Skeletal system includes

- Bones of the skeleton
- Cartilages, ligaments, and connective tissues
Functions of the Skeletal System

- Support
- Storage of minerals (calcium)
- Storage of lipids (yellow marrow)
- Blood cell production (red marrow)
- Protection
- Leverage (force of motion)
Classification of Bones

- Bones are classified by
  - Shape
  - Internal tissue organization
  - Bone markings (surface features; marks)
Figure 6–1 A Classification of Bones by Shape.
Classification of Bones

- Bone Shapes
  - Long bones
    - Are long and thin
    - Are found in arms, legs, hands, feet, fingers, and toes
  - Flat bones
    - Are thin with parallel surfaces
    - Are found in the skull, sternum, ribs, and scapulae
  - Sutural bones
    - Are small, irregular bones
    - Are found between the flat bones of the skull
Classification of Bones

- Bone Shapes
  - Irregular bones
    - Have complex shapes
    - Examples: spinal vertebrae, pelvic bones
  - Short bones
    - Are small and thick
    - Examples: ankle and wrist bones
  - Sesamoid bones
    - Are small and flat
    - Develop inside tendons near joints of knees, hands, and feet
Classification of Bones

- Bone Markings
  - Depressions or grooves
    - Along bone surface
  - Projections
    - Where tendons and ligaments attach
    - At articulations with other bones
  - Tunnels
    - Where blood and nerves enter bone
## Classification of Bones

<table>
<thead>
<tr>
<th>General Description</th>
<th>Anatomical Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevations and projections (general)</td>
<td>Process</td>
<td>Any projection or bump</td>
</tr>
<tr>
<td></td>
<td>Ramus</td>
<td>An extension of a bone making an angle with the rest of the structure</td>
</tr>
<tr>
<td>Processes formed where tendons or ligaments attach</td>
<td>Trochanter</td>
<td>A large, rough projection</td>
</tr>
<tr>
<td></td>
<td>Tuberosity</td>
<td>A smaller, rough projection</td>
</tr>
<tr>
<td></td>
<td>Tubercle</td>
<td>A small, rounded projection</td>
</tr>
<tr>
<td></td>
<td>Crest</td>
<td>A prominent ridge</td>
</tr>
<tr>
<td></td>
<td>Line</td>
<td>A low ridge</td>
</tr>
<tr>
<td></td>
<td>Spine</td>
<td>A pointed or narrow process</td>
</tr>
<tr>
<td>Processes formed for articulation with adjacent bones</td>
<td>Head</td>
<td>The expanded articular end of an epiphysis, separated from the shaft by a neck</td>
</tr>
<tr>
<td></td>
<td>Neck</td>
<td>A narrow connection between the epiphysis and the diaphysis</td>
</tr>
<tr>
<td></td>
<td>Condyle</td>
<td>A smooth, rounded articular process</td>
</tr>
<tr>
<td></td>
<td>Trochlea</td>
<td>A smooth, grooved articular process shaped like a pulley</td>
</tr>
<tr>
<td></td>
<td>Facet</td>
<td>A small, flat articular surface</td>
</tr>
<tr>
<td>Depressions</td>
<td>Fossa</td>
<td>A shallow depression</td>
</tr>
<tr>
<td></td>
<td>Sulcus</td>
<td>A narrow groove</td>
</tr>
<tr>
<td>Openings</td>
<td>Foramen</td>
<td>A rounded passageway for blood vessels or nerves</td>
</tr>
<tr>
<td></td>
<td>Canal or Meatus</td>
<td>A passageway through the substance of a bone</td>
</tr>
<tr>
<td></td>
<td>Fissure</td>
<td>An elongated cleft</td>
</tr>
<tr>
<td></td>
<td>Sinus or Antrum</td>
<td>A chamber within a bone, normally filled with air</td>
</tr>
</tbody>
</table>
Classification of Bones

- **Structure of a Long Bone**
  - **Diaphysis**
    - The shaft
    - A heavy wall of compact bone, or dense bone
    - A central space called medullary (marrow) cavity
  - **Epiphysis**
    - Wide part at each end
    - Articulation with other bones
    - Mostly spongy (cancellous) bone
    - Covered with compact bone (cortex)
  - **Metaphysis**
    - Where diaphysis and epiphysis meet
Figure 6–2 Bone Structure.
Classification of Bones

- Structure of a Flat Bone
  - The *parietal bone* of the skull
  - Resembles a sandwich of spongy bone
  - Between two layers of compact bone
  - Within the cranium, the layer of spongy bone between the compact bone is called the *diploë*
Figure 6–2 Bone Structure.
Bone (Osseous) Tissue

- Dense, supportive connective tissue
- Contains specialized cells
- Produces solid matrix of calcium salt deposits
- Around collagen fibers
Bone (Osseous) Tissue

- **Characteristics of Bone Tissue**
  - Dense **matrix**, containing
    - Deposits of calcium salts
    - **Osteocytes (bone cells)** within *lacunae* organized around blood vessels
  - **Canaliculi**
    - Form pathways for blood vessels
    - Exchange nutrients and wastes
  - **Periosteum**
    - Covers outer surfaces of bones
    - Consists of outer **fibrous** and inner **cellular** layers
Bone (Osseous) Tissue

- **Matrix Minerals**
  - Two thirds of bone matrix is calcium phosphate, $\text{Ca}_3(\text{PO}_4)_2$
    - Reacts with calcium hydroxide, $\text{Ca}(\text{OH})_2$
    - To form crystals of hydroxyapatite, $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$
    - Which incorporates other calcium salts and ions

- **Matrix Proteins**
  - One third of bone matrix is protein fibers (collagen)
Bone (Osseous) Tissue

- The Cells of Bone
  - Make up only 2% of bone mass
  - Bone contains four types of cells
    - Osteocytes
    - Osteoblasts
    - Osteoprogenitor cells
    - Osteoclasts
Bone (Osseous) Tissue

- **Osteocytes**
  - Mature bone cells that maintain the bone matrix
  - Live in lacunae
  - Are between layers *(lamellae)* of matrix
  - Connect by cytoplasmic extensions through *canaliculi* in lamellae
  - Do not divide

- **Functions**
  - To maintain protein and mineral content of matrix
  - To help repair damaged bone
Bone (Osseous) Tissue

- Osteoblasts
  - Immature bone cells that secrete matrix compounds (osteogenesis)
  - Osteoid—matrix produced by osteoblasts, but not yet calcified to form bone
  - Osteoblasts surrounded by bone become osteocytes
Bone (Osseous) Tissue

- Osteoprogenitor cells
  - Mesenchymal stem cells that divide to produce osteoblasts
  - Are located in endosteum, the inner, cellular layer of periosteum
  - Assist in fracture repair
Bone (Osseous) Tissue

- **Osteoclasts**
  - Secrete acids and protein-digesting enzymes
  - Giant, multinucleate cells
  - Dissolve bone matrix and release stored minerals (**osteolysis**)
  - Are derived from stem cells that produce macrophages
Bone (Osseous) Tissue

Figure 6–3 Types of Bone Cells.

- **Osteocyte**: Mature bone cell that maintains the bone matrix.
- **Osteoblast**: Immature bone cell that secretes organic components of matrix.
- **Osteoprogenitor cell**: Stem cell whose divisions produce osteoblasts.
- **Osteoclast**: Multinucleate cell that secretes acids and enzymes to dissolve bone matrix.
Bone (Osseous) Tissue

- **Homeostasis**
  - Bone building (by osteoblasts) and bone recycling (by osteoclasts) must balance
    - More breakdown than building, bones become weak
    - Exercise, particularly weight-bearing exercise, causes osteoblasts to build bone
Compact and Spongy Bone

- The Structure of Compact Bone
  - **Osteon** is the basic unit
    - Osteocytes are arranged in **concentric lamellae**
    - Around a **central canal** containing blood vessels
    - Perforating Canals:
      - perpendicular to the central canal
      - carry blood vessels into bone and marrow
  - **Circumferential Lamellae**
    - Lamellae wrapped around the long bone
    - Bind osteons together
Figure 6–4a The Histology of Compact Bone.
Compact and Spongy Bone

Figure 6-4b The Histology of Compact Bone.
Compact and Spongy Bone

Figure 6–5 The Structure of Compact Bone.
Figure 6–5 The Structure of Compact Bone.
Compact and Spongy Bone

- The Structure of Spongy Bone
  - Does not have osteons
  - The matrix forms an open network of **trabeculae**
  - Trabeculae have no blood vessels
  - The space between trabeculae is filled with **red bone marrow**:
    - Which has blood vessels
    - Forms red blood cells
    - And supplies nutrients to osteocytes
- Yellow marrow
  - In some bones, spongy bone holds yellow bone marrow
  - Is yellow because it stores fat
Compact and Spongy Bone

Figure 6–6 The Structure of Spongy Bone.
Compact and Spongy Bone

- Weight-Bearing Bones
  - The femur transfers weight from hip joint to knee joint
    - Causing tension on the lateral side of the shaft
    - And compression on the medial side
Compact and Spongy Bone

Figure 6–7 The Distribution of Forces on a Long Bone.
Compact and Spongy Bone

- Compact bone is covered with a membrane
  - **Periosteum** on the outside
    - Covers all bones except parts enclosed in joint capsules
    - Is made up of an outer, fibrous layer and an inner, cellular layer
  - **Perforating fibers:** collagen fibers of the periosteum:
    - connect with collagen fibers in bone
    - and with fibers of joint capsules; attach tendons, and ligaments
Compact and Spongy Bone

- Functions of Periosteum
  - Isolates bone from surrounding tissues
  - Provides a route for circulatory and nervous supply
  - Participates in bone growth and repair
Figure 6–8a The Periosteum.

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

- **Endosteum** on the inside

  - An incomplete cellular layer:
    - lines the medullary (marrow) cavity
    - covers trabeculae of spongy bone
    - lines central canals
    - contains osteoblasts, osteoprogenitor cells, and osteoclasts
    - is active in bone growth and repair
Compact and Spongy Bone

Figure 6–8b The Endosteum.
Bone Formation and Growth

- Bone Development
  - Human bones grow until about age 25
  - Osteogenesis
    - Bone formation
  - Ossification
    - The process of replacing other tissues with bone
Bone Formation and Growth

- Bone Development
  - Calcification
    - The process of depositing calcium salts
    - Occurs during bone ossification and in other tissues
  - Ossification
    - The two main forms of ossification are
      - intramembranous ossification
      - endochondral ossification
Bone Formation and Growth

- **Endochondral Ossification**
  - Ossifies bones that originate as hyaline cartilage
  - Most bones originate as hyaline cartilage
  - There are six main steps in endochondral ossification
Figure 6–10 Endochondral Ossification.

**STEP 1**
As the cartilage enlarges, chondrocytes near the center of the shaft increase greatly in size. The matrix is reduced to a series of small struts that soon begin to calcify. The enlarged chondrocytes then die and disintegrate, leaving cavities within the cartilage.

**STEP 2**
Blood vessels grow around the edges of the cartilage, and the cells of the perichondrium convert to osteoblasts. The shaft of the cartilage then becomes ensheathed in a superficial layer of bone.
Figure 6–10 Endochondral Ossification.

**STEP 3**
Blood vessels penetrate the cartilage and invade the central region. Fibroblasts migrating with the blood vessels differentiate into osteoblasts and begin producing spongy bone at a primary center of ossification. Bone formation then spreads along the shaft toward both ends.

**STEP 4**
Remodeling occurs as growth continues, creating a medullary cavity. The bone of the shaft becomes thicker, and the cartilage near each epiphysis is replaced by shafts of bone. Further growth involves increases in length (Steps 5 and 6) and diameter.
Figure 6–10 Endochondral Ossification.
Bone Formation and Growth

- **Appositional growth**
  - Compact bone thickens and strengthens long bone with layers of *circumferential lamellae*
Bone Formation and Growth

- **Epiphyseal Lines**
  - When long bone stops growing, after puberty
    - Epiphyseal cartilage disappears
    - Is visible on X-rays as an epiphyseal line

- **Mature Bones**
  - As long bone matures
    - Osteoclasts enlarge medullary (marrow) cavity
    - Osteons form around blood vessels in compact bone
Bone Formation and Growth

(a) Epiphyseal cartilages

Figure 6–11 Bone Growth at an Epiphyseal Cartilage.
Figure 6–11 Bone Growth at an Epiphyseal Cartilage.
Bone Formation and Growth

- Intramembranous Ossification
  - Also called dermal ossification
    - Because it occurs in the dermis
    - Produces dermal bones such as mandible (lower jaw) and clavicle (collarbone)
  - There are three main steps in intramembranous ossification
Bone Formation and Growth

Figure 6–12 Intramembranous Ossification.

Mesenchymal cells aggregate, differentiate into osteoblasts, and begin the ossification process. The bone expands as a series of spicules that spread into surrounding tissues.
Bone Formation and Growth

**Figure 6–12 Intramembranous Ossification.**

**STEP 2**
As the spicules interconnect, they trap blood vessels within the bone.

- Osteocytes in lacunae
- Blood vessels
- Osteoblast layer

**STEP 3**
Over time, the bone assumes the structure of spongy bone. Areas of spongy bone may later be removed, creating medullary cavities. Through remodeling, spongy bone formed in this way can be converted to compact bone.

- Blood vessel
Bone Formation and Growth

- Blood Supply of Mature Bones
  - Three major sets of blood vessels develop
    - **Nutrient artery and vein:**
      - a single pair of large blood vessels
      - enter the diaphysis through the nutrient foramen
      - femur has more than one pair
    - **Metaphyseal vessels:**
      - supply the epiphyseal cartilage
      - where bone growth occurs
    - **Periosteal vessels** provide:
      - blood to superficial osteons
      - secondary ossification centers
Figure 6–13 The Blood Supply to a Mature Bone.
Bone Formation and Growth

- Lymph and Nerves
  - The periosteum also contains
    - Networks of lymphatic vessels
    - Sensory nerves
Bone Formation and Growth

Figure 6–9 Heterotopic Bone Formation.
Bone Remodeling

- **Process of Remodeling**
  - The adult skeleton
    - Maintains itself
    - Replaces mineral reserves
    - Recycles and renews bone matrix
    - Involves osteocytes, osteoblasts, and osteoclasts
  - Bone continually remodels, recycles, and replaces
  - Turnover rate varies
    - If deposition is greater than removal, bones get stronger
    - If removal is faster than replacement, bones get weaker
Exercise, Hormones, and Nutrition

- Effects of Exercise on Bone
  - Mineral recycling allows bones to adapt to stress
  - Heavily stressed bones become thicker and stronger

- Bone Degeneration
  - Bone degenerates quickly
  - Up to one third of bone mass can be lost in a few weeks of inactivity
Normal bone growth and maintenance requires nutritional and hormonal factors

- A dietary source of **calcium** and **phosphate salts**
  - Plus small amounts of **magnesium**, **fluoride**, **iron**, and **manganese**
- The hormone **calcitriol**
  - Is made in the kidneys
  - Helps absorb calcium and phosphorus from digestive tract
  - Synthesis requires **vitamin D₃ (cholecalciferol)**
Normal bone growth and maintenance depend on nutritional and hormonal factors:

- Vitamin C is required for collagen synthesis, and stimulation of osteoblast differentiation.
- Vitamin A stimulates osteoblast activity.
- Vitamins K and B₁₂ help synthesize bone proteins.
- Growth hormone and thyroxine stimulate bone growth.
- Estrogens and androgens stimulate osteoblasts.
- Calcitonin and parathyroid hormone regulate calcium and phosphate levels.
<table>
<thead>
<tr>
<th>Hormone</th>
<th>Primary Source</th>
<th>Effects on Skeletal System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcitriol</td>
<td>Kidneys</td>
<td>Promotes calcium and phosphate ion absorption along the digestive tract</td>
</tr>
<tr>
<td>Growth hormone</td>
<td>Pituitary gland</td>
<td>Stimulates osteoblast activity and the synthesis of bone matrix</td>
</tr>
<tr>
<td>Thyroxine</td>
<td>Thyroid gland (follicle cells)</td>
<td>With growth hormone, stimulates osteoblast activity and the synthesis of bone matrix</td>
</tr>
<tr>
<td>Sex hormones</td>
<td>Ovaries (estrogens)</td>
<td>Stimulate osteoblast activity and the synthesis of bone matrix</td>
</tr>
<tr>
<td></td>
<td>Testes (androgens)</td>
<td></td>
</tr>
<tr>
<td>Parathyroid hormone</td>
<td>Parathyroid glands</td>
<td>Stimulates osteoclast (and osteoblast) activity; elevates calcium ion concentrations in body fluids</td>
</tr>
<tr>
<td>Calcitonin</td>
<td>Thyroid gland (C cells)</td>
<td>Inhibits osteoclast activity; promotes calcium loss at kidneys; reduces calcium ion concentrations in body fluids</td>
</tr>
</tbody>
</table>
FIGURE 6–14 Examples of Abnormal Bone Development.
Calcium Homeostasis

- The Skeleton as a Calcium Reserve
  - Bones store calcium and other minerals
  - Calcium is the most abundant mineral in the body
  - Calcium ions are vital to:
    - membranes
    - neurons
    - muscle cells, especially heart cells
Calcium Homeostasis

- Calcium Regulation
  - Calcium ions in body fluids
    - Must be closely regulated
  - Homeostasis is maintained
    - By calcitonin and parathyroid hormone
    - Which control storage, absorption, and excretion
Calcium Homeostasis

- Calcitonin and parathyroid hormone control and affect
  - Bones
    - Where calcium is stored
  - Digestive tract
    - Where calcium is absorbed
  - Kidneys
    - Where calcium is excreted
Calcium Homeostasis

- **Parathyroid Hormone (PTH)**
  - Produced by parathyroid glands in neck
  - Increases calcium ion levels by
    - Stimulating osteoclasts
    - Increasing intestinal absorption of calcium
    - Decreasing calcium excretion at kidneys

- **Calcitonin**
  - Secreted by C cells (parafollicular cells) in thyroid
  - *Decreases* calcium ion levels by
    - Inhibiting osteoclast activity
    - Increasing calcium excretion at kidneys
Calcium Homeostasis

Figure 6–15 A Chemical Analysis of Bone.

<table>
<thead>
<tr>
<th>COMPOSITION OF BONE</th>
<th>AMOUNT IN BONE as percentage of the total amount in the body</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium 39%</td>
<td>Calcium 99%</td>
</tr>
<tr>
<td>Potassium 0.2%</td>
<td>Potassium 4%</td>
</tr>
<tr>
<td>Sodium 0.7%</td>
<td>Sodium 35%</td>
</tr>
<tr>
<td>Magnesium 0.5%</td>
<td>Magnesium 50%</td>
</tr>
<tr>
<td>Carbonate 9.8%</td>
<td>Carbonate 80%</td>
</tr>
<tr>
<td>Phosphate 17%</td>
<td>Phosphate 88%</td>
</tr>
<tr>
<td>Organic compounds (mostly collagen) 33%</td>
<td>Total inorganic components 67%</td>
</tr>
</tbody>
</table>
Figure 6–16a Factors That Alter the Concentration of Calcium Ions in Body Fluids.
Figure 6–16b Factors That Alter the Concentration of Calcium Ions in Body Fluids.
Fractures

- Cracks or breaks in bones
- Caused by physical stress
Fractures are repaired in four steps

- **Bleeding**
  - Produces a clot (**fracture hematoma**)
  - Establishes a fibrous network
  - Bone cells in the area die

- **Cells of the endosteum and perosteum**
  - Divide and migrate into fracture zone

- **Calluses** stabilize the break:
  - **external callus** of cartilage and bone surrounds break
  - **internal callus** develops in medullary cavity
Fractures

- Fractures are repaired in four steps
  - Osteoblasts
    - Replace central cartilage of external callus
    - With spongy bone
  - Osteoblasts and osteocytes remodel the fracture for up to a year
    - Reducing bone calluses

Steps in the Repair of a Fracture
Figure 6–17 Steps in the Repair of a Fracture.
Figure 6–17 Steps in the Repair of a Fracture.

**STEP 3**
The cartilage of the external callus has been replaced by bone, and struts of spongy bone now unite the broken ends. Fragments of dead bone and the areas of bone closest to the break have been removed and replaced.

**STEP 4**
A swelling initially marks the location of the fracture. Over time, this region will be remodeled, and little evidence of the fracture will remain.
Fractures

The Major Types of Fractures

- Pott fracture
- Comminuted fractures
- Transverse fractures
- Spiral fractures
- Displaced fractures
- Colles fracture
- Greenstick fracture
- Epiphyseal fractures
- Compression fractures
Fractures

Figure 6–18 Major Types of Fractures.

A Pott fracture occurs at the ankle and affects both bones of the leg.

Comminuted fractures, such as this fracture of the femur, shatter the affected area into a multitude of bony fragments.

Transverse fractures, such as this fracture of the ulna, break a bone shaft across its long axis.
Figure 6–18 Major Types of Fractures.

Spiral fractures, such as this fracture of the tibia, are produced by twisting stresses that spread along the length of the bone.

Displaced fractures produce new and abnormal bone arrangements; nondisplaced fractures retain the normal alignment of the bones or fragments.

A Colles fracture, a break in the distal portion of the radius, is typically the result of reaching out to cushion a fall.
Fractures

Figure 6–18 Major Types of Fractures.

In a greenstick fracture, such as this fracture of the radius, only one side of the shaft is broken, and the other is bent. This type of fracture generally occurs in children, whose long bones have yet to ossify fully.

Epiphyseal fractures, such as this fracture of the femur, tend to occur where the bone matrix is undergoing calcification and chondrocytes are dying. A clean transverse fracture along this line generally heals well. Unless carefully treated, fractures between the epiphysis and the epiphyseal cartilage can permanently stop growth at this site.

Compression fractures occur in vertebrae subjected to extreme stresses, such as those produced by the forces that arise when you land on your seat in a fall.
Osteopenia

- Bones become thinner and weaker with age
  - **Osteopenia** begins between ages 30 and 40
  - Women lose 8% of bone mass per decade, men 3%
Osteopenia

- The epiphyses, vertebrae, and jaws are most affected:
  - Resulting in fragile limbs
  - Reduction in height
  - Tooth loss

- **Osteoporosis**
  - Severe bone loss
  - Affects normal function
  - Over age 45, occurs in
    - 29% of women
    - 18% of men
Osteopenia

Figure 6-19 The Effects of Osteoporosis on Spongy Bone.
Hormones and Bone Loss
- Estrogens and androgens help maintain bone mass
- Bone loss in women accelerates after menopause

Cancer and Bone Loss
- Cancerous tissues release osteoclast-activating factor
  - That stimulates osteoclasts
  - And produces severe osteoporosis