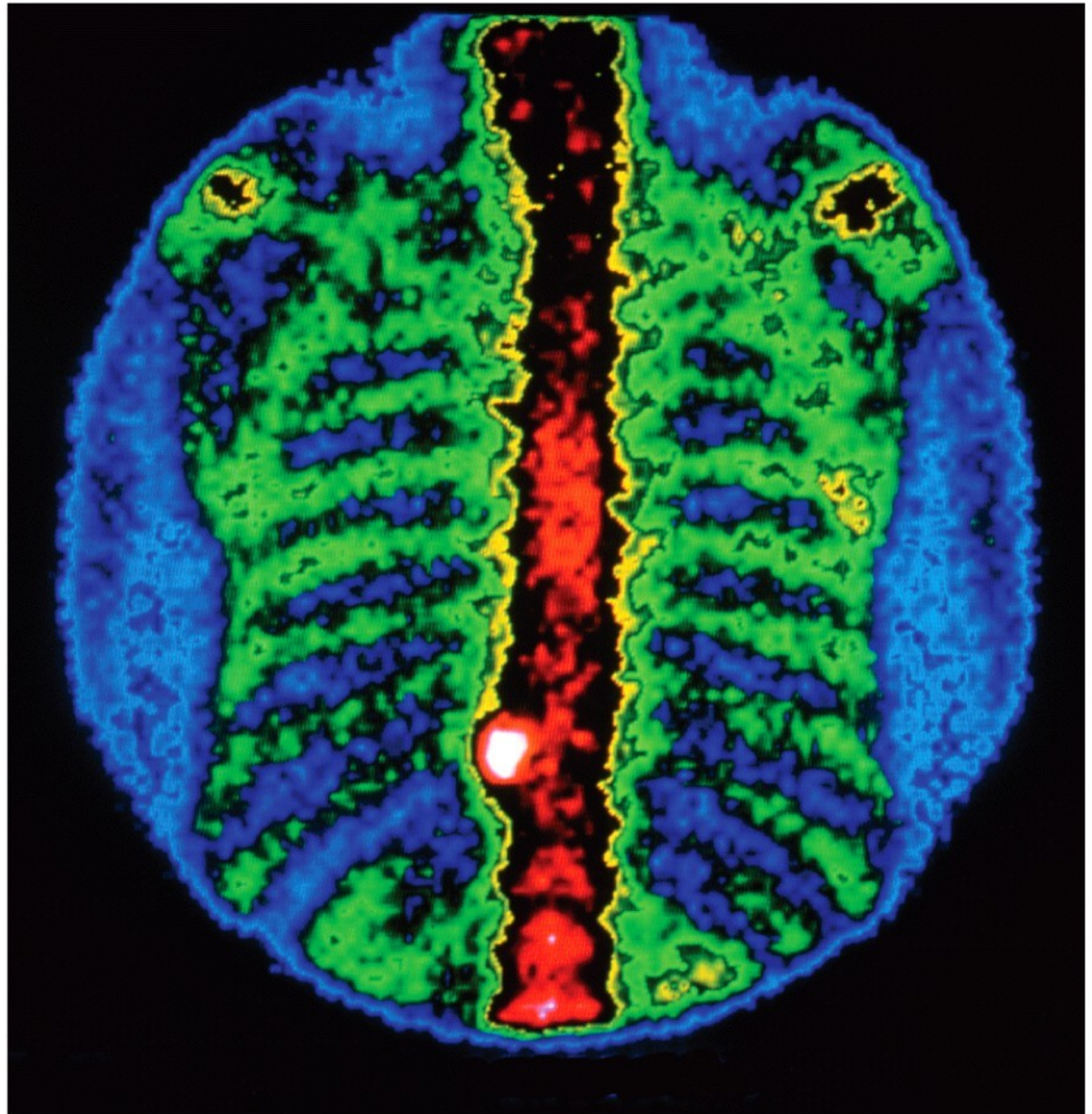
Adults new bone formed during remodeling fails to calcify

- varying degrees of pain and tenderness in bones, especially the hips and legs.
- Bone fractures also result from minor trauma.

Prevention/treatment: administration of adequate vitamin D and exposure to moderate amounts of sunlight.

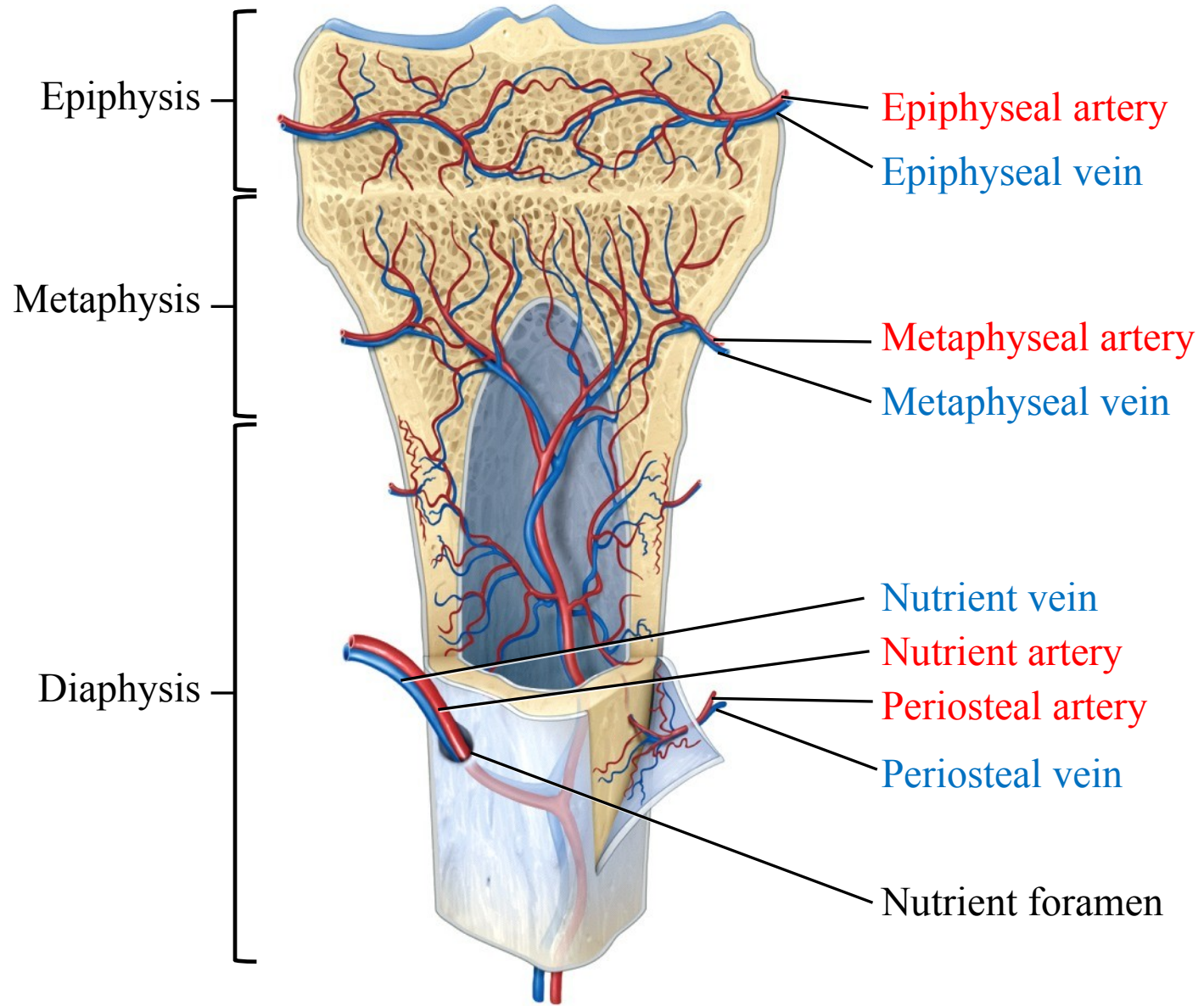
# Clinical Connection

- Bone Scan



CNRI/Photo Researchers, Inc.

Hot spot (white area) in a cancerous vertebra  
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Partially sectioned tibia (shin bone)

# Blood and Nerve Supply of Bone

- Periosteal arteries
- Nutrient arteries
- Nutrient foramen
- Metaphyseal and epiphyseal arteries
- **NERVES:** accompany the blood vessels that supply bones.
- The periosteum is rich in sensory nerves
- , some carry pain sensations - especially sensitive to tearing or tension, which explains the severe pain resulting from a fracture or a bone tumour.

# Draining Blood from Bone

- Nutrient veins
- Metaphyseal/epiphyseal veins
- Periosteal veins
- Lymphatic vessels: The periosteum surrounding the bone has numerous lymphatic capillaries and lymph vessels, but there is no evidence of any lymphatic vessels within the bone tissue.

# Animation:

- Bone Formation

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# Bone Formation

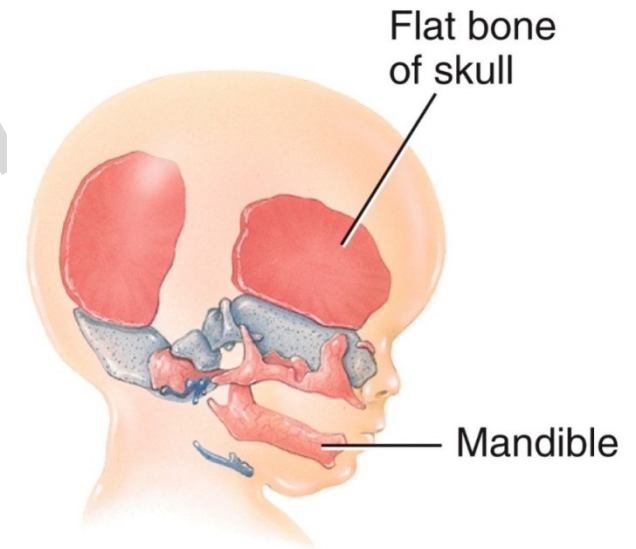
The **embryonic “skeleton”** is composed of mesenchyme in the general shape of bones.

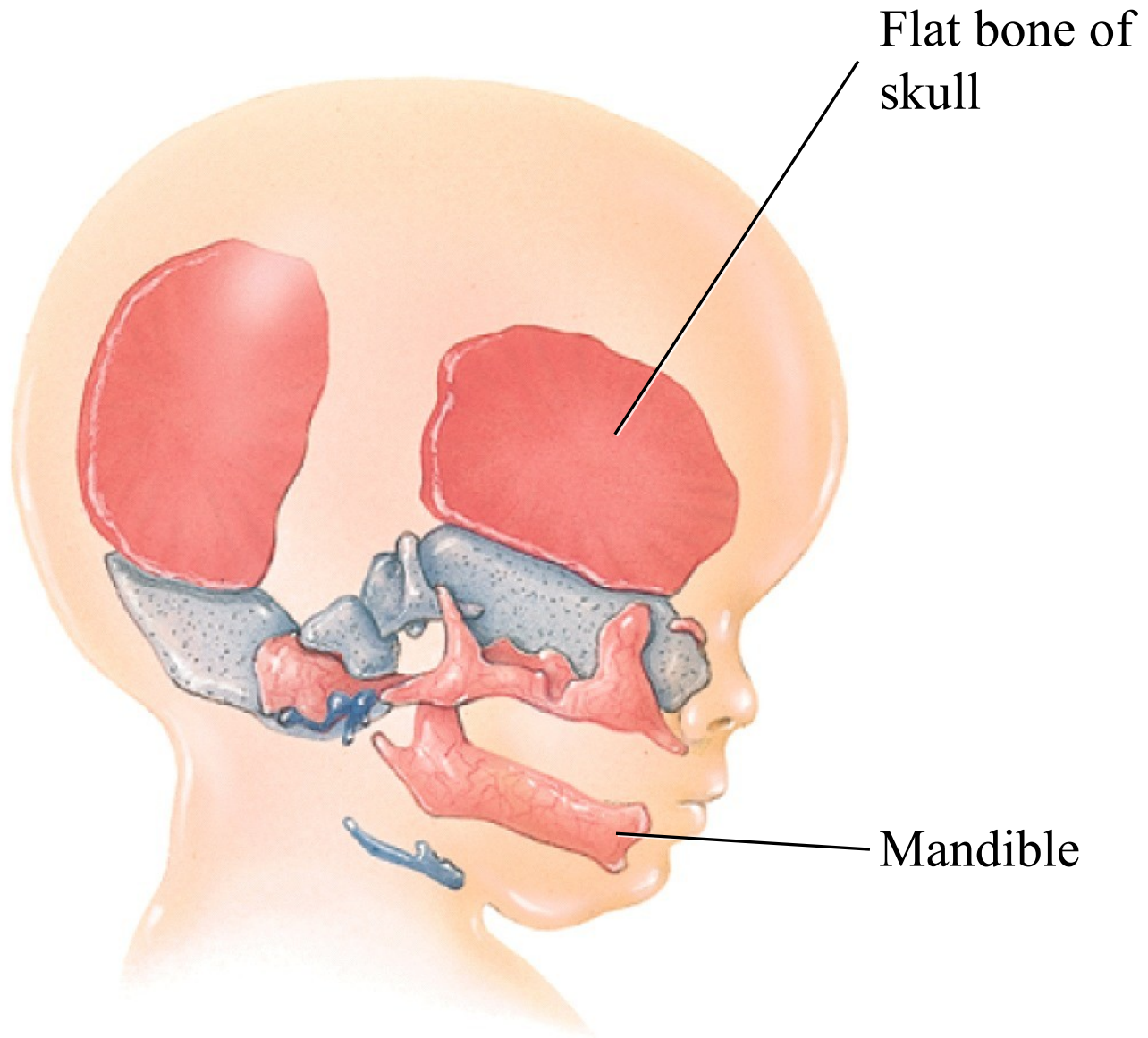
During the 6<sup>th</sup> week of embryonic development, these become the sites where subsequent cartilage formation and then ossification occurs in one of two patterns:

- **Intramembranous ossification** bone forms directly within mesenchyme, which is arranged in sheet like
- layers that resemble membranes
- **Endochondral ossification** bone forms within hyaline cartilage that develops from mesenchyme.

# Intramembranous Ossification

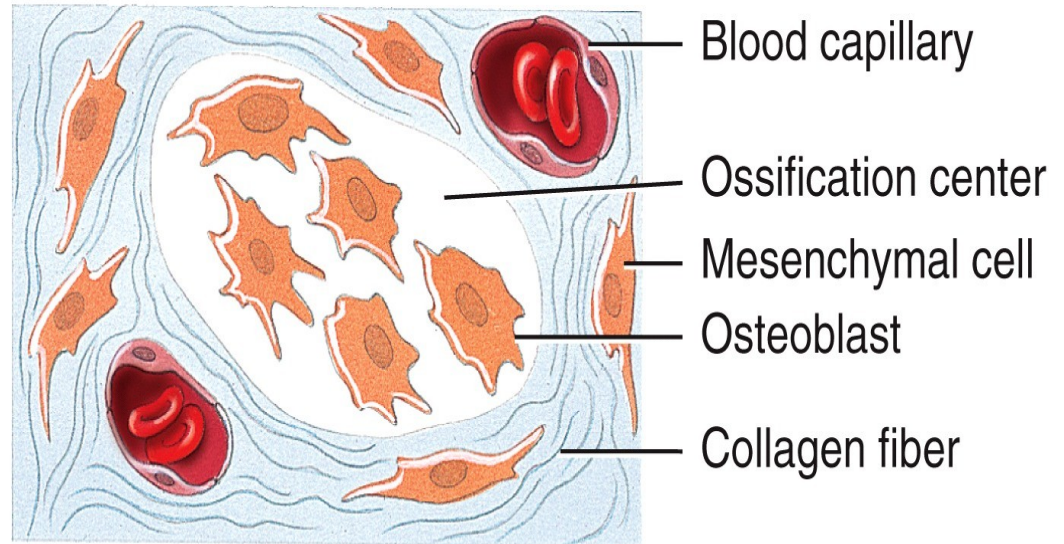
- Simpler process than endochondral ossification
- Examples: flat bones of the skull
- Involves a 4-step process
- Intramembranous ossification is the simpler of the two methods of bone formation.
- The flat bones of the skull, most of the facial bones, mandible (lower jawbone), and the medial part of the clavicle (collar bone) are formed in this way.
- Also, the “soft spots” that help the fetal skull pass through the birth canal later harden as they undergo
- intramembranous ossification





# Intramembranous Ossification

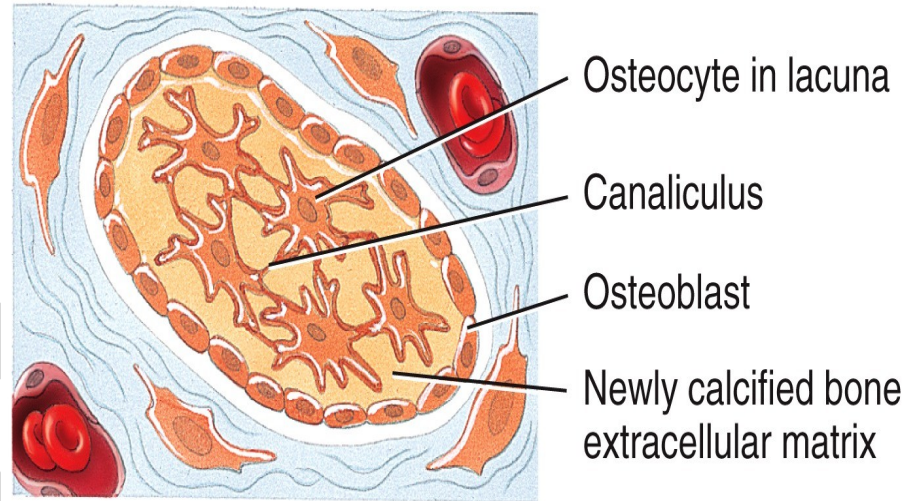
**Development of the ossification center.** At the site where the bone will develop, specific chemical messages cause the mesenchymal cells to cluster together and differentiate, first into osteogenic cells and then into osteoblasts. The site of such a cluster is called an **ossification center**. Osteoblasts secrete the organic extracellular matrix of bone until they are surrounded by it.



- 1 Development of ossification center: osteoblasts secrete organic extracellular matrix

# Intramembranous Ossification

**Calcification.** Next, the secretion of extracellular matrix stops and the cells, now called osteocytes, lie in lacunae and extend their narrow cytoplasmic processes into canaliculi that radiate in all directions. Within a few days, calcium and other mineral salts are deposited and the extracellular matrix hardens or calcifies (calcification).

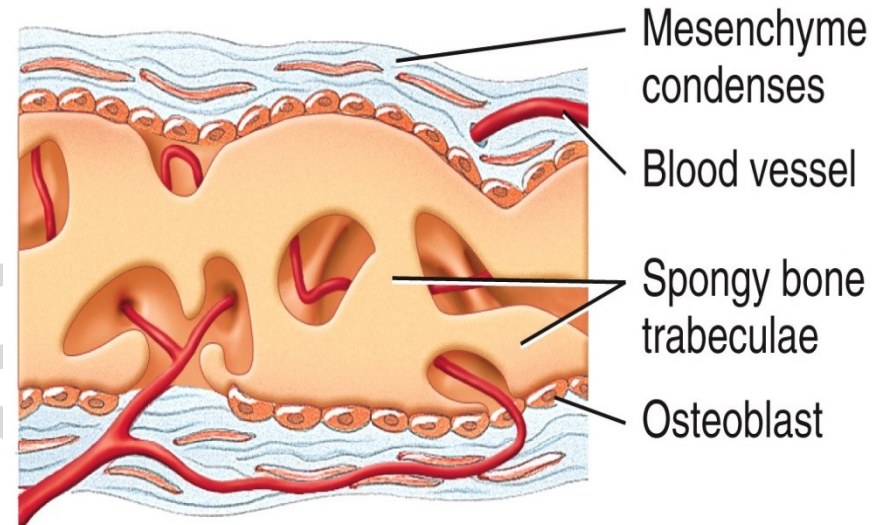


- 2 Calcification: calcium and other mineral salts are deposited and extracellular matrix calcifies (hardens)

# Intramembranous Ossification

## Formation of trabeculae.

As the bone extracellular matrix forms, it develops into trabeculae that fuse with one another to form spongy bone around the network of blood vessels in the tissue. ***Connective tissue that is associated with the blood vessels in the trabeculae differentiates into red bone marrow.***

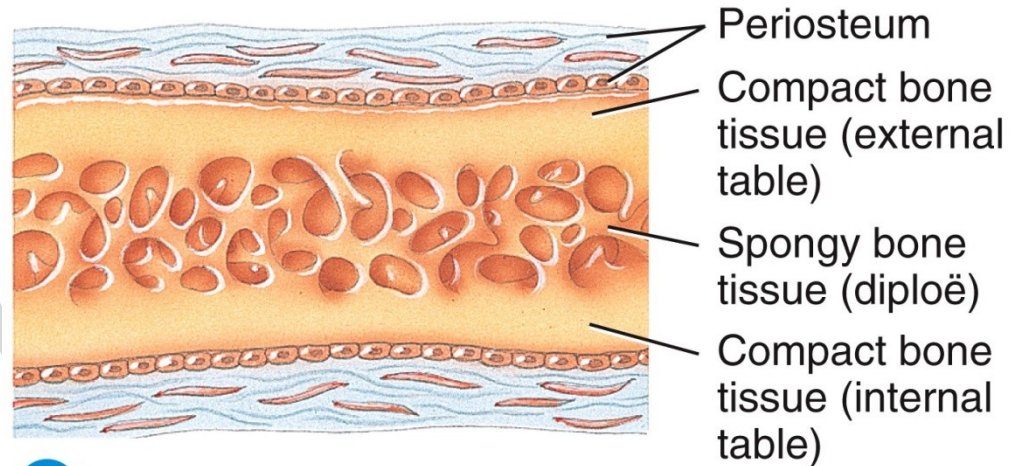


- 3 Formation of trabeculae: extracellular matrix develops into trabeculae that fuse to form spongy bone

# Intramembranous Ossification

## Development of the periosteum.

In conjunction with the formation of trabeculae, the mesenchyme at the periphery of the bone condenses and develops into the periosteum. Eventually, a thin layer of compact bone replaces the surface layers of the spongy bone, but spongy bone remains in the center. Much of the newly formed bone is remodeled (destroyed and reformed) as the bone is transformed into its adult size and shape.



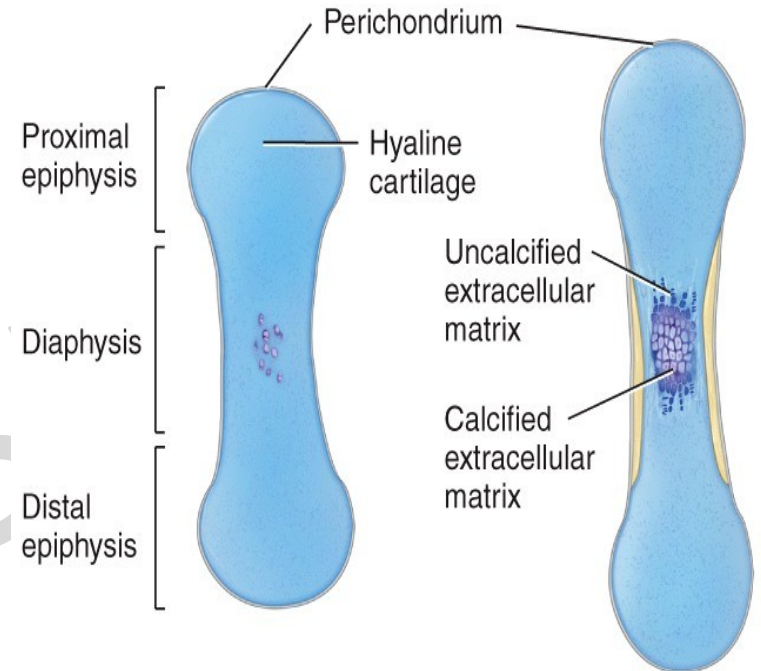
- 4 Development of the periosteum: mesenchyme at the periphery of the bone develops into the periosteum

# Endochondral Ossification

- The process by which the embryonic cartilaginous model of most bones contributes to longitudinal growth and is gradually replaced by bone.
- Cartilage model that starts **solid** and becomes **hollow**.
- 6 major stages: Chondrocytes proliferate, undergo hypertrophy and die; the cartilage extracellular matrix they construct is then invaded by blood vessels, osteoclasts, bone marrow cells and osteoblasts, the last of which deposit bone on remnants of cartilage matrix.

# Endochondral Ossification

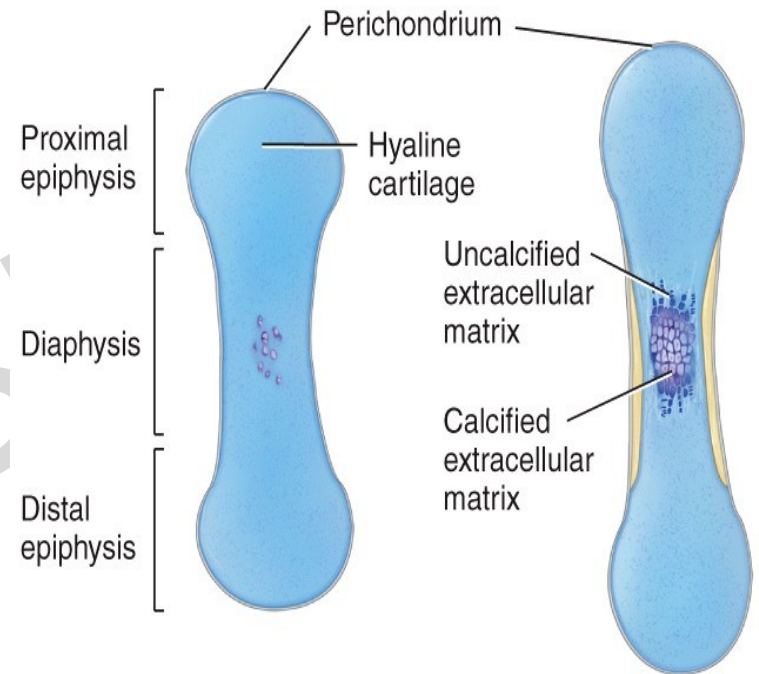
**1) Development of the cartilage model.** At the site where the bone is going to form, specific chemical messages cause the mesenchymal cells to crowd together in the general shape of the future bone, and then develop into chondroblasts. The chondroblasts secrete cartilage extracellular matrix, producing a **cartilage model** consisting of hyaline cartilage. A covering called the **perichondrium** develops around the cartilage model.



- 1 Development of cartilage model: mesenchymal cells develop into chondroblasts, which form the cartilage model.
- 2 Growth of cartilage model: growth occurs by cell division of chondrocytes.

# Endochondral Ossification

**2) Growth of the cartilage model.** Once chondroblasts become deeply buried in the cartilage extracellular matrix, they are called chondrocytes. The cartilage model grows in length by continual cell division of chondrocytes, accompanied by further secretion of the cartilage extracellular matrix. This type of cartilaginous growth, called **interstitial (endogenous) growth** (growth from within), results in an increase in length. In contrast, growth of the cartilage in thickness is due mainly to the deposition of extracellular matrix material on the cartilage surface of the model by new chondroblasts that develop from the perichondrium in a process called **appositional (exogenous) growth** meaning growth of the outer surface



**1** Development of cartilage model: mesenchymal cells develop into chondroblasts, which form the cartilage model.

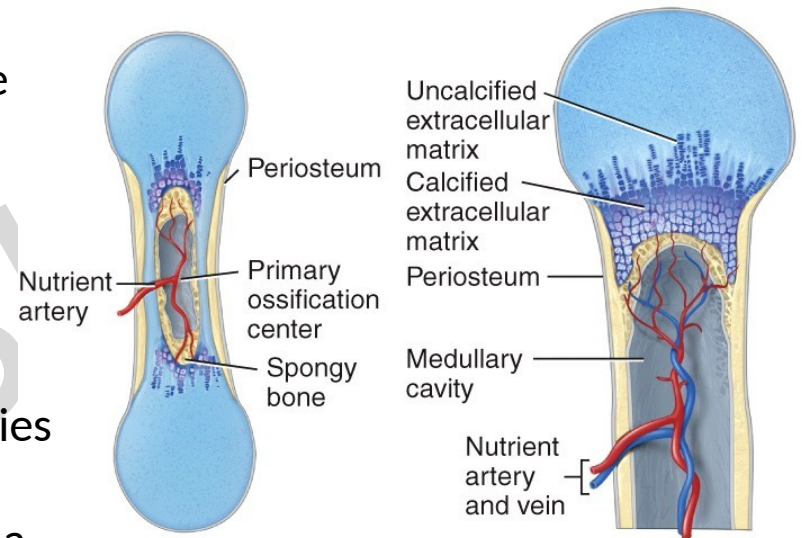
**2** Growth of cartilage model: growth occurs by cell division of chondrocytes.

# Endochondral Ossification

## 3. Development of the primary ossification center

Primary ossification proceeds *inward* from the external surface of the bone. A nutrient artery penetrates the perichondrium and the calcifying cartilage model through a nutrient foramen in the midregion of the cartilage model, **stimulating osteogenic cells in the perichondrium to differentiate into osteoblasts**. Once the perichondrium starts to form bone, it is known as the **periosteum**.

- Near the middle of the model, periosteal capillaries grow into the disintegrating calcified cartilage, inducing growth of a **primary ossification center**, a region where bone tissue will replace most of the cartilage. Osteoblasts then begin to deposit bone extracellular matrix over the remnants of calcified cartilage, forming spongy bone trabeculae. Primary ossification spreads from this central location toward both ends of the cartilage model.

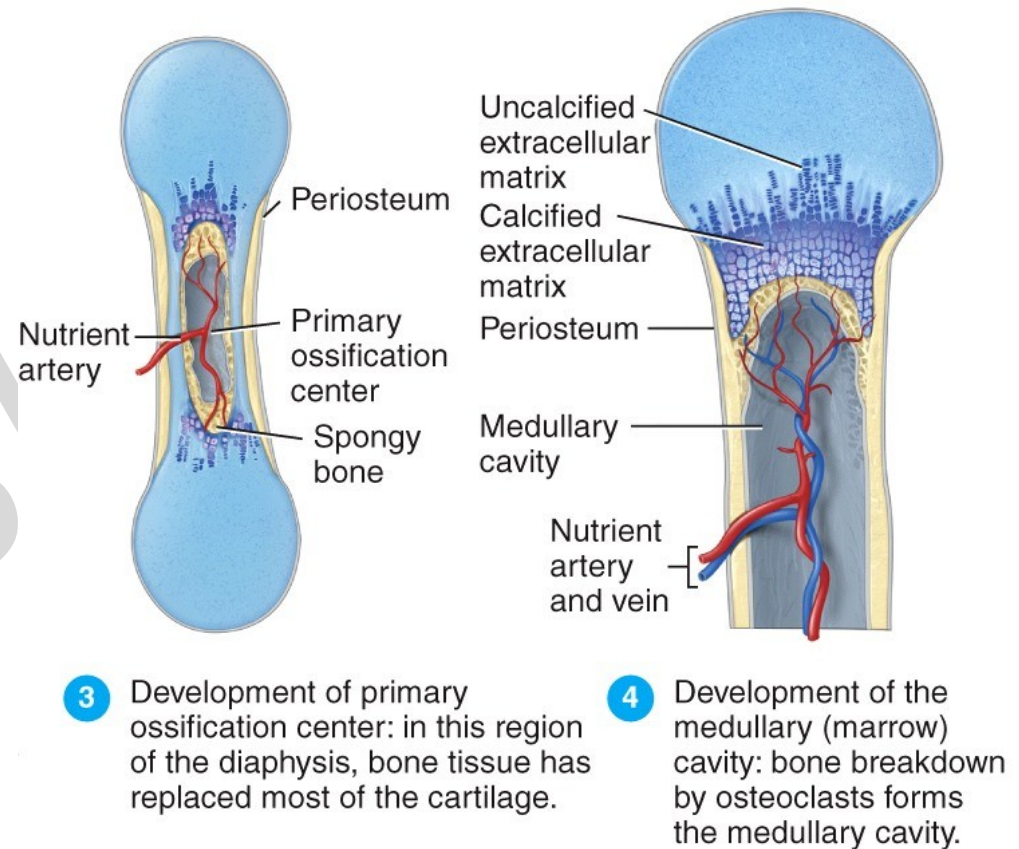


**3** Development of primary ossification center: in this region of the diaphysis, bone tissue has replaced most of the cartilage.

**4** Development of the medullary (marrow) cavity: bone breakdown by osteoclasts forms the medullary cavity.

# Endochondral Ossification

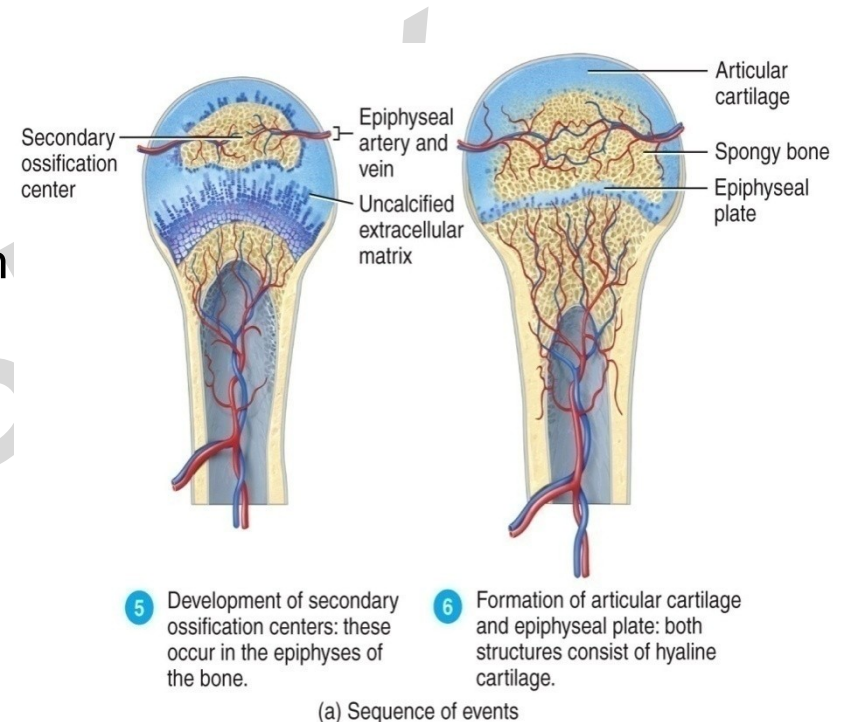
**4. Development of the medullary (marrow) cavity.** As the primary ossification center grows toward the ends of the bone, osteoclasts break down some of the newly formed spongy bone trabeculae. This activity leaves a cavity, the medullary (marrow) cavity, in the diaphysis (shaft). Eventually, most of the wall of the diaphysis is replaced by compact bone.



# Endochondral Ossification

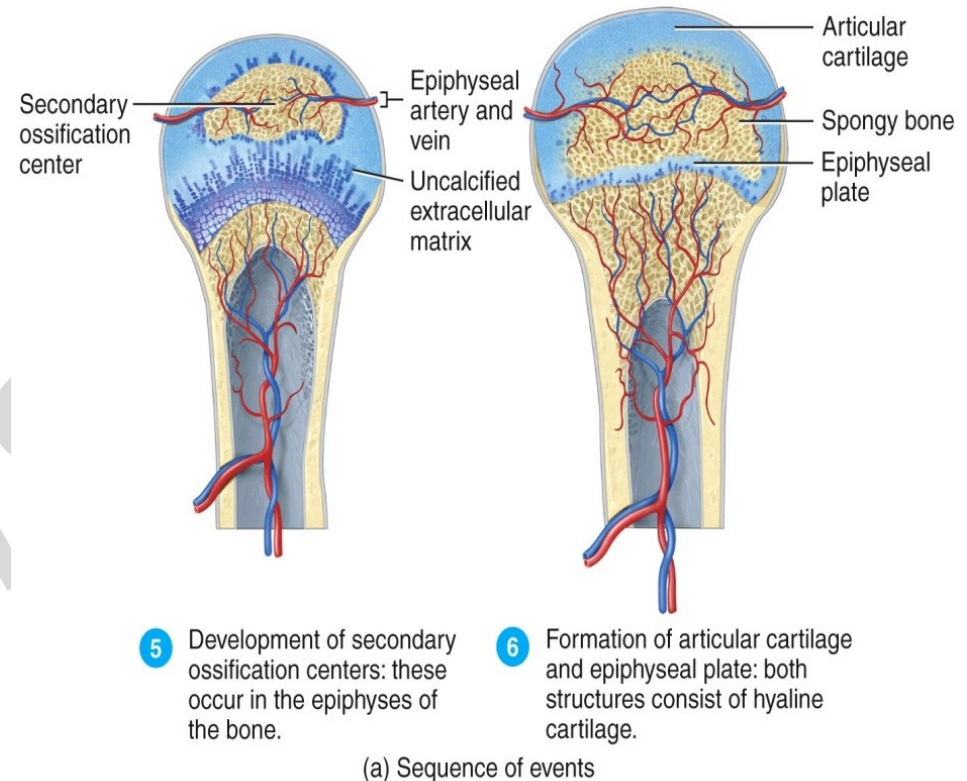
## 5. Development of the secondary ossification centers.

When branches of the epiphyseal artery enter the epiphyses, **secondary ossification centers** develop, usually around the time of birth. Bone formation is similar to what occurs in primary ossification centers. However, in the secondary ossification centers spongy bone remains in the interior of the epiphyses (no medullary cavities are formed here). ***In contrast to primary ossification***, secondary ossification proceeds *outward* from the center of the epiphysis toward the outer surface of the bone.

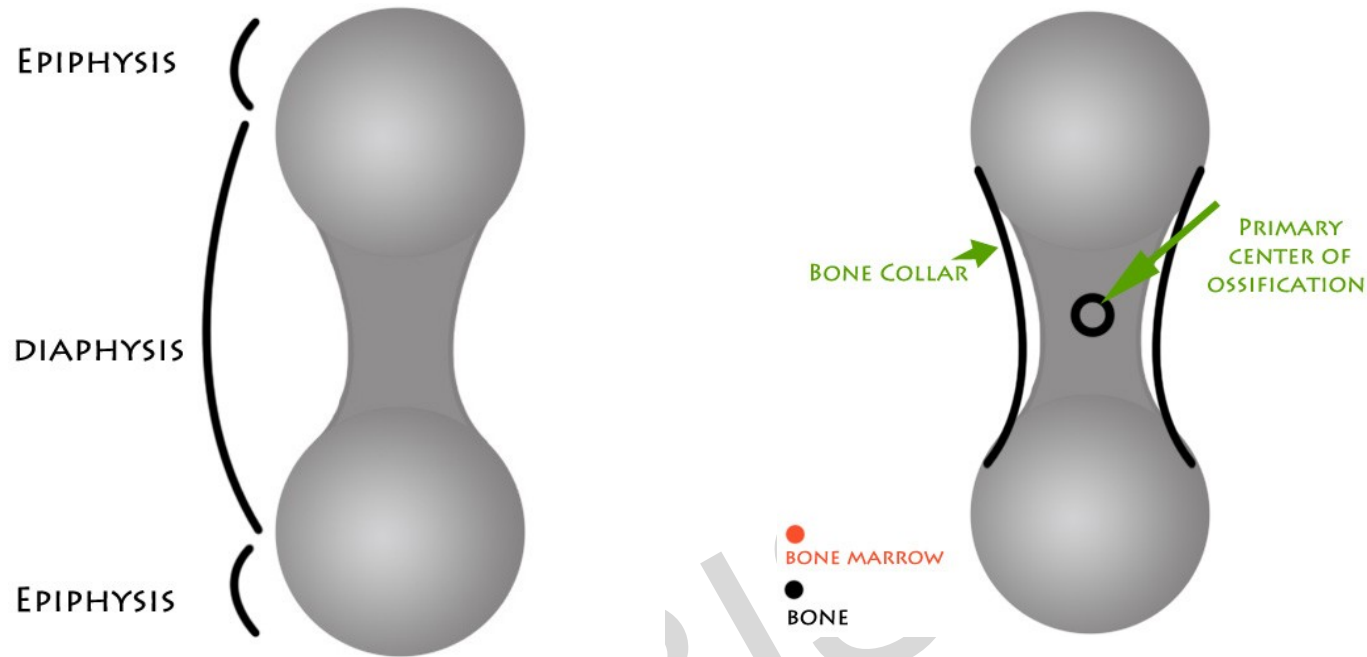


# Endochondral Ossification

**6. Formation of articular cartilage and the epiphyseal (growth) plate.** The hyaline cartilage that covers the epiphyses becomes the articular cartilage. Prior to adulthood, hyaline cartilage remains between the diaphysis and epiphysis as the epiphyseal (growth) plate, the region responsible for the lengthwise growth of long bones



# Bone Collar Formation



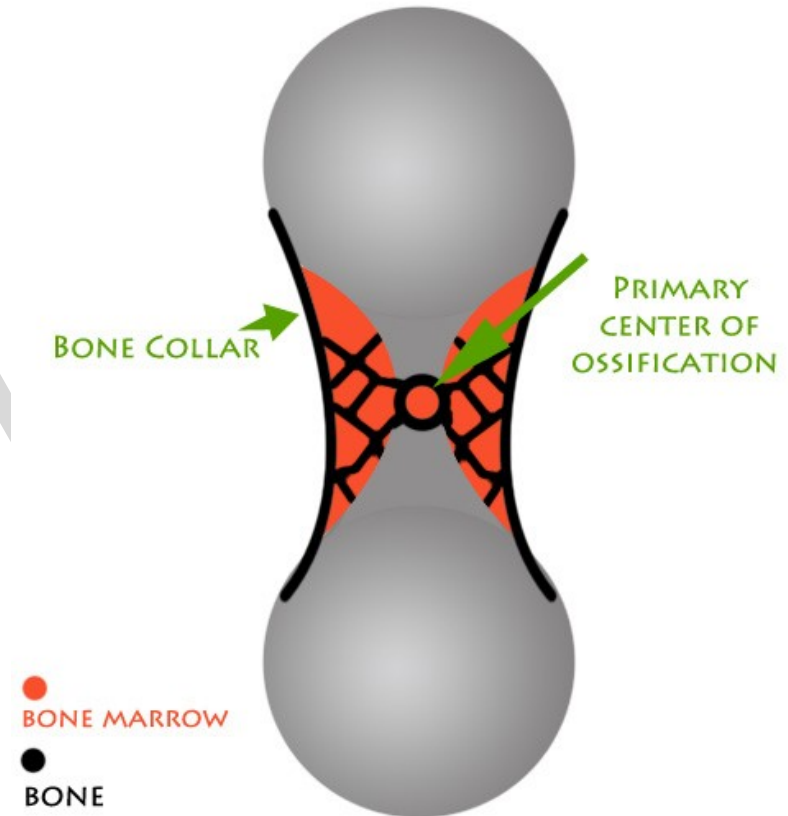
Periosteum forms around a piece of hyaline cartilage. Then the osteogenic cells (stem cells) on the inside of the periosteum differentiate (specialize) into *osteoblasts*.

The osteoblasts then secrete their organic fibers (proteins) on the outside of the cartilage. Remember that these condensed fibers are called the osteoid. The end result of this is the formation of a bony collar on the outside of the cartilage.

# Cavitation

## Cavitation

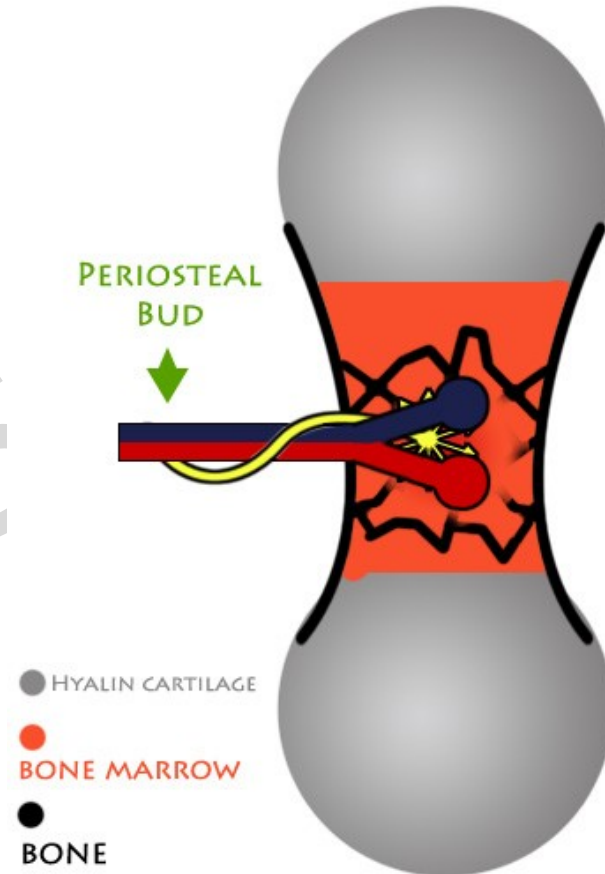
While step #1 occurs, the cartilage in the center of the model begins to ossify (form into bone). This centered cartilage is called the **primary ossification center**. The chondrocytes (cartilage cells) go through **hypertrophication** or enlargement and signal the hyalin cartilage to harden into bone. This hardening into bone is called calcification. The calcified hyalin cartilage is impermeable to the diffusion of nutrients. Since the chondrocytes can't receive any nutrients they begin to die and leave small cavities. These small cavities leave room in the hardened bone for blood vessels to travel through.



# Periosteal Bud Invasion

## Periosteal Bud Invasion

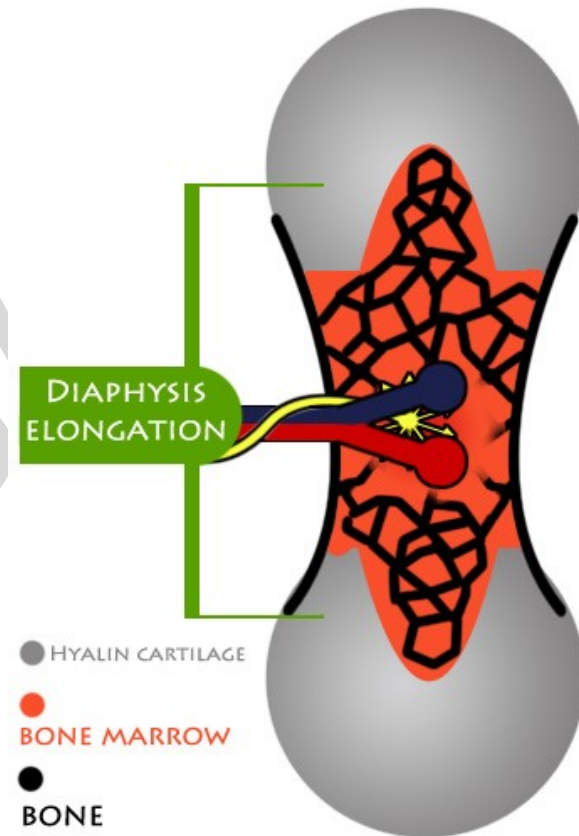
The introduction of a nutrient highway to the bone. Previously nutrients were delivered through the cartilage by simple diffusion. To support the capacity of the hardening bone, the periosteal region is invaded by a bud containing blood vessels and nerves. This allows not only nutrients, but osteoblasts and osteoclasts cells to enter into the cavities that were previously inhabited by chondrocytes. The osteoblasts secrete osteoid into the remaining hyalin cartilage and give rise to early spongy bone. Think of the periosteal bud invasion as a group of grave robbers who invaded the graves (cavities) where fallen chondrocytes used to rest.



# Diaphysis Elongation

## Diaphysis Elongation

After the nutrient source is delivered to the center of the bone, the diaphysis region has the resources to elongate. The elongated region is powered by cells dividing in the primary center of ossification. This elongated region is known as the medullary cavity. The **medullary cavity** is where the bone marrow is contained.



# Epiphyseal Ossification

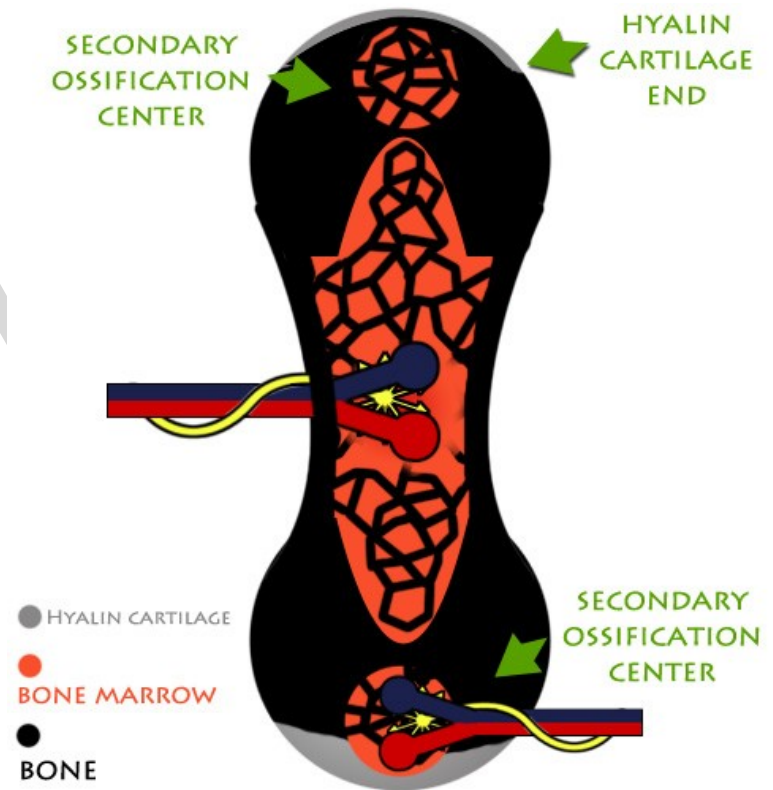
## Epiphyseal Ossification

Just before birth the ends of the bone or Epiphysis will develop their own centers of ossification. They can't stay made of cartilage or they would be structurally weak. These centers are known as the **secondary centers of ossification**. They go through the same process as the primary center of ossification: hypertrophication, calcification, cavitation, and periosteal bud invasion.

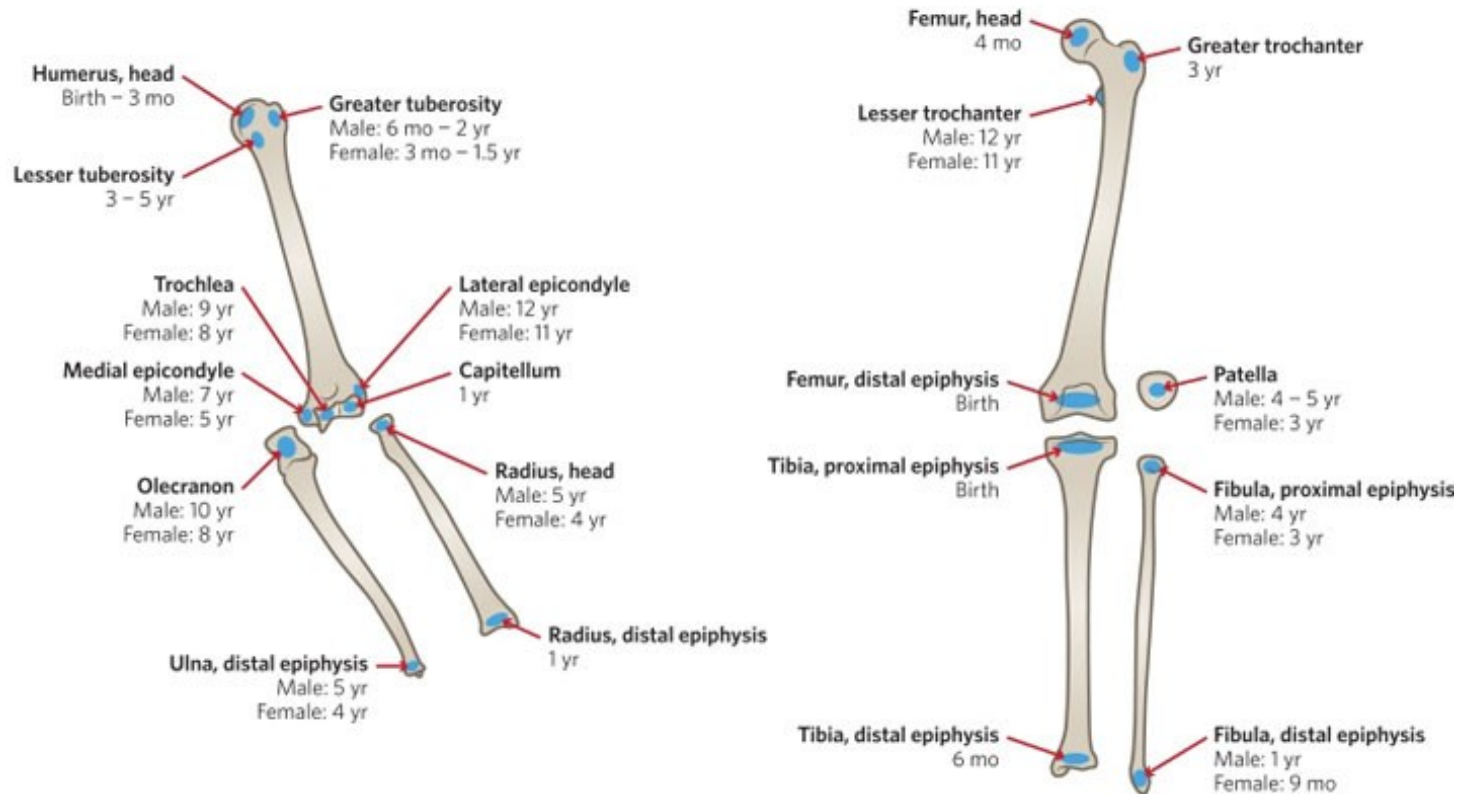
Why not just grow completely from the center?

Why do we need secondary centers?

There is a region left between the primary and secondary centers of ossification known as the Epiphyseal Plate. This is more commonly known as the growth plate. This is how your bones grow after you are born.



## Time of appearance of secondary ossification centres

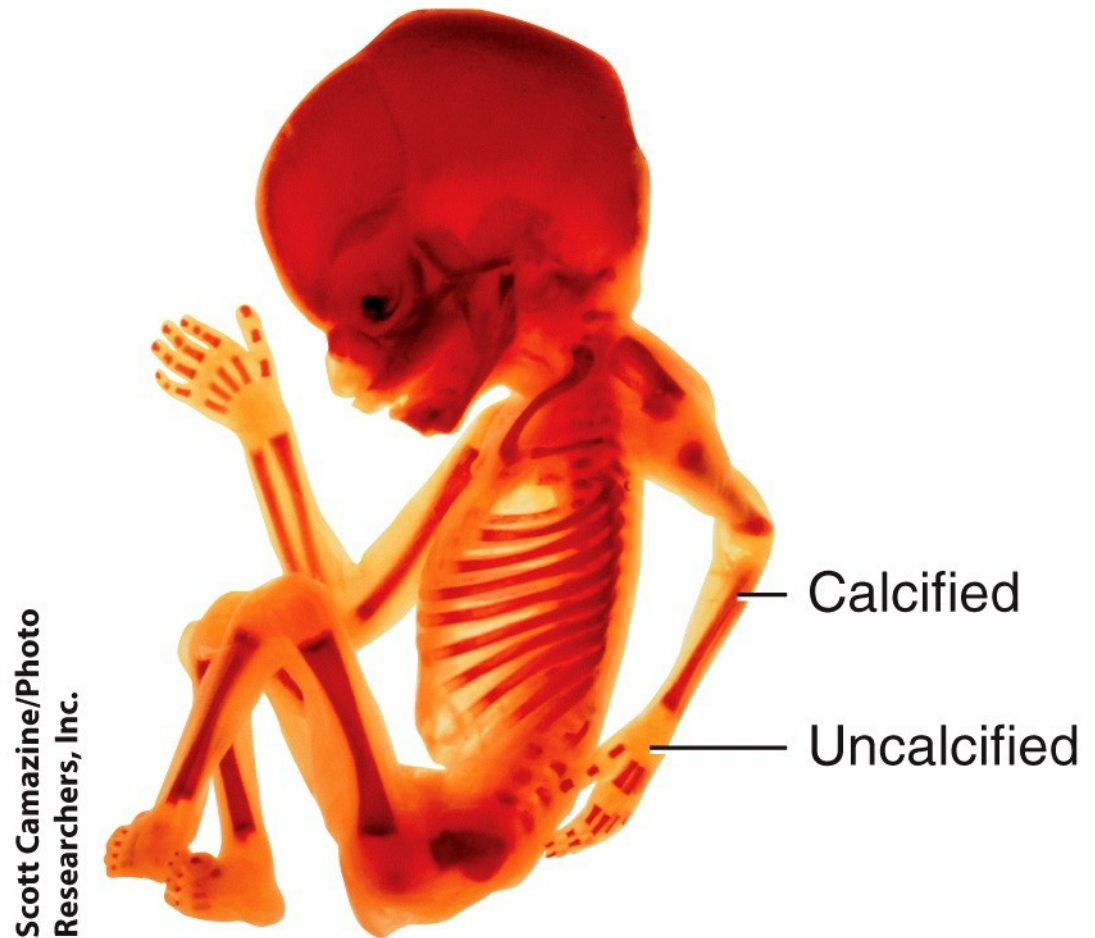


© The Royal Children's Hospital, Melbourne, Australia

## Typical age of appearance of the secondary ossification centers in the upper limb and lower limb.

With the exception of the distal femur, the ends of the long bones in the newborn are completely cartilaginous. The secondary ossification centers appear during growth in a predictable pattern and knowledge of the timing and pattern of appearance is important in assessing fractures around and into the joints.

# Endochondra Ossification



(b) Twelve-week-old fetus. The red areas represent bones that are forming (calcified). Translucent areas represent cartilage (uncalcified).

# Bone Growth After Birth

During infancy, childhood, and adolescence,

bones throughout the body

- grow in *thickness* by **appositional growth**,

and long bones

- lengthen* by **interstitial growth**.

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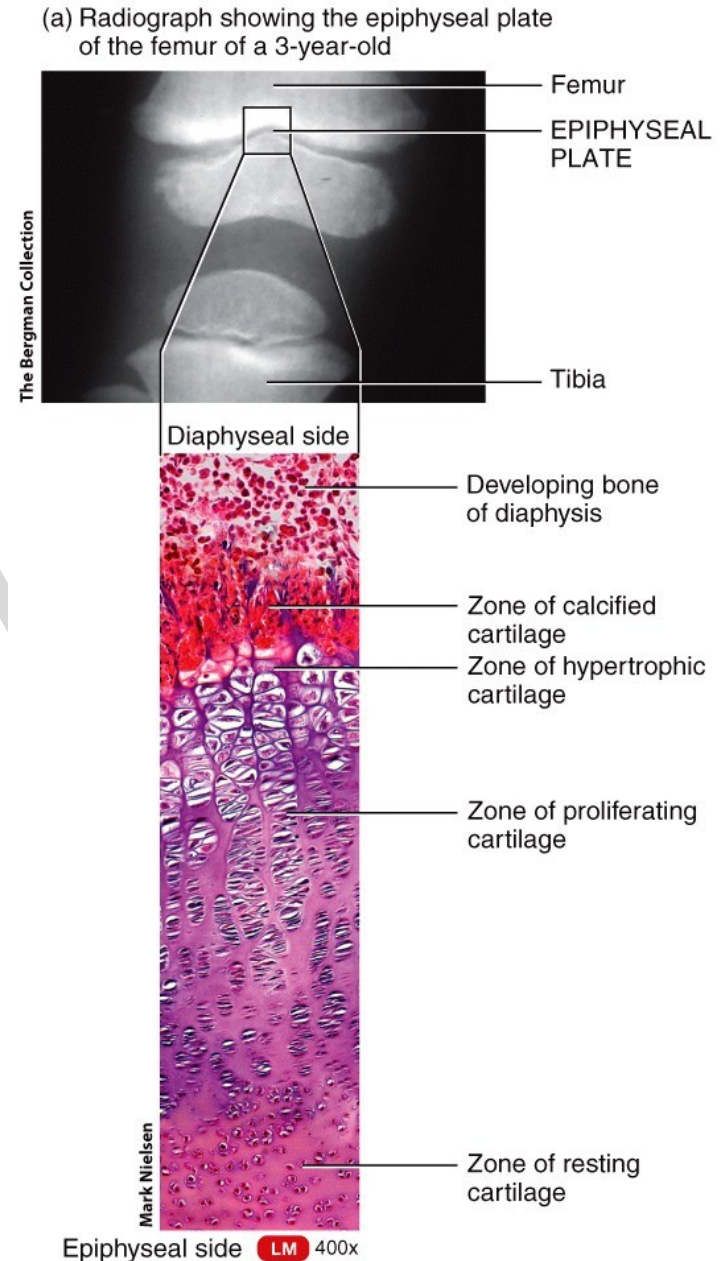
# Animation:

- Bone Growth and Remodeling

# Role of the Epiphyseal Plate in Bone Growth

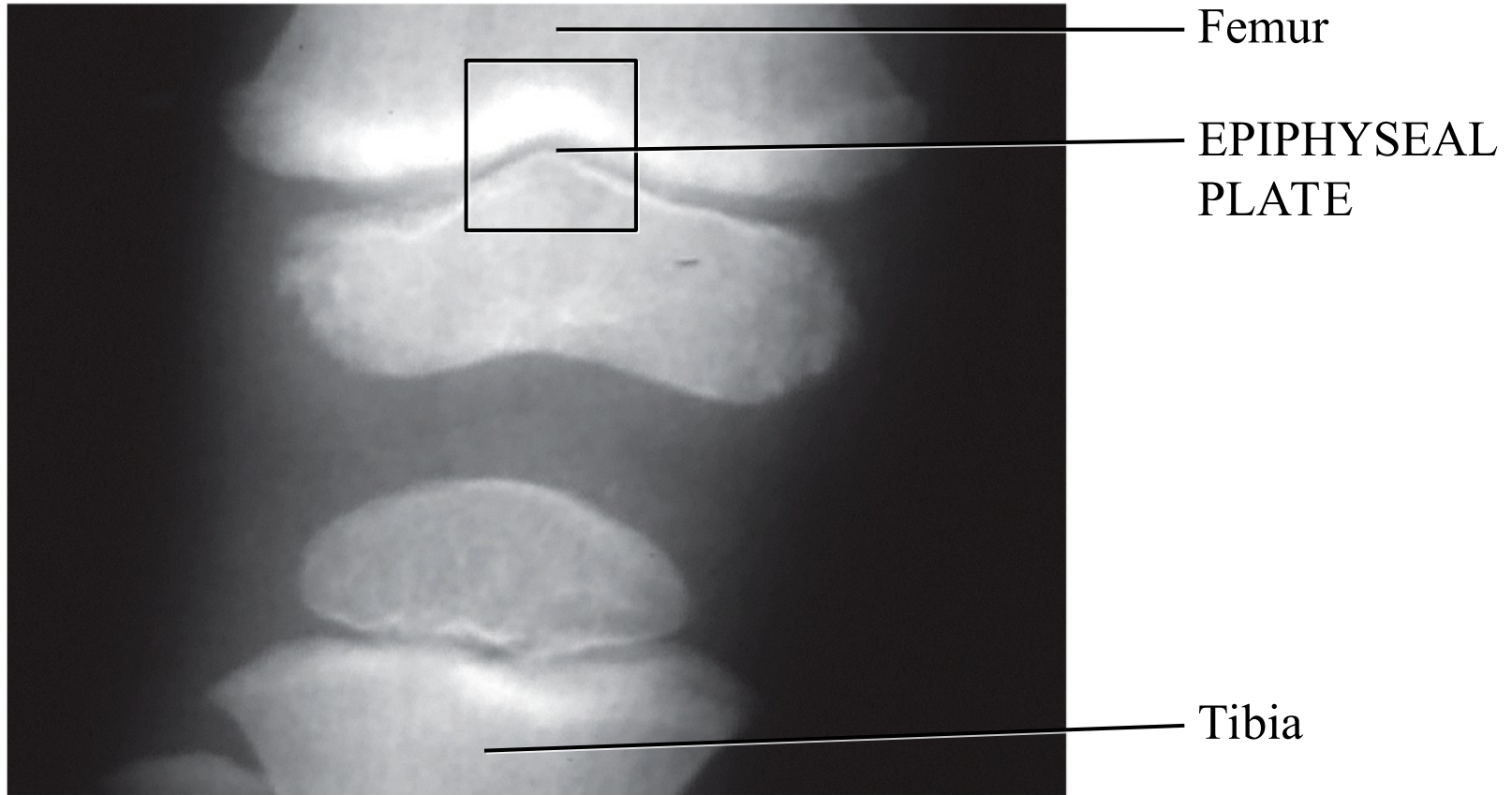
- The growth in length of a long bone involves
  - Interstitial growth
  - Replacement of cartilage with bone by endochondral ossification on the diaphyseal side of the epiphyseal plate
- In the long bones of the limbs, growth in length does not occur equally at both ends of the bones; one end is always the dominant growing end. The dominant growing end is always directed away from the orientation angle of the nutrient foramen in the diaphysis.
- Therefore, the ends of the femur, tibia, and fibula toward the knee are the dominant growing epiphyseal plates and the ends of the humerus, ulna, and radius at the ends opposite the elbow are the dominant growing epiphyseal plates.

# Radiograph of Epiphyseal Plate of a 3-year old

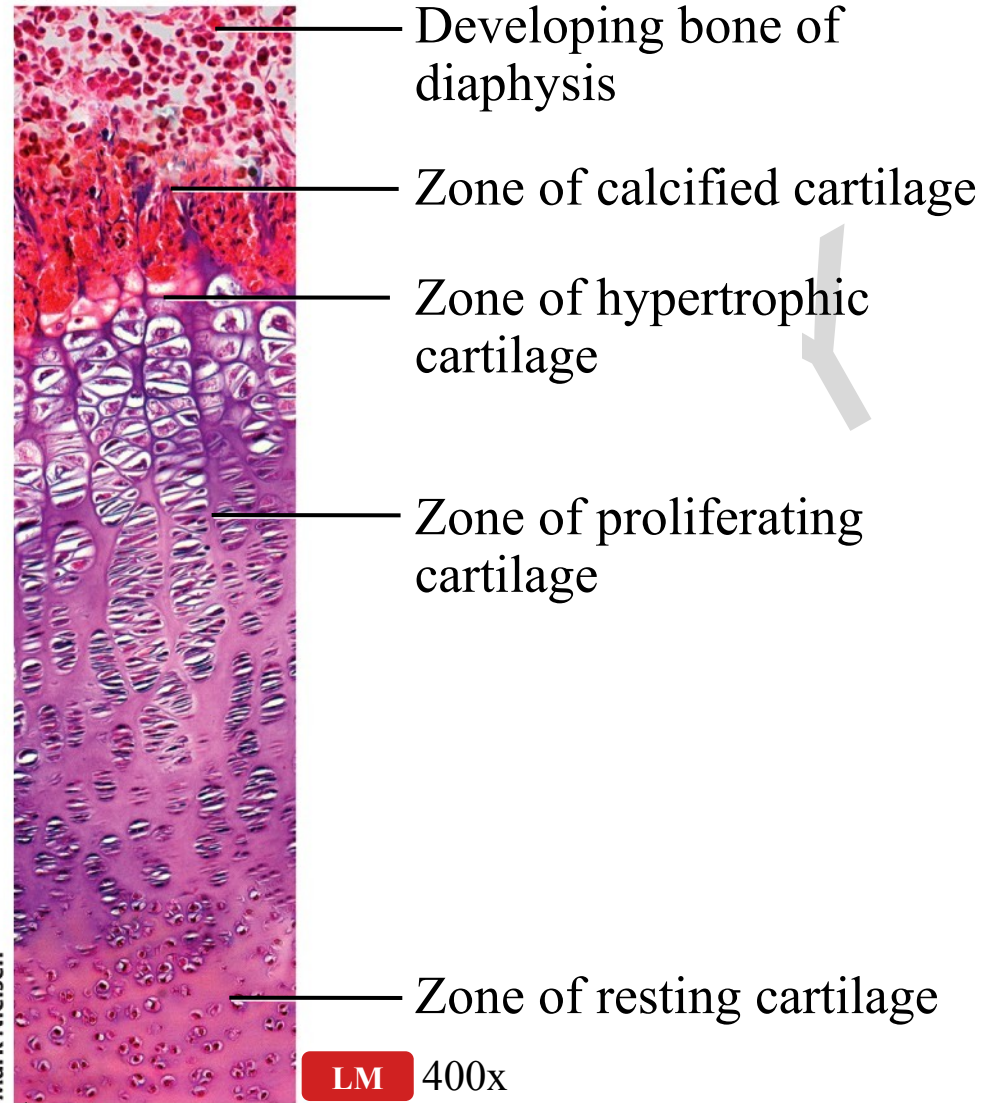


(a) Radiograph showing the epiphyseal plate of the femur of a 3-year-old

The Bergman Collection



Diaphyseal side



Epiphyseal side

(b) Histology of the epiphyseal plate

# Histology of the epiphyseal plate

To understand how a bone grows in length, you need to know some of the details of the structure of the epiphyseal plate

The **epiphyseal (growth) plate** is a layer of hyaline cartilage in the metaphysis of a growing bone that consists of four zones

**1.Zone of resting cartilage.** This layer is nearest the epiphysis and consists of small, scattered chondrocytes. The term *resting* is used because the cells do not function in bone growth. Rather, they anchor the epiphyseal plate to the epiphysis of the bone.

**2.Zone of proliferating cartilage.** Slightly larger chondrocytes arranged like stacks of coins undergo interstitial growth as they divide and secrete extracellular matrix. The chondrocytes in this zone divide to replace those that die at the diaphyseal side of the epiphyseal plate.

# Histology of the epiphyseal plate

**3. Zone of hypertrophic cartilage** This layer consists of large, maturing chondrocytes arranged in columns.

**4. Zone of calcified cartilage.** The final zone of the epiphyseal plate is only a few cells thick and consists mostly of *chondrocytes* that are dead because the extracellular matrix around them has calcified. Osteoclasts dissolve the calcified cartilage, and osteoblasts and capillaries from the diaphysis invade the area. The osteoblasts lay down bone extracellular matrix, replacing the calcified cartilage by the process of endochondral ossification. As a result, the zone of calcified cartilage becomes “new diaphysis” that is firmly cemented to the rest of the diaphysis of the bone.

# Clinical Connections – Epiphyseal Plate Closure & Fractures

- closure of the epiphyseal plate is a gradual process
- ~ age 18 in females and age 21 in males
- **epiphyseal line:** bony transformation of the plate
- useful in determining bone age, to predict adult height, and to establish age at death from skeletal remains, especially in infants, children, and adolescents
- Damage to the hyaline cartilage (epiphyseal plate), which is avascular, accelerates closure
- closure of the epiphyseal plate, on average, takes place 1–2 years earlier in females.
- If a bone fracture damages the epiphyseal plate prior to closure, the fractured bone may be shorter than normal once adult stature is reached. This is because damage to cartilage, which is avascular, accelerates closure of the epiphyseal plate due to the cessation of cartilage cell division, thus inhibiting lengthwise growth of the bone.

# Clinical Connection:

## Salter – Harris classification of Physeal Injuries

**TYPE I:** Accounts for 6% of all physeal injuries.

**Transverse** fracture through the **growth plate**.

In a type I separation, the epiphysis separates from the metaphysis. The plane of separation is horizontal and the germinal cells remain with the epiphysis.

When the **periosteum** is torn, displacement may occur. The periosteum is usually torn on the convex side and is intact on the concave side. Displacement is usually easily reduced by reversing the deforming forces and these are often stable and treated by closed means.

When the periosteum is not torn, there is no displacement and these injuries are diagnosed by suspicion, by the sign of local tenderness and by the normal appearance on x-ray. They are usually misdiagnosed as sprains because little is seen on the x-ray.

- Healing is rapid for type I fractures, within 2-3 weeks of injury and problems are rare especially in sites such as the distal radius.



Type I

# Clinical Connection:

## Salter – Harris classification of Physeal Injuries

- **TYPE II:** Most common type and accounts for 75% of all physeal injuries.
- **Transverse** fracture through the **growth plate** and an **oblique or vertical** fracture through the **metaphysis**.

The type II injury starts as a horizontal separation (like type I) but this is completed by exiting through the metaphysis, resulting in a triangular fragment which varies in size.

- This is the most common type of physeal separation and is usually easily reduced but not always easy to hold reduced, in a cast. Sometimes the torn periosteum becomes trapped in the fracture site preventing a full reduction by closed means. The trapped periosteum sometimes needs to be released by open operation, especially at the ankle.



# Clinical Connection:

## Salter – Harris classification of Physeal Injuries

- **TYPE III:** Accounts for 8% of all physeal injuries.
- **Transverse** fracture through the **growth plate** and a **vertical** fracture through the **epiphysis**.
- Type III injuries are more commonly seen in older children where the growth plates have started to close. It is a combination of a horizontal fracture line through the physis and a vertical fracture line which runs from the growth plate through the epiphysis to the articular surface.
- Displaced injuries may result in a **physeal bar**, leading to growth disturbance and joint incongruity, leading to arthritis.
- Most displaced type III injuries require open reduction internal fixation (ORIF).



**Type III**

# Clinical Connection:

## Salter – Harris classification of Physeal Injuries

- **TYPE IV:** Accounts for 10% of all physeal injuries.
- **Vertical** fracture through all three components, **metaphysis, physis and epiphysis**.
- In type IV separations, the fracture line is vertical. It extends through four distinct tissues/areas: metaphyseal bone, physeal cartilage, epiphyseal bone or cartilage and articular cartilage. The most common example of a type IV physeal injury is separation of the lateral condyle of the distal humerus. The four injured tissues must be accurately reduced and lined up with each other, to minimise the risk of a physeal bar and articular incongruity. Most displaced type IV injuries require ORIF and long-term follow-up to detect growth disturbance.

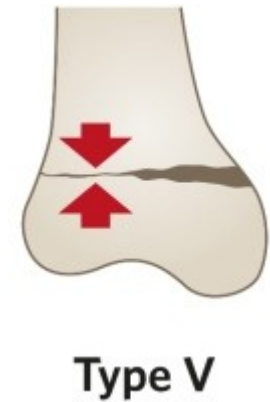


**Type IV**

## Clinical Connection:

### Salter – Harris classification of Physeal Injuries

- **TYPE V:** This injury is rare and difficult to see on x-ray.
- Compression fracture or crushing of the growth plate.
- These injuries are almost always diagnosed retrospectively, when a growth arrest has occurred.



A



B





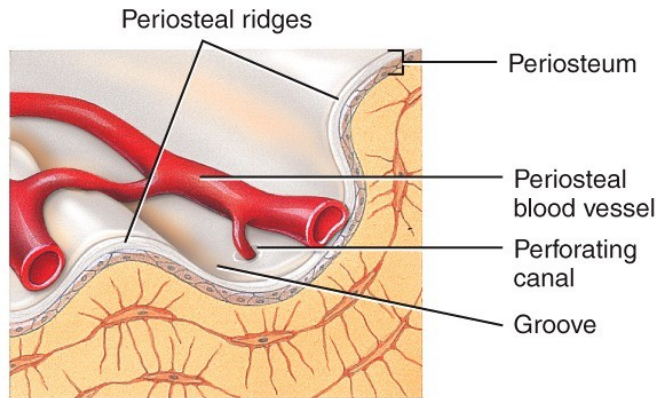


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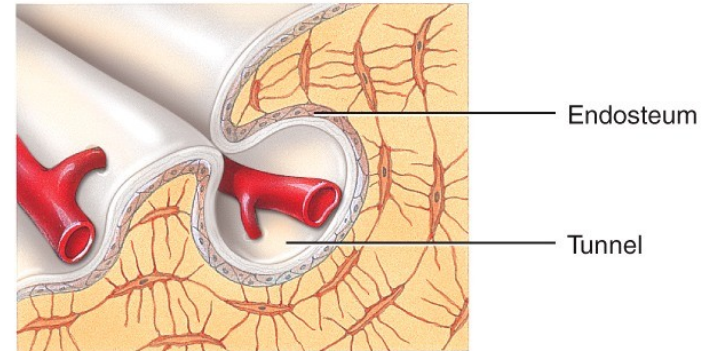
# Endochondral Growth – Length and Width

- The cartilage model grows in length by mitosis and by the deposition of extracellular matrix
- In contrast, growth of cartilage in thickness is due mainly to the addition of more extracellular matrix to the periphery

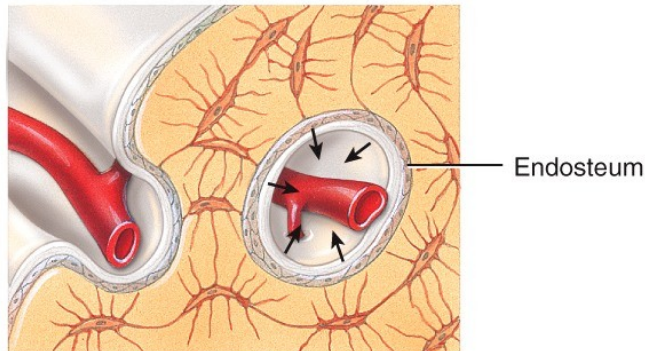
# Bone Growth in Thickness



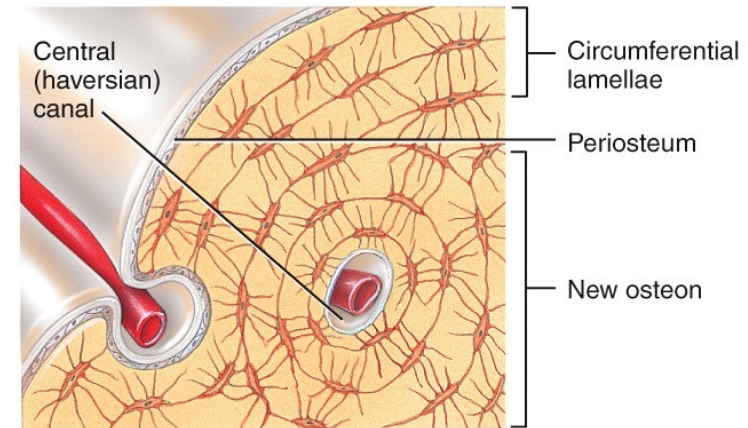
- 1 Ridges in periosteum create groove for periosteal blood vessel.



- 2 Periosteal ridges fuse, forming an endosteum-lined tunnel.



- 3 Osteoblasts in endosteum build new concentric lamellae inward toward center of tunnel, forming a new osteon.



- 4 Bone grows outward as osteoblasts in periosteum build new circumferential lamellae. Osteon formation repeats as new periosteal ridges fold over blood vessels.

# Bone Growth in Thickness

Like cartilage, bone can grow in thickness (diameter) only by appositional growth

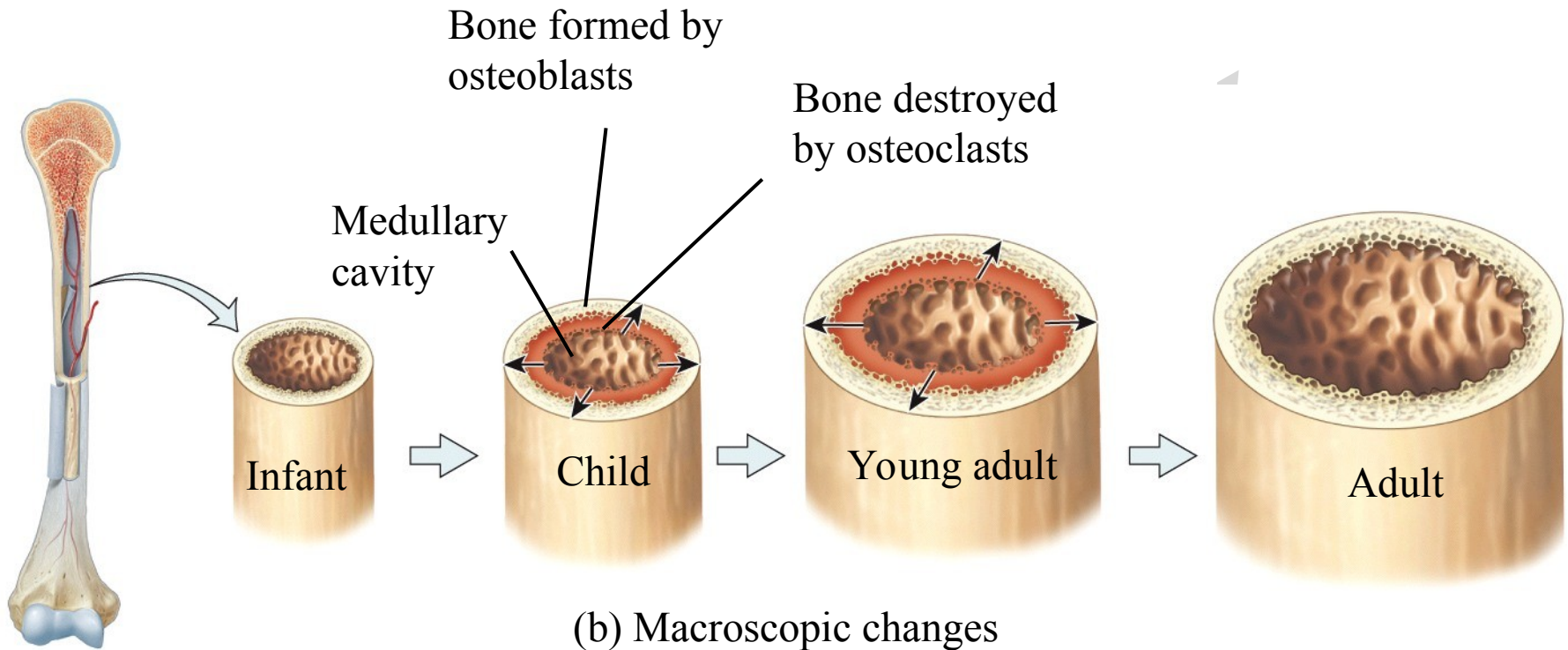
**1. At the bone surface, periosteal cells differentiate into *osteoblasts***, which secrete the collagen fibers and other organic molecules that form bone extracellular matrix. The osteoblasts become surrounded by extracellular matrix and *develop into osteocytes*. This process forms bone ridges on either side of a periosteal blood vessel. The ridges slowly enlarge and create a groove for the periosteal blood vessel.

**2. Eventually, the ridges fold together and fuse**, and the groove becomes a tunnel that encloses the blood vessel. The former *periosteum now becomes the endosteum* that lines the tunnel.

**3. Osteoblasts in the endosteum deposit bone extracellular matrix**, forming new concentric lamellae. The formation of additional concentric lamellae proceeds inward toward the periosteal blood vessel. In this way, the tunnel fills in, and a new osteon is created.

**4. As an osteon is forming, osteoblasts under the periosteum deposit new circumferential lamellae**, further increasing the thickness of the bone. As additional periosteal blood vessels become enclosed as in step , the growth process continues.

# Bone Growth in Thickness



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# Animation:

- Bone Dynamics and Tissue

# Remodeling of Bone

The ongoing replacement of old bone tissue by new bone tissue. It involves:

**Bone resorption** = breakdown of bone ECM

- The removal of minerals and collagen fibers from bone by osteoclasts.

**Bone deposition** = formation of bone ECM

- The addition of minerals and collagen fibers to bone by osteoblasts.
- Like skin, bone forms before birth but continually renews itself.
- At any given time, about 5 percent of the total bone mass in the body is being remodeled.

# Remodeling of Bone

- **renewal rate for compact bone tissue is ~ 4% per year, for spongy bone tissue ~20% per year.**
- takes place at different rates in different regions of the body.
- removes injured bone, replacing it with new bone tissue.
- triggered by factors such as exercise, lifestyle modifications, and changes in diet.
- Strength dependent on stresses
- Strain patterns
- new bone is more resistant to fracture than old bone.

# Remodeling of Bone

- The distal portion of the femur is replaced about every four months. By contrast, bone in certain areas of the shaft of the femur will not be replaced completely during an individual's life.
- Even after bones have reached their adult shapes and sizes, old bone is continually destroyed and new bone is formed in its place.
- Since the strength of bone is related to the degree to which it is stressed, if newly formed bone is subjected to heavy loads, it will grow thicker and therefore be stronger than the old bone.
- Also, the shape of a bone can be altered for proper support based on the strain patterns experienced during the remodeling process.
- Finally, new bone is more resistant to fracture than old bone.

# Clinical Connections - Orthodontics

- Branch of dentistry concerned with the prevention and correction of poorly aligned teeth.
- The movement of teeth by braces places a stress on the bone that forms the sockets that anchor the teeth.
- In response to this artificial stress, osteoclasts and osteoblasts remodel the sockets so that the teeth align properly.

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# Animation:

- Regulation of Bone Growth & Blood Calcium

# Clinical Connection - Osteoporosis

- Osteoporosis literally means “porous bones”
- The problem is that bone resorption (destruction) outpaces bone deposition (formation)
- Estrogens and testosterone stimulate osteoblast activity and synthesis of bone matrix.

# Osteoporosis Risk Factors

- Gender: females more than males: **WHY?**
  - a family history of the disease
  - European or Asian ancestry
  - thin or small body build
  - inactive lifestyle
  - cigarette smoking
  - diet low in calcium and vitamin D
  - 2 alcoholic drinks a day
  - the use of certain medications like PPIs
- 1) Women's bones are less massive than men's bones, and
- 2) production of estrogens in women declines dramatically at menopause, while production of the main androgen, testosterone, in older men wanes gradually and only slightly.

# Osteoporosis Treatment

- diet high in calcium is important to reduce the risk of fractures.
- Vitamin D is necessary for the body to utilize calcium.
- Resistance exercise - regular performance of weight-bearing exercises has been shown to maintain and build bone mass. (walking, jogging, hiking, climbing stairs, playing tennis, and dancing).
- Medications:

# Osteoporosis Treatment - Medications

(1) **Anti-reabsorptive drugs** slow down the progression of bone loss.

- **bisphosphonates**, which inhibit osteoclasts (Fosamax<sup>®</sup>, Actonel<sup>®</sup>, Boniva<sup>®</sup>, and calcitonin);
- **selective estrogen receptor modulators**, which mimic the effects of estrogens without unwanted side effects (Raloxifene<sup>®</sup>, Evista<sup>®</sup>);
- **Estrogen replacement therapy (ERT)**, which replaces estrogens lost during and after menopause (Premarin<sup>®</sup>), and **hormone replacement therapy (HRT)**, which replaces estrogens and progesterone lost during and after menopause (Prempro<sup>®</sup>).

• *ERT helps maintain and increase bone mass after menopause. Women on ERT have a slight increased risk of stroke and blood clots. HRT also helps maintain and increase bone mass. Women on HRT have increased risks of heart disease, breast cancer, stroke, blood clots, and dementia.*

# Osteoporosis Treatment - Medications

(2) **Bone-building drugs** promote increasing bone mass.

- parathyroid hormone (PTH), which stimulates osteoblasts to produce new bone (Forteo®).

# Osteoporosis



**SEM** 30x

(A) Normal bone



**SEM** 30x

(B) Osteoporotic bone

P. Motta/Photo Researchers, Inc.

# Clinical Connection – Paget's Disease

- excessive proliferation of osteoclasts so that bone resorption occurs faster than bone deposition.
- In response, osteoblasts attempt to compensate, but the new bone is weaker because it has a higher proportion of spongy to compact bone, mineralization is decreased, and the newly synthesized extracellular matrix contains abnormal proteins.
- The newly formed bone, especially that of the pelvis, limbs, lower vertebrae, and skull, becomes enlarged, hard, and brittle and fractures easily.

# Bone Fractures

A **fracture** is any break in a bone.

Named according to

- their severity,
- the shape or position of the fracture line,
- the physician who first described them.

# Bone Fractures

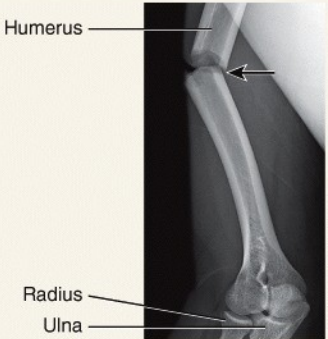
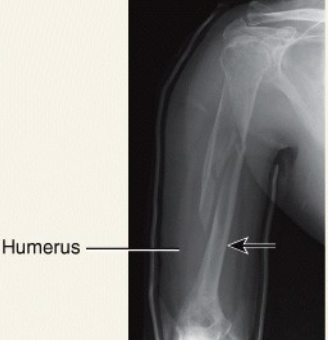
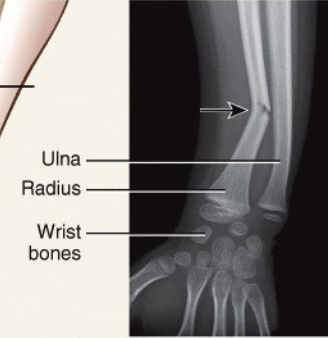
- In some cases, a bone may fracture without visibly breaking.
- **stress fracture** is a series of microscopic fissures in bone that forms without any evidence of injury to other tissues.
- In healthy adults, stress fractures result from repeated, strenuous activities such as running, jumping, or aerobic dancing.
- quite painful and also result from disease processes that disrupt normal bone calcification, such as osteoporosis. About 25 percent of stress fractures involve the tibia. Although standard x-ray images often fail to reveal the presence of stress fractures, they show up clearly in a bone scan.

# Common Types of Bone Fractures

- Open (compound) fracture
- Comminuted fracture
- Greenstick fracture
- Impacted fracture
- Pott's fracture
- Colles' fracture
- Stress fracture

TABLE 6.2

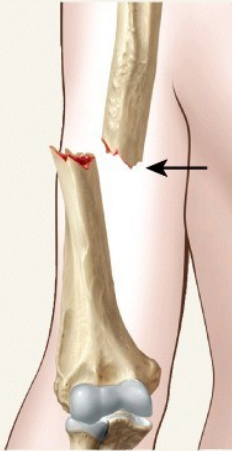
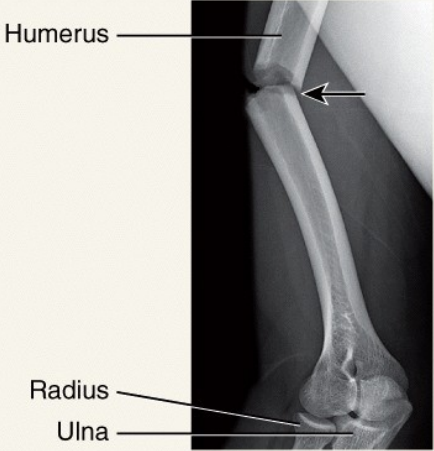
## Some Common Fractures

| FRACTURE                                                                              | DESCRIPTION                                                                                                                                                                                                                                                                                                 | ILLUSTRATION                                                                         | RADIOGRAPH                                                                                                                                                        |
|---------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Open (Compound)                                                                       | The broken ends of the bone protrude through the skin. Conversely, a <b>closed (simple) fracture</b> does not break the skin.                                                                                                                                                                               |   | <br>Humerus<br>Radius<br>Ulna<br><small>Courtesy Dr. Brent Layton</small>      |
| Comminuted<br>(KOM-i-noo-ted;<br><i>com</i> -=together;<br><i>-minuted</i> =crumbled) | The bone is splintered, crushed, or broken into pieces at the site of impact, and smaller bone fragments lie between the two main fragments.                                                                                                                                                                |   | <br>Humerus<br><small>Courtesy Per Amundson, M.D.</small>                      |
| Greenstick                                                                            | A partial fracture in which one side of the bone is broken and the other side bends; similar to the way a green twig breaks on one side while the other side stays whole, but bends; occurs only in children, whose bones are not fully ossified and contain more organic material than inorganic material. |  | <br>Ulna<br>Radius<br>Wrist bones<br><small>Courtesy Dr. Brent Layton</small> |

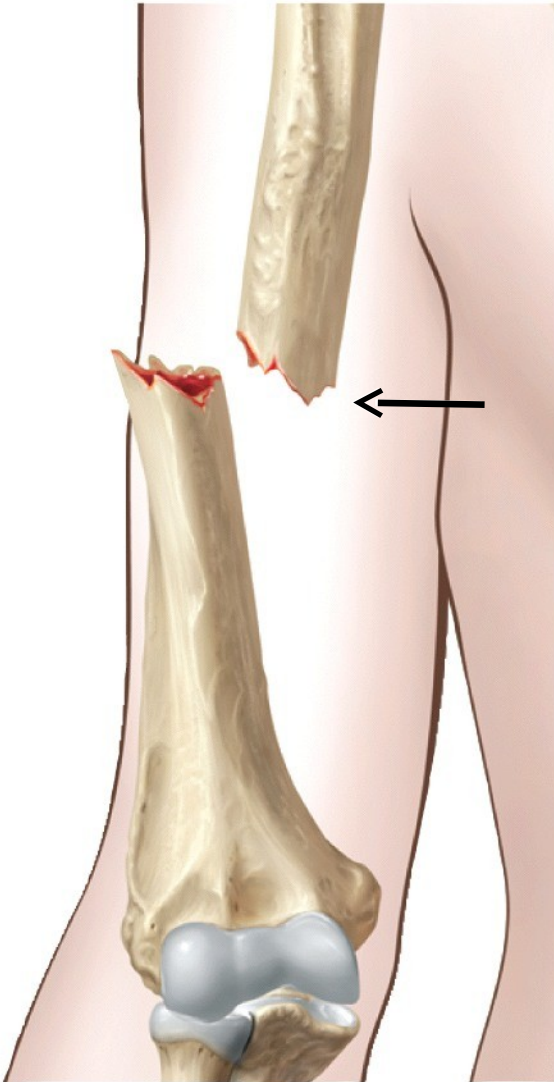
# Common Types of Bone Fractures

**TABLE 6.2**

## Some Common Fractures

| FRACTURE        | DESCRIPTION                                                                                                                   | ILLUSTRATION                                                                        | RADIOGRAPH                                                                                                                                                          |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Open (Compound) | The broken ends of the bone protrude through the skin. Conversely, a <b>closed (simple) fracture</b> does not break the skin. |  |  <p>Humerus —</p> <p>Radius —</p> <p>Ulna —</p> <p>Courtesy Dr. Brent Layton</p> |

## Open (Compound)



Humerus

Radius

Ulna

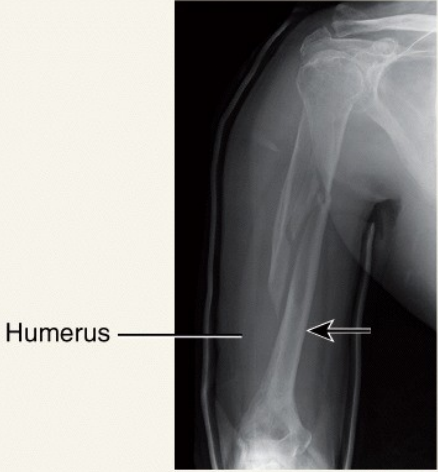


Courtesy Dr. Brent Layton

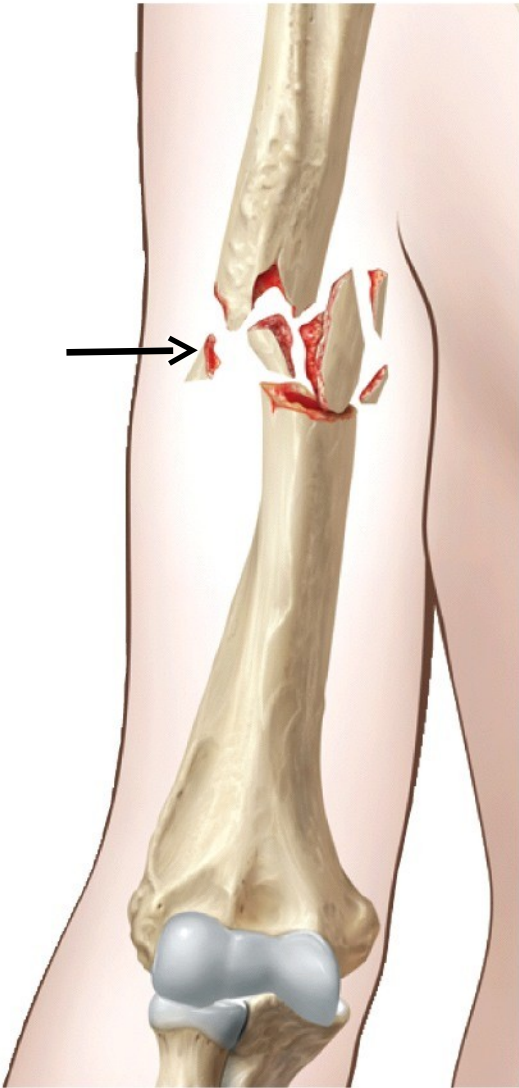
# Common Types of Bone Fractures

**TABLE 6.2**

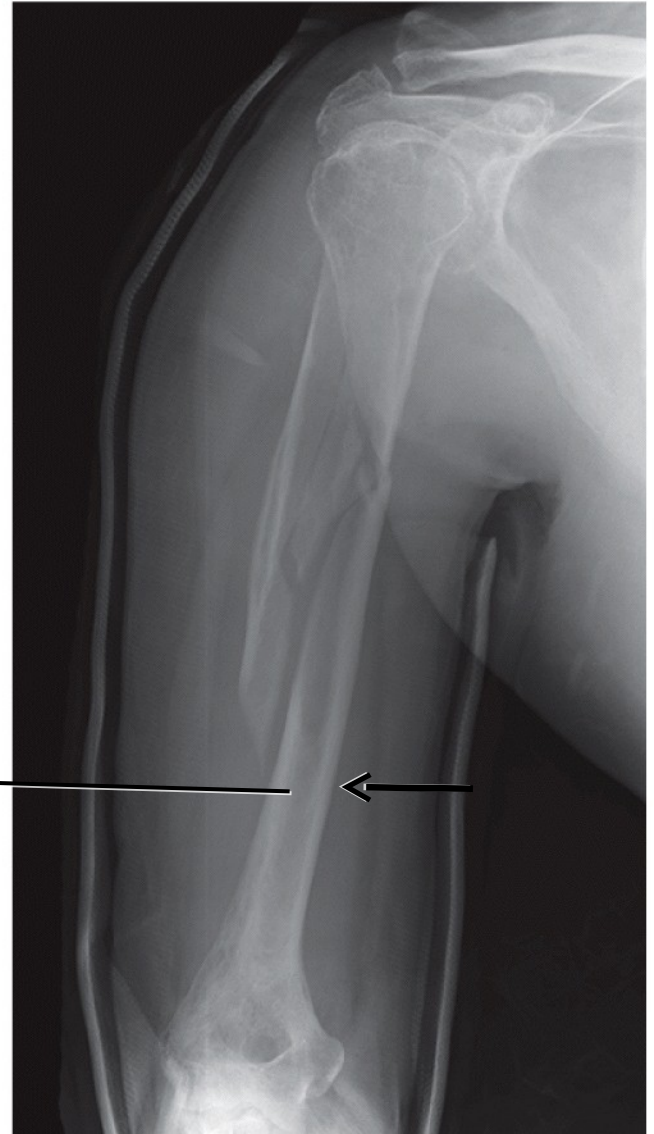
## Some Common Fractures

| FRACTURE                                                                                     | DESCRIPTION                                                                                                                                  | ILLUSTRATION                                                                        | RADIOGRAPH                                                                                                                             |
|----------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| <b>Comminuted</b><br>(KOM-i-noo-ted;<br><i>com-</i> =together;<br><i>-minuted</i> =crumbled) | The bone is splintered, crushed, or broken into pieces at the site of impact, and smaller bone fragments lie between the two main fragments. |  |  <p>Humerus</p> <p>Courtesy Per Amundson, M.D.</p> |

## Comminuted



Humerus

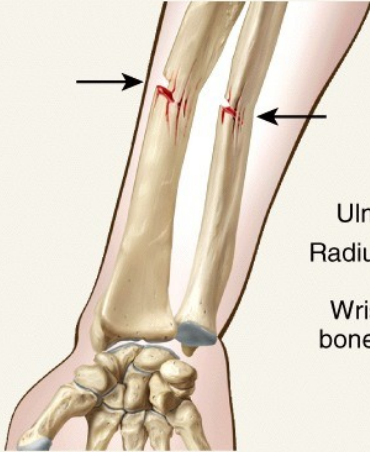
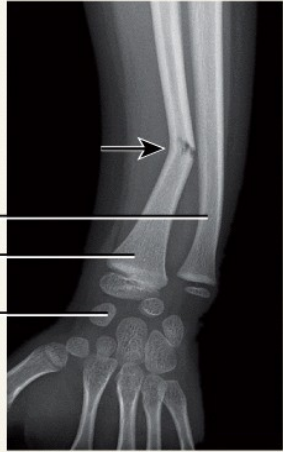


Courtesy Per Amundson, M.D.

# Common Types of Bone Fractures

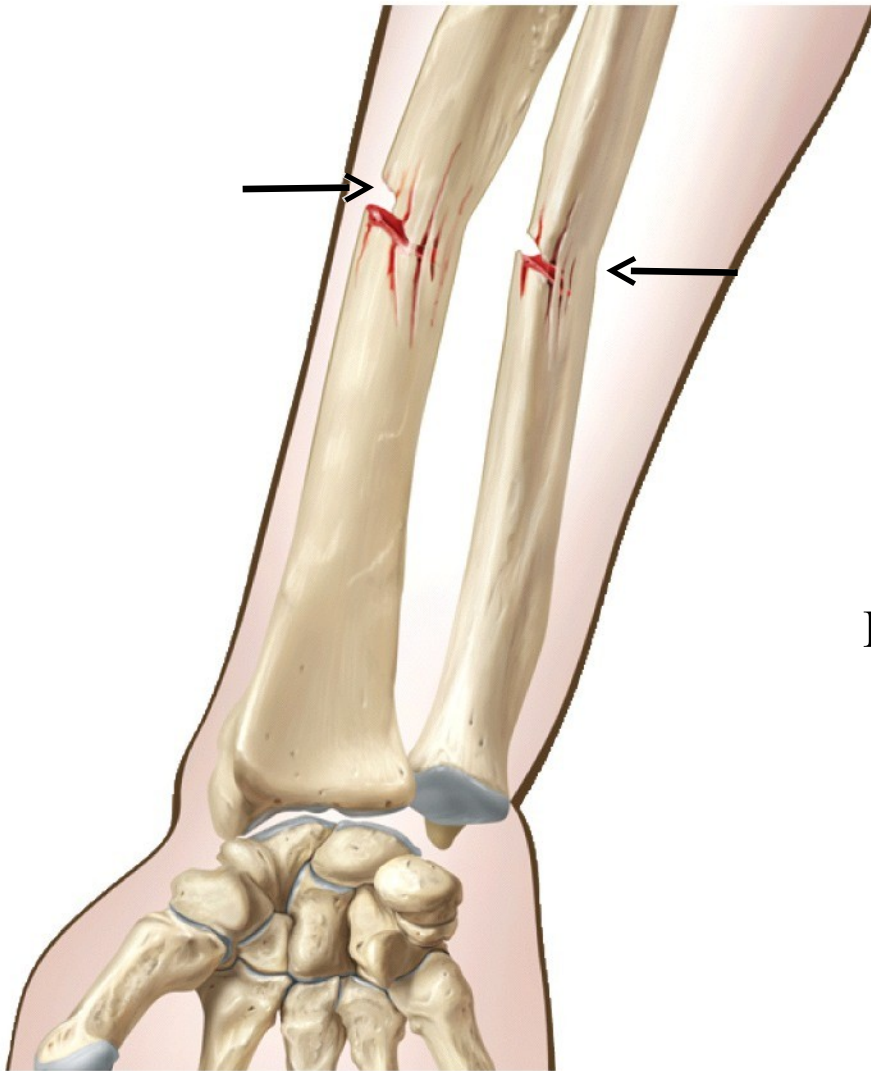
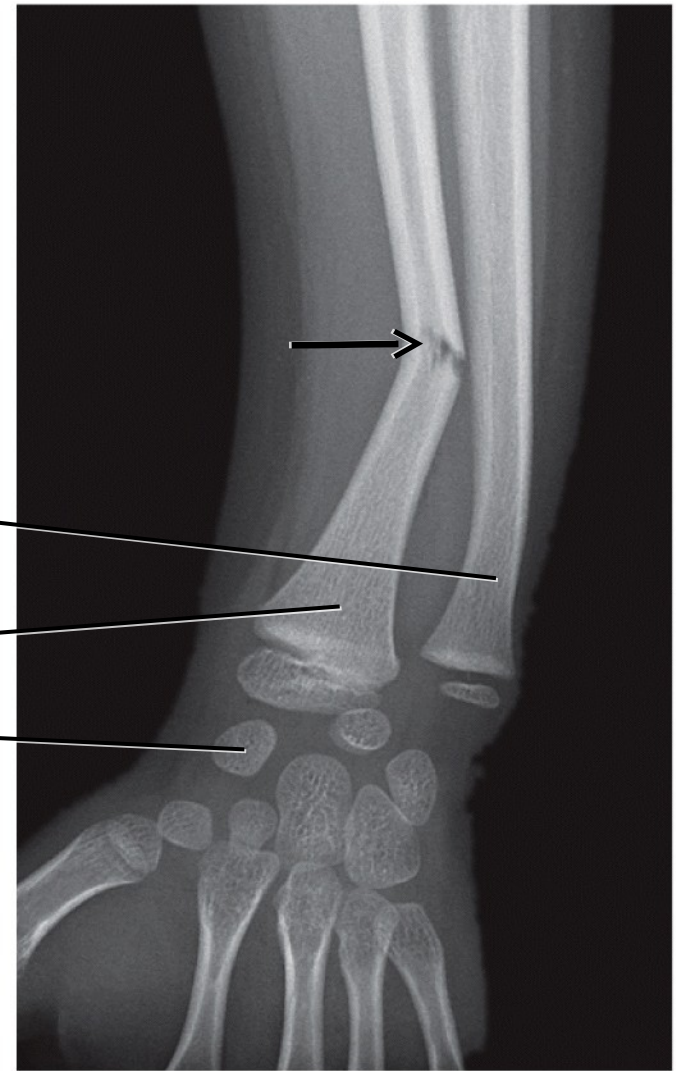
**TABLE 6.2**

## Some Common Fractures

| FRACTURE   | DESCRIPTION                                                                                                                                                                                                                                                                                                 | ILLUSTRATION                                                                        | RADIOGRAPH                                                                                                           |
|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|
| Greenstick | A partial fracture in which one side of the bone is broken and the other side bends; similar to the way a green twig breaks on one side while the other side stays whole, but bends; occurs only in children, whose bones are not fully ossified and contain more organic material than inorganic material. |  | <br>Ulna<br>Radius<br>Wrist bones |

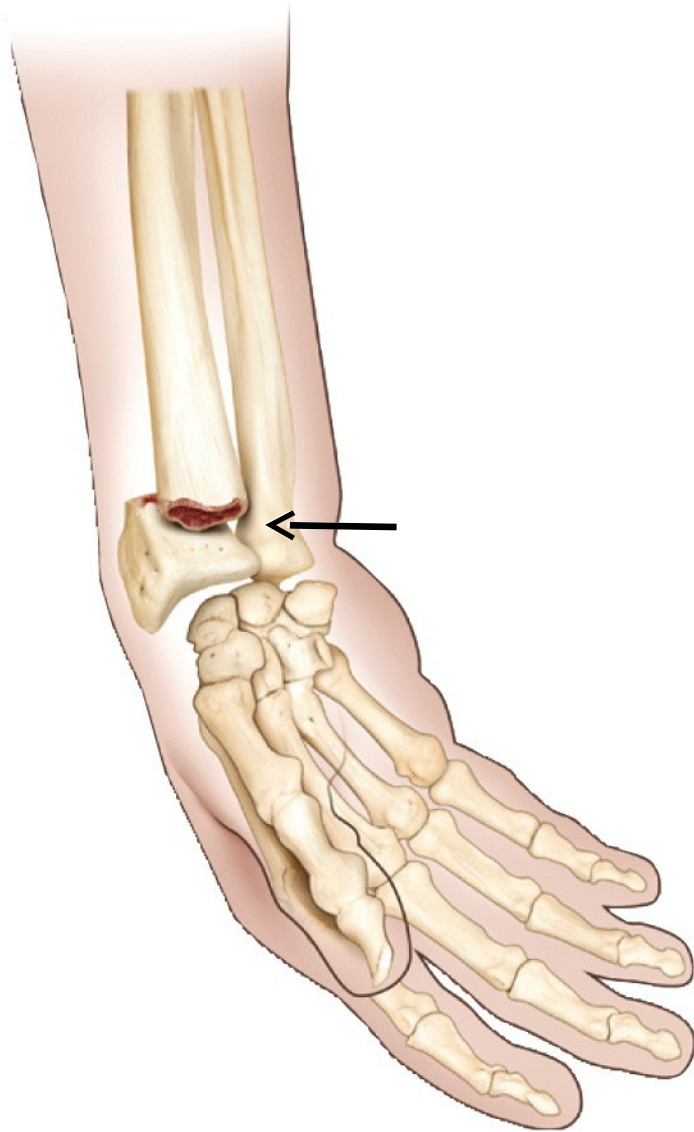
Courtesy Dr. Brent Layton

## Greenstick



Courtesy Dr. Brent Layton

## Colles



Radius

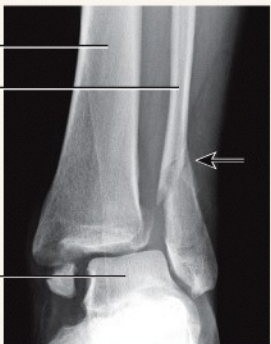
Ulna

Wrist  
bones



Watney Collection/Phototake

**TABLE 6.2****Some Common Fractures**

| <b>FRACTURE</b>        | <b>DESCRIPTION</b>                                                                                                     | <b>ILLUSTRATION</b>                                                                                                                                                                                                                                                                    | <b>RADIOGRAPH</b>                                                                                                                                                                                                                                                                                                                           |
|------------------------|------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Impacted</b>        | One end of the fractured bone is forcefully driven into the interior of the other.                                     |  An anatomical illustration of a humerus (upper arm bone) showing an impacted fracture. A black arrow points to the fracture site where the bone ends are driven into each other.                   |  An anteroposterior radiograph of a humerus showing an impacted fracture. A white arrow points to the fracture site. The bone is labeled 'Humerus'.<br><small>Courtesy Dr. Brent Layton</small>                                                          |
| <b>Pott</b>            | Fracture of the distal end of the lateral leg bone (fibula), with serious injury of the distal tibial articulation.    |  An anatomical illustration of a Pott fracture, showing a fracture of the distal end of the fibula. A black arrow points to the fracture site. Labels include 'Tibia', 'Fibula', and 'Ankle bones'. |  An anteroposterior radiograph of a Pott fracture, showing a fracture of the distal end of the fibula. A white arrow points to the fracture site. Labels include 'Tibia', 'Fibula', and 'Ankle bones'.<br><small>Courtesy Dr. Brent Layton</small>       |
| <b>Colles (KOL-ēz)</b> | Fracture of the distal end of the lateral forearm bone (radius) in which the distal fragment is displaced posteriorly. |  An anatomical illustration of a Colles fracture, showing a fracture of the distal end of the radius. A black arrow points to the fracture site.                                                   |  An anteroposterior radiograph of a Colles fracture, showing a fracture of the distal end of the radius. A white arrow points to the fracture site. Labels include 'Radius', 'Ulna', and 'Wrist bones'.<br><small>Watney Collection / Phototake</small> |

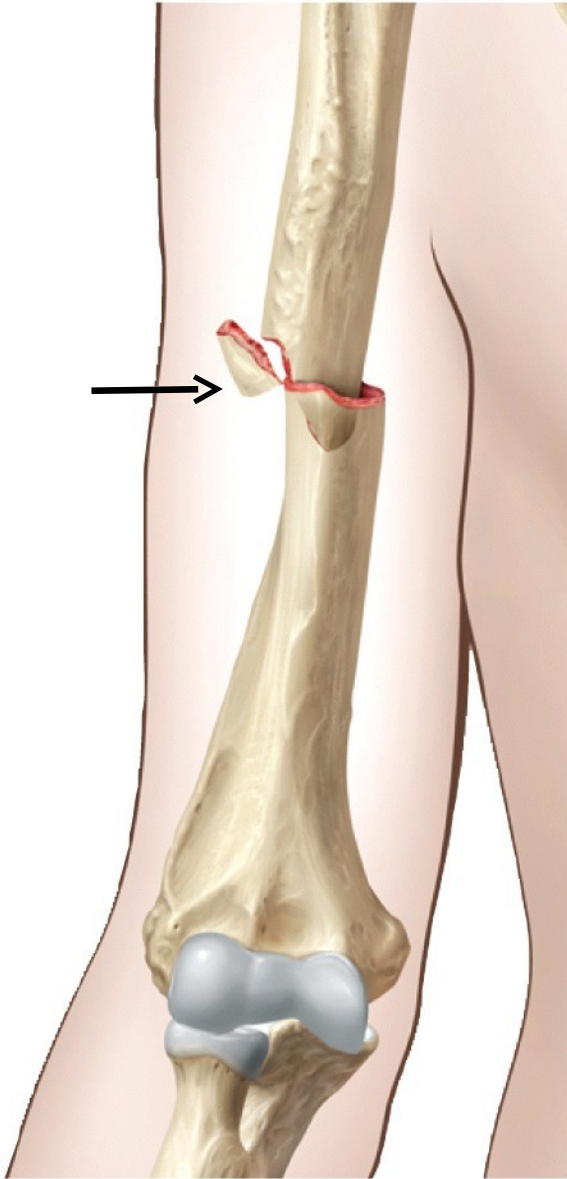
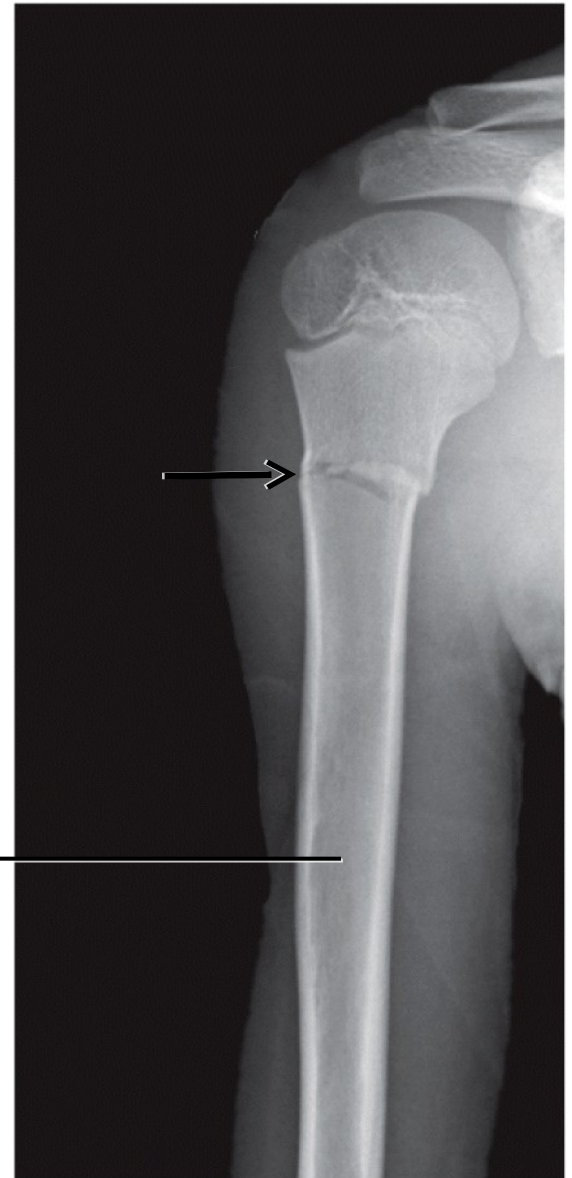
# Common Types of Bone Fractures

**TABLE 6.2**

**Some Common Fractures**

| FRACTURE | DESCRIPTION                                                                        | ILLUSTRATION                                                                                                                                                                                                                                                                                          | RADIOGRAPH                                                                                                                                 |
|----------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| Impacted | One end of the fractured bone is forcefully driven into the interior of the other. |  An anatomical illustration of a human arm showing a humerus with a fracture. A red line indicates the fracture site, and a black arrow points to the point of impact where one bone end is driven into the other. | <br>Humerus<br><small>Courtesy Dr. Brent Layton</small> |

## Impacted



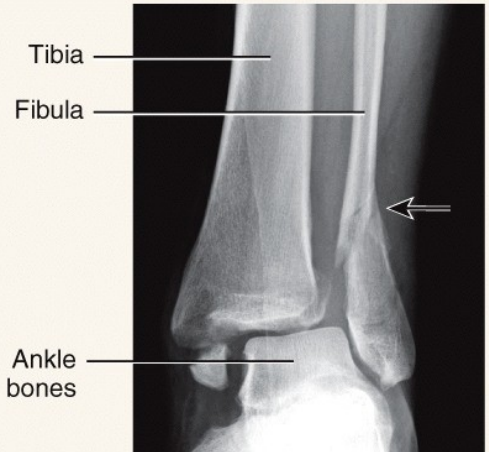
Humerus

Courtesy Dr. Brent Layton

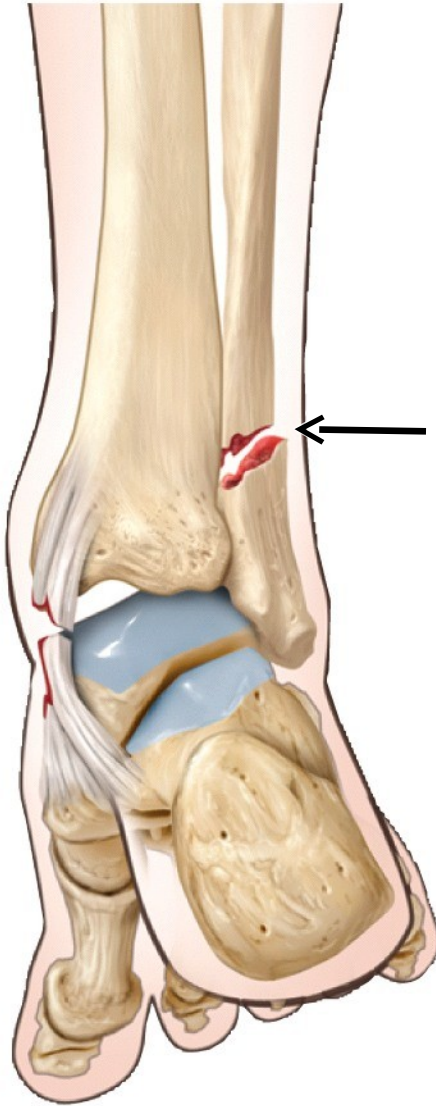
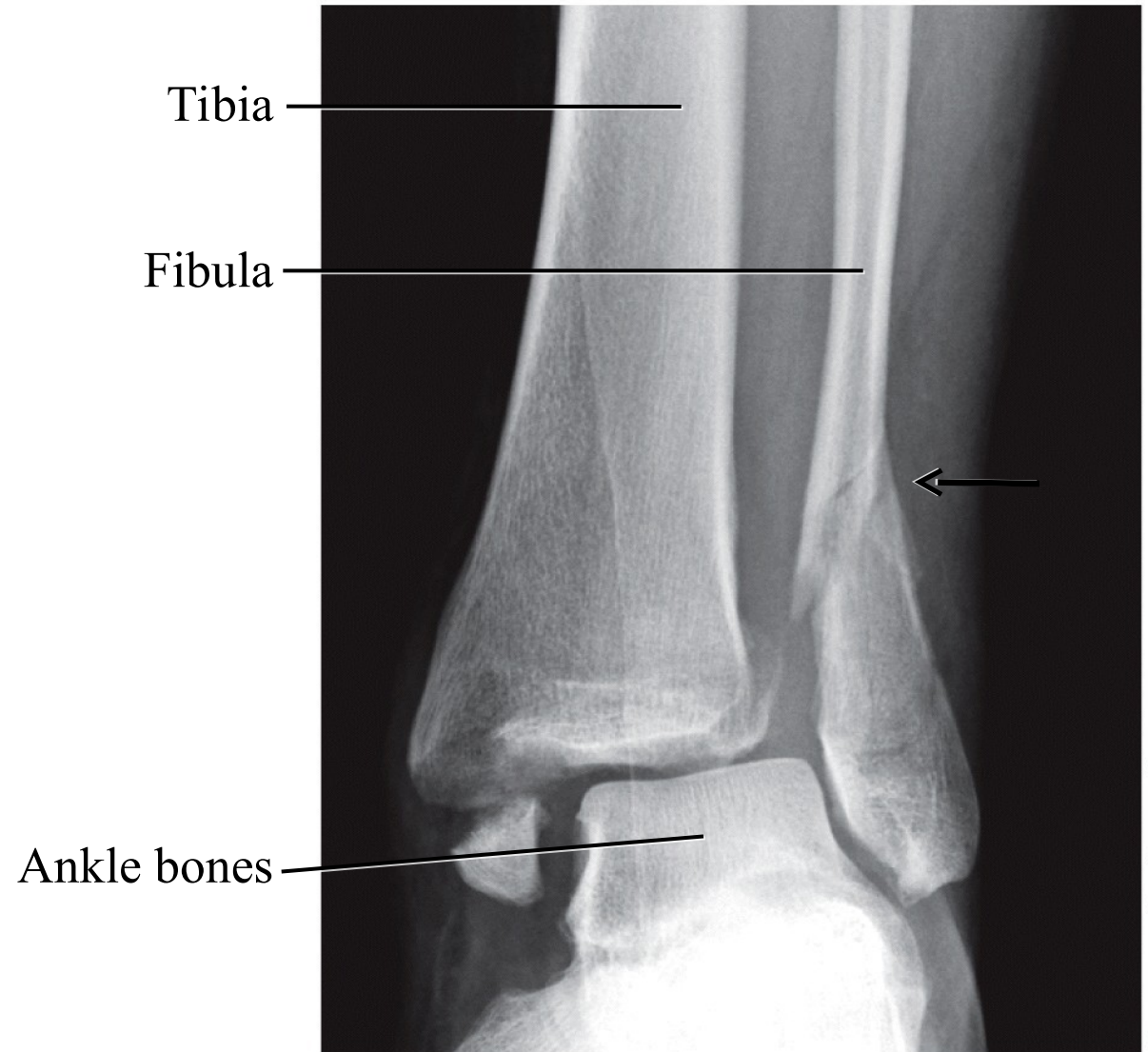
# Common Types of Bone Fractures

**TABLE 6.2**

**Some Common Fractures**

| FRACTURE | DESCRIPTION                                                                                                         | ILLUSTRATION                                                                        | RADIOGRAPH                                                                                                                                                         |
|----------|---------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Pott     | Fracture of the distal end of the lateral leg bone (fibula), with serious injury of the distal tibial articulation. |  |  <p>Tibia</p> <p>Fibula</p> <p>Ankle bones</p> <p>Courtesy Dr. Brent Layton</p> |

## Pott



Courtesy Dr. Brent Layton

# Common Types of Bone Fractures

**TABLE 6.2**

## Some Common Fractures

| FRACTURE        | DESCRIPTION                                                                                                            | ILLUSTRATION                                                                                                                                                                                                                                                                                                                             | RADIOGRAPH                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-----------------|------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Colles (KOL-ēz) | Fracture of the distal end of the lateral forearm bone (radius) in which the distal fragment is displaced posteriorly. |  An anatomical illustration of a human forearm and hand. The radius and ulna are shown in yellow. A black arrow points to a fracture site on the distal end of the radius, where the bone is broken and the distal fragment is displaced posteriorly. |  An anteroposterior (AP) radiograph of a human forearm and wrist. The radius and ulna are visible. A black arrow points to a fracture site on the distal end of the radius, where the bone is broken and the distal fragment is displaced posteriorly. Labels with leader lines point to the Radius, Ulna, and Wrist bones. A vertical credit line on the right reads 'Watney Collection / Phototake'. |

# Treatment of Bone Fractures

Vary according to age, type of fracture, and the bone involved

Ultimate goals:

- realignment of the bone fragments,
- immobilization to maintain realignment, and
- restoration of function.

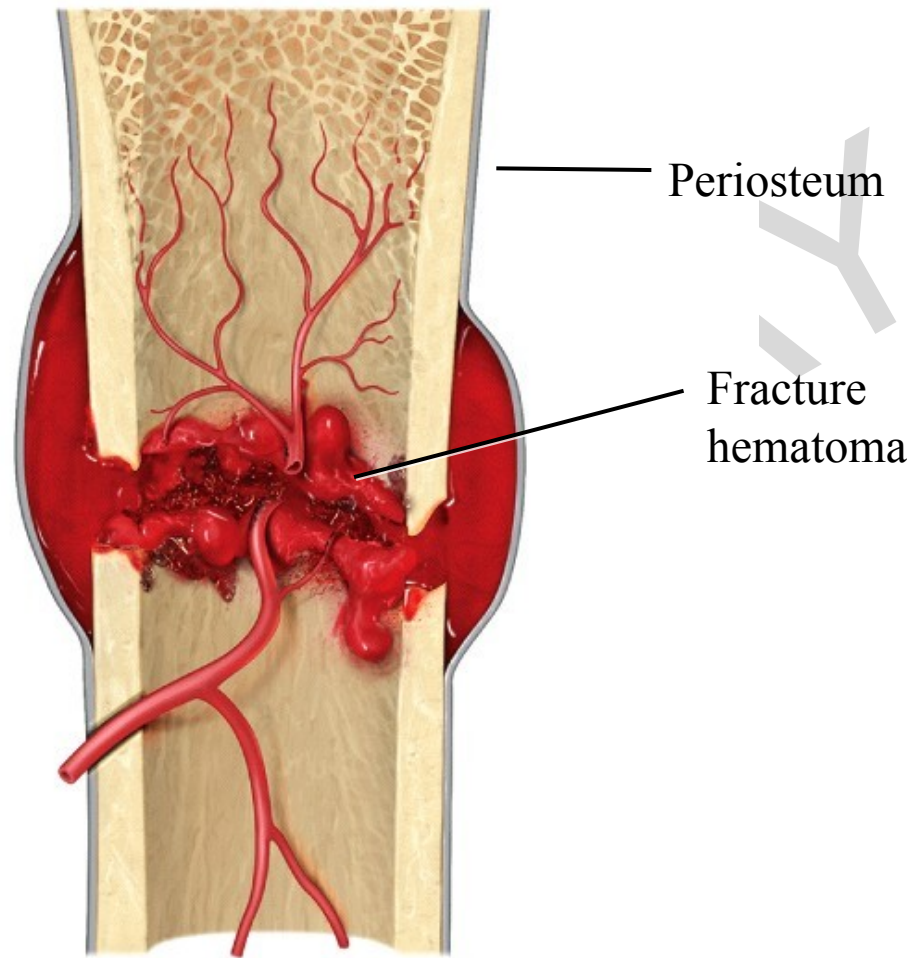
**Reduction** (commonly referred to as setting a fracture) - the fractured ends brought into alignment.

- **closed reduction** - fractured ends are brought into alignment by manual manipulation, skin remains intact
- **open reduction**, the fractured ends are brought into alignment by a surgical procedure using internal fixation devices such as screws, plates, pins, rods, and wires
- Following reduction, a fractured bone may be kept immobilized by a cast, sling, splint, elastic bandage, external fixation device, or a combination of these devices.

# Bone Fracture Repair

- Formation of fracture hematoma
- Fibrocartilaginous callus formation
- Bony callus formation
- Bone remodeling

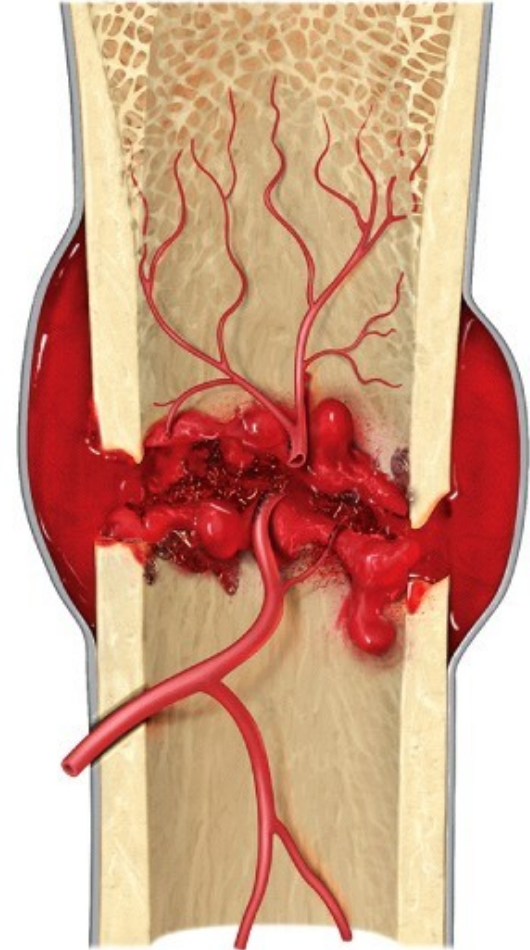
# Steps in Repair of Bone Fracture



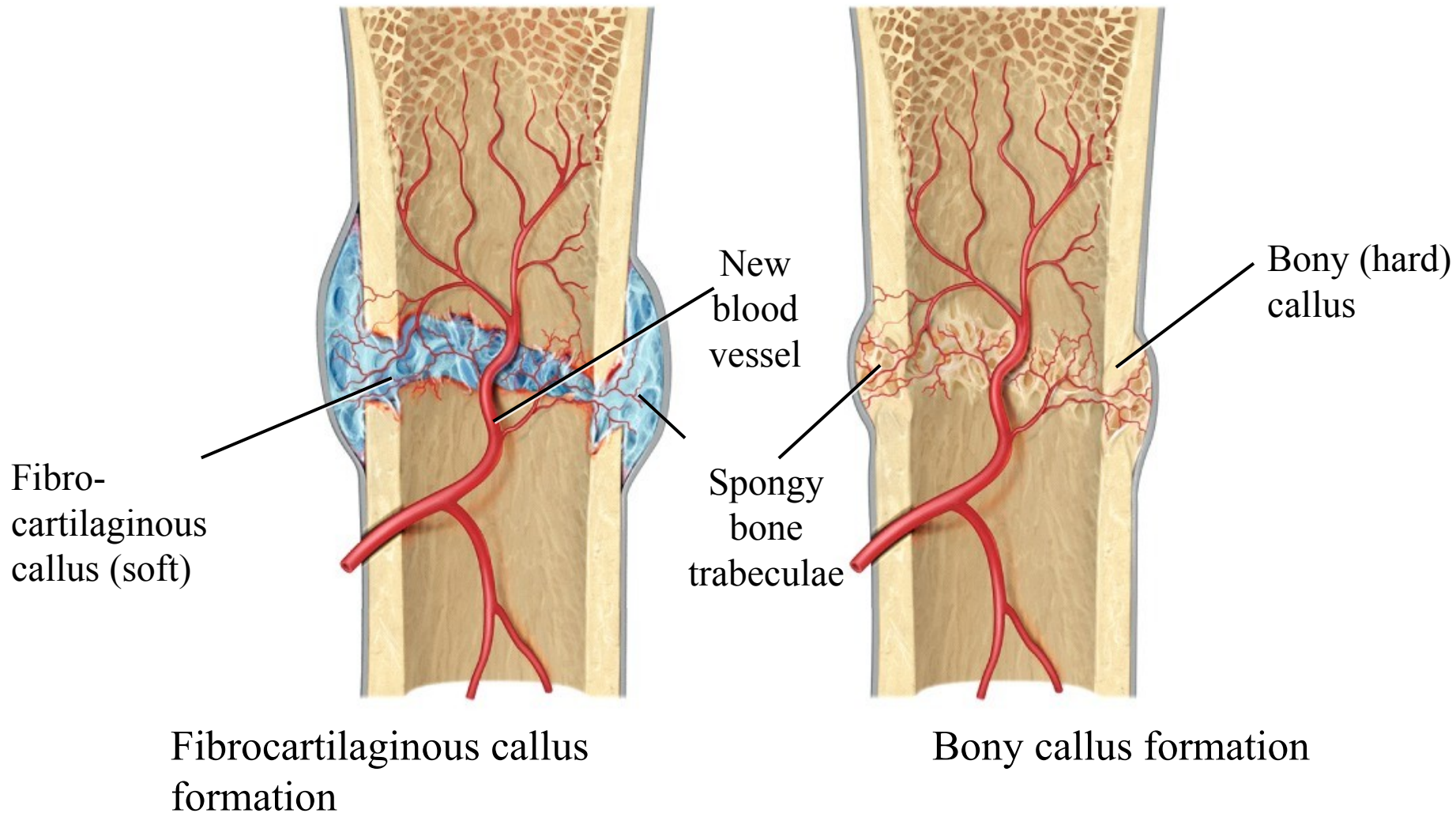
- 1 Reactive phase: formation of fracture hematoma

# 1- Reactive phase: formation of fracture hematoma

**REACTIVE PHASE: Formation of fracture hematoma.** Blood vessels crossing the fracture line are broken. As blood leaks from the torn ends of the vessels, it forms a mass of blood (usually clotted) around the site of the fracture. This clot, called a **fracture hematoma** usually forms 6 to 8 hours after the injury. Because the circulation of blood stops at the site where the fracture hematoma forms, nearby bone cells die. Swelling and inflammation occur in response to dead bone cells, producing additional cellular debris. Phagocytes (neutrophils and macrophages) and osteoclasts begin to remove the dead or damaged tissue in and around the fracture hematoma. This stage may last up to several weeks.



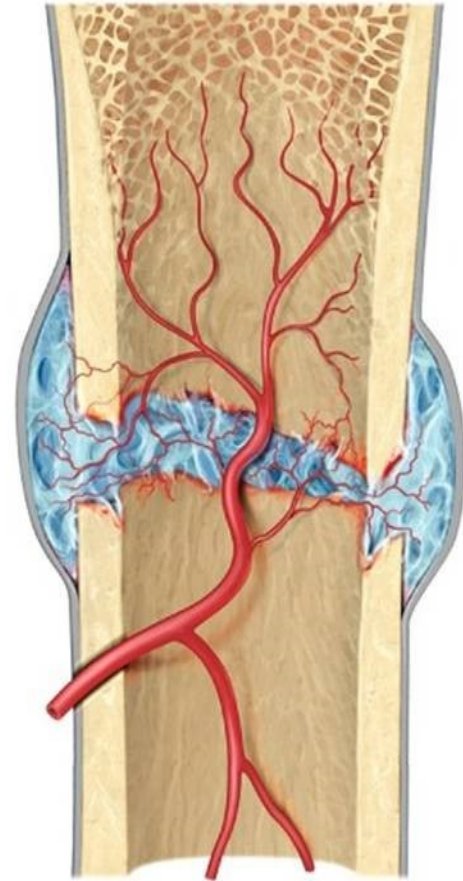
# Steps in Repair of Bone Fracture



## 2- REPARATIVE PHASE

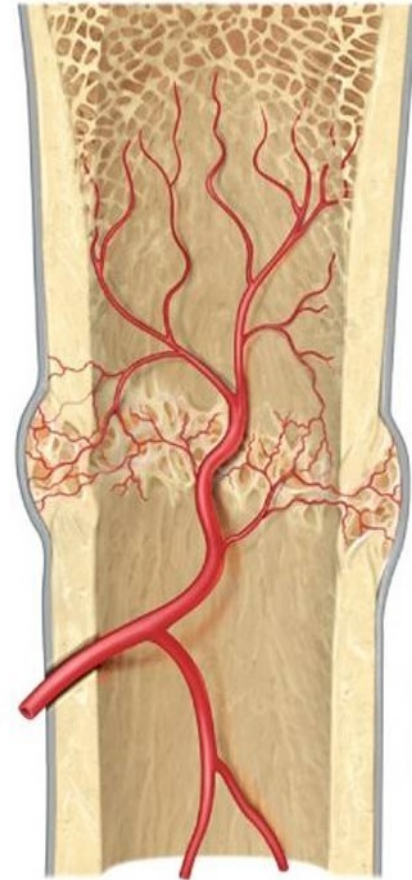
### Fibrocartilaginous callus formation.

Fibroblasts from the periosteum invade the fracture site and produce collagen fibers. In addition, cells from the periosteum develop into chondroblasts and begin to produce fibrocartilage in this region. These events lead to the development of a **fibrocartilaginous (soft) callus**, a mass of repair tissue consisting of collagen fibers and cartilage that bridges the broken ends of the bone. Formation of the fibrocartilaginous callus takes about three weeks.

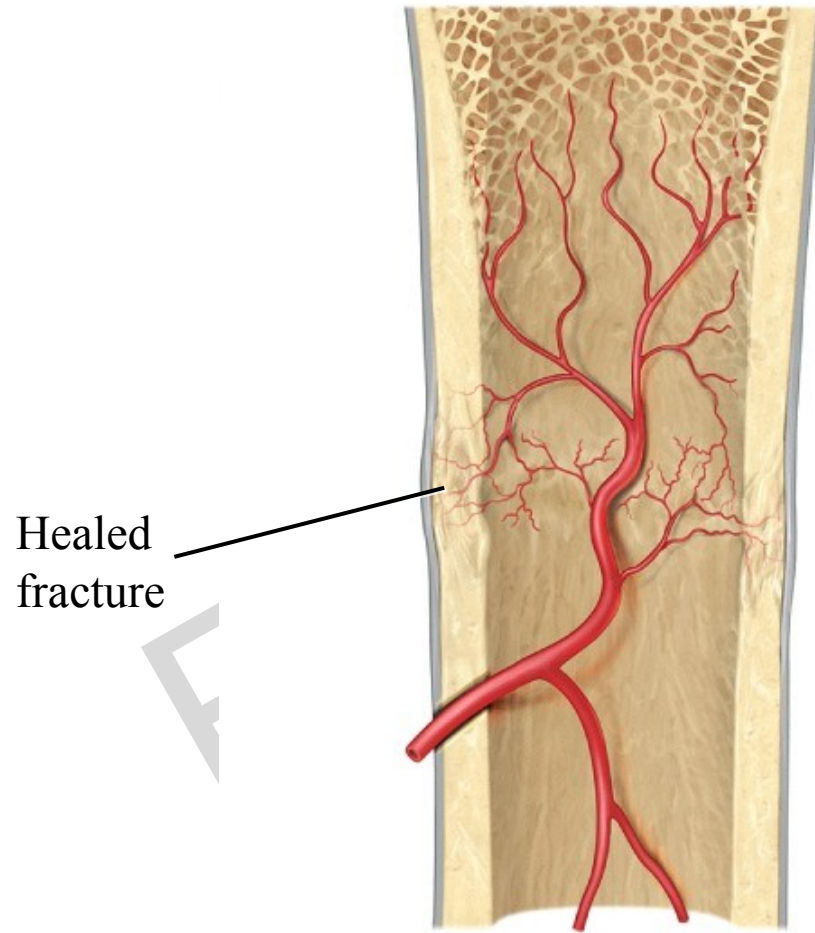


## 2- REPARATIVE PHASE

**Bony callus formation.** In areas closer to well-vascularized healthy bone tissue, osteogenic cells develop into osteoblasts, which begin to produce spongy bone trabeculae. The trabeculae join living and dead portions of the original bone fragments. In time, the fibrocartilage is converted to spongy bone, and the callus is then referred to as a **bony (hard) callus**. The bony callus lasts about three to four months.



# Steps in Repair of Bone Fracture



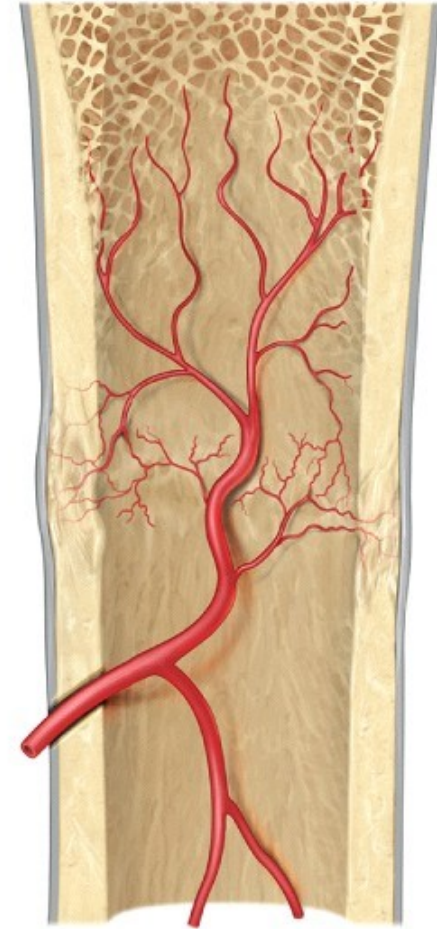
3

Bone remodeling phase

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# 3- BONE REMODELING PHASE

**BONE REMODELING PHASE:** The final phase of fracture repair is **bone remodeling** of the callus. Dead portions of the original fragments of broken bone are gradually resorbed by osteoclasts. Compact bone replaces spongy bone around the periphery of the fracture. Sometimes, the repair process is so thorough that the fracture line is undetectable, even in a radiograph (x-ray). However, a thickened area on the surface of the bone remains as evidence of a healed fracture.



# Bone Remodeling

## *Interactions Animation*

- Bone Growth and Remodeling

R.BISHAY

You must be connected to the internet to run this animation.

# The Effects of Aging on Bone Tissue

- There are two principal effects of aging on bone tissue
  - Loss of bone mass results from the loss of calcium and other minerals from bone extracellular matrix (demineralization)
  - Brittleness occurs as the production of collagen fibers (which give bone tissue its tensile strength) slows

# Factors Affecting Bone Growth and Repair

- Availability of minerals, particularly calcium and phosphorus
- Availability of vitamins (A, C, D, K, B<sub>12</sub>)
- Availability of specific hormones (insulin, insulin-like growth factors (IGFs), and the thyroid hormones)

**TABLE 6.3****Summary of Factors That Affect Bone Growth**

| FACTOR                         | COMMENT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>MINERALS</b>                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Calcium and phosphorus         | Make bone extracellular matrix hard.                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Magnesium                      | Helps form bone extracellular matrix.                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Fluoride                       | Helps strengthen bone extracellular matrix.                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Manganese                      | Activates enzymes involved in synthesis of bone extracellular matrix.                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>VITAMINS</b>                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Vitamin A                      | Needed for the activity of osteoblasts during remodeling of bone; deficiency stunts bone growth; toxic in high doses.                                                                                                                                                                                                                                                                                                                                                                                  |
| Vitamin C                      | Needed for synthesis of collagen, the main bone protein; deficiency leads to decreased collagen production, which slows down bone growth and delays repair of broken bones.                                                                                                                                                                                                                                                                                                                            |
| Vitamin D                      | Active form (calcitriol) is produced by the kidneys; helps build bone by increasing absorption of calcium from gastrointestinal tract into blood; deficiency causes faulty calcification and slows down bone growth; may reduce the risk of osteoporosis but is toxic if taken in high doses. People who use sunscreens, have minimal exposure to ultraviolet rays, or do not take vitamin D supplements may not have sufficient vitamin D to absorb calcium. This interferes with calcium metabolism. |
| Vitamins K and B <sub>12</sub> | Needed for synthesis of bone proteins; deficiency leads to abnormal protein production in bone extracellular matrix and decreased bone density.                                                                                                                                                                                                                                                                                                                                                        |

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**TABLE 6.3****Summary of Factors That Affect Bone Growth**

| FACTOR                                                       | COMMENT                                                                                                                                                                                                                                                                                                                                                                                                                              |
|--------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>HORMONES</b>                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Human growth hormone (hGH)</b>                            | Secreted by the anterior lobe of the pituitary gland; promotes general growth of all body tissues, including bone, mainly by stimulating production of insulinlike growth factors.                                                                                                                                                                                                                                                   |
| <b>Insulinlike growth factors (IGFs)</b>                     | Secreted by the liver, bones, and other tissues upon stimulation by human growth hormone; promotes normal bone growth by stimulating osteoblasts and by increasing the synthesis of proteins needed to build new bone.                                                                                                                                                                                                               |
| <b>Thyroid hormones<br/>(thyroxine and triiodothyronine)</b> | Secreted by thyroid gland; promote normal bone growth by stimulating osteoblasts.                                                                                                                                                                                                                                                                                                                                                    |
| <b>Insulin</b>                                               | Secreted by the pancreas; promotes normal bone growth by increasing the synthesis of bone proteins.                                                                                                                                                                                                                                                                                                                                  |
| <b>Sex hormones<br/>(estrogens and testosterone)</b>         | Secreted by the ovaries in women (estrogens) and by the testes in men (testosterone); stimulate osteoblasts and promote the sudden “growth spurt” that occurs during the teenage years; shut down growth at the epiphyseal plates around age 18–21, causing lengthwise growth of bone to end; contribute to bone remodeling during adulthood by slowing bone resorption by osteoclasts and promoting bone deposition by osteoblasts. |
| <b>Parathyroid hormone (PTH)</b>                             | Secreted by the parathyroid glands; promotes bone resorption by osteoclasts; enhances recovery of calcium ions from urine; promotes formation of the active form of vitamin D (calcitriol).                                                                                                                                                                                                                                          |
| <b>Calcitonin (CT)</b>                                       | Secreted by the thyroid gland; inhibits bone resorption by osteoclasts.                                                                                                                                                                                                                                                                                                                                                              |
| <b>EXERCISE</b>                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                                              | Weight-bearing activities stimulate osteoblasts and, consequently, help build thicker, stronger bones and retard loss of bone mass that occurs as people age.                                                                                                                                                                                                                                                                        |
| <b>AGING</b>                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                                              | As the level of sex hormones diminishes during middle age to older adulthood, especially in women after menopause, bone resorption by osteoclasts outpaces bone deposition by osteoblasts, which leads to a decrease in bone mass and an increased risk of osteoporosis.                                                                                                                                                             |

# Clinical Connection

Excessive or deficient secretion of hormones that normally control bone growth can cause a person to be abnormally tall or short.

- Giantism
- Pituitary dwarfism
- Acromegaly
- Achondroplasia/achondroplastic dwarfism