Bone Tissue

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Bone Tissue

- Bone is a type of connective tissue which is composed of calcified extracellular matrix (ECM) and cells.

- Provides solid support for the body.

- Protects many vital internal organs such as those in the cranial and thoracic cavities.

- Has cavities containing bone marrow.

- Reservoir of calcium, phosphate, and other ions to maintain constant concentrations in body fluids.
Bone Tissue

Composed of:

- **Cells:**
  1. Osteocytes
  2. Osteoblasts
  3. Osteoclasts

- **Extracellular matrix (Bone matrix)**
Bone Cells

Bone is composed of three major cell types:

- **Osteocytes**: found in *lacunae* between bone matrix layers *lamellae*, with cytoplasmic processes extending into small *canaliculi* between lamellae.

- **Osteoblasts**: synthesize the organic components of the matrix.

- **Osteoclasts**: are multinucleated, giant cells involved in the resorption and remodeling of bone tissue.

- **Bone resorption** is the process by which osteoclasts break down *bone* and release the minerals, resulting in a transfer of calcium from *bone* to the blood.

- **Bone remodeling** (*bone* metabolism) where mature *bone* tissue is removed from the skeleton (resorption) and new *bone* tissue is formed (ossification or new *bone* formation).
Bone Tissue

1 Lacunae
2 Canaliculi
3 Central (Haversian) canal
4 Lamellae
5 Interstitial lamellae
6 Cement line
7 Lacunae
Bone Cells

Osteogenic cell (develops into an osteoblast)

Osteoblast (forms bone tissue)

Osteocyte (maintains bone tissue)

Osteoclast (functions in resorption, the destruction of bone matrix)

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Osteoprogenitor Cells

- **Mesenchymal** stem cells, found in the periosteum.

- **Transform** to osteoblasts.

- **Secrete** bone matrix.

- Vital role in growth and repair.
**Osteoblasts**

- **Active**: Cuboidal or polygonal shape, found in the periosteum and endosteum.

- Synthesize and secrete the organic components of bone matrix (*type I collagen fibers, proteoglycans*, and several glycoproteins such as *osteonectin*).

- **Osteoblasts** secret *osteoid* (newly made *uncalcified* matrix). This is followed by subsequent deposition of calcium salts into the newly formed matrix. Therefore osteoblasts are responsible for bone calcification.

Osteoblast may change to **osteocyte**.
Bone Cells

- Osteoclast
- Osteoblast
- Osteocyte
- Mesenchyme
- Bone matrix
- Newly formed matrix (osteoid)

**Image:**
- Ob: Osteoblast
- Os: Osteocyte
- B: Bone
- Oc: Osteoclast
- M: Mesenchyme
Osteocytes

- Located in Lacunae

- Extend cytoplasmic processes through *canaliculi* for nutrition.

- **Maintain** bone matrix.

- Death of **Osteocytes** will lead to bone **resorption**

- Communicate by gap junctions.
Osteocytes

- It’s flat, almond-shaped with less RER, smaller Golgi complexes, and more condensed nuclear chromatin (comparing to osteoblasts).

- **Osteocyte** products such as sclerostin and certain cytokines help regulate bone remodeling.

- The extensive lacunar-canalicular network and their communication with all other bone cells suggest additional roles for osteocytes in calcium homeostasis.

- As sensors for detection of mechanical stresses on bone, important in directing bone remodeling.
Bone Cells

Osteogenic cell (develops into an osteoblast)

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Osteoclasts

- Large, multinucleated, branched, motile cells.

- Play a major role in matrix **resorption** during bone growth and remodeling

- The surface of osteoclast facing matrix have *projections* → ruffled border.

- Acidophilic cytoplasm, many lysosomes, many mitochondria.

- Found in resorption cavities
Osteoclasts

- Osteoclast secretes *collagenase* and other enzymes and pumps *protons* to produce an acidic environment locally promoting the localized digestion of matrix proteins.
Bone Matrix

- Inorganic material represents about 50% of the dry weight of bone matrix.

- **Calcium hydroxyapatite** is most abundant, but bicarbonate, citrate, magnesium, potassium, and sodium ions are also found.

- Significant quantities of *amorphous* (noncrystalline) calcium phosphate are also present.
Bone Matrix

• The organic matter embedded in the calcified matrix includes **type I collagen**, **proteoglycan aggregates**, and bonespecific multiadhesive glycoproteins such as **osteonectin**.

• Calcium-binding glycoproteins, **osteocalcin**, and the **phosphatases** released in matrix vesicles by **osteoblasts** promote calcification of the matrix.
Bone Matrix

• The association of **minerals** with **collagen** fibers during calcification is responsible for the **hardness** and resistance of bone tissue.

• After a bone is decalcified, its shape is preserved, but it becomes as flexible as a tendon.
Periosteum and Endosteum

- All bones are lined on both internal and external surfaces by membranes made of layers of connective tissue containing osteogenic cells.

- These membranes are called
  1- Endosteum is a membrane on the internal surface surrounding the marrow cavity
  2- Periosteum is a membrane surround the external surface of the bone.
Periosteum

- The principal functions of **periosteum** are to **nourish** the **osseous tissue** and **provide** a continuous supply of **new osteoblasts** for **bone growth** or **repair**.
- The **periosteum** is organized much like the perichondrium.
- The outer layer is dense connective tissue, with small **blood vessels**, **collagen bundles**, and **fibroblasts**.
Periosteum

• Bundles of periosteal collagen fibers, called perforating fibers, penetrate the bone matrix, binding the periosteum to bone.

• The inner region of periosteum is a more cellular layer containing osteoblasts, and mesenchymal stem cells (osteoprogenitor cells).
**Endosteum**

- Internally the very thin endosteum covers small **trabeculae** of bony matrix that project into the marrow cavities.

- Although considerably thinner than the periosteum, **endosteum** also contains **osteoprogenitor cells**, **osteoblasts**
Bone type

- Types of bone tissue is classified according to the component of the bony tissue into:

1- Lamellar Bone
   A- Compact Bone
   B- Spongy Bone

2- Non Lamellar (Woven Bone)
Type of Bone

- In long bones, the bulbous ends, (epiphyses) are composed of spongy bone.
- The cylindrical part (diaphysis) is almost totally composed of compact bone, with a thin region of spongy bone on the inner surface around the central medullary cavity.
• Short bones such as those of the wrist and ankle usually composed of spongy bone surrounded completely by compact bone.

• The flat bones that form the calvaria (skullcap) have two layers of compact bone called plates, separated by a thicker layer of spongy bone called the diploë.
Most bones in adults, **compact** and **cancellous**, are organized as **lamellar bone**, characterized by multiple layers or lamellae of calcified matrix.

The highly ordered organization of collagen fibers in lamellae adds greatly to the strength of lamellar bone.

When we examine a long bone, the dense area near the surface is called **compact (cortical)** bone, which represents **80%** of the total bone mass.

Deeper areas with numerous interconnecting cavities, called **cancellous (spongy)** bone, constituting about **20%** of total bone mass.
Compact Bone

- Compact bone is formed of units called **osteons** or **Haversian systems**.

- **Osteons** contains central canal called **Haversian canal** contains **blood vessels, lymphatic vessels, nerves**.

- Surrounding this canal are concentric rings of osteocytes along with the calcified matrix.

- **Osteons** are aligned in the same direction along lines of stress. These lines can slowly change as the stresses on the bone changes.
An osteon (or Haversian system).
• Each osteon consists of a central canal surrounded by 4-10 concentric lamellae.

• The central canals communicate with the marrow cavity and the periosteum and with one another through **transverse perforating canals** (or **Volkmann canals**).
• Scattered among the intact osteons are numerous irregularly shaped groups of parallel lamellae called **interstitial lamellae**.

• The **interstitial lamellae** are lamellae remaining from osteons partially destroyed by osteoclasts during growth and remodeling of bone.
• In **compact bone** (e.g., the diaphysis of long bones) the lamellae exhibit a typical organization consisting of multiple **external circumferential lamellae** and often some **inner circumferential lamellae**.

• **External circumferential lamellae** are located immediately beneath the **periosteum**.

• **Inner circumferential lamellae** are located around the marrow cavity.
Spongy Bone

- **Spongy (cancellous) bone** does not contain osteons.
- It consists of *trabeculae* surrounding many red marrow filled spaces.
- It forms most of the structure of **short, flat, and irregular bones**, and the **epiphyses** of long bones.
- **Spongy bone** tissue is light and supports and protects the red bone marrow.
Woven Bone

- **Non-lamellar** and characterized by random disposition of **type I collagen fibers** and is the first bone tissue to appear in embryonic development and in fracture repair.

**Composition of non lamellar bone**

- *Irregular, interwoven* array of **collagen fibers**.
- Has a lower mineral content (it is more easily penetrated by x-rays).
- Have higher proportion of **Osteocytes** than mature lamellar bone.
Woven Bone

- Usually temporary and is replaced in adults by lamellar bone, except in a very few places in the body (e.g. near the sutures of the calvaria and in the insertions of some tendons).

- **Woven bone** forms more quickly but has less strength than **lamellar bone**.
## Bone types and their organization

<table>
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<th>Type of Bone</th>
<th>Histological Features</th>
<th>Major Locations</th>
<th>Synonyms</th>
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</thead>
<tbody>
<tr>
<td><strong>Woven bone, newly calcified</strong></td>
<td>Irregular and random arrangement of cells and collagen; lightly calcified</td>
<td>Developing and growing bones; hard callus of bone fractures</td>
<td>Immature bone; primary bone; bundled bone</td>
</tr>
<tr>
<td><strong>Lamellar bone, remodeled from woven bone</strong></td>
<td>Parallel bundles of collagen in thin layers (lamellae), with regularly spaced cells between; heavily calcified</td>
<td>All normal regions of adult bone</td>
<td>Mature bone; secondary bone</td>
</tr>
<tr>
<td><strong>Compact bone, ~80% of all lamellar bone</strong></td>
<td>Parallel lamellae or densely packed osteons, with interstitial lamellae</td>
<td>Thick, outer region (beneath periosteum) of bones</td>
<td>Cortical bone</td>
</tr>
<tr>
<td><strong>Cancellous bone, ~20% of all lamellar bone</strong></td>
<td>Interconnected thin spicules or trabeculae covered by endosteum</td>
<td>Inner region of bones, adjacent to marrow cavities</td>
<td>Spongy bone; trabecular bone; medullary bone</td>
</tr>
</tbody>
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Bone remodeling

• **Bone remodeling** is continuous throughout life and involves a process of bone resorption and bone formation.

• In **compact bone**, remodeling resorbs parts of old **osteons** and produces new ones.

• **Resorption** involves the actions of **osteoclasts**, often working in groups to remove old bone in **tunnel-like** cavities having the approximate diameter of new **osteons**.
Bone remodeling

- Tunnels are quickly invaded by many osteoprogenitor cells from the **endosteum** or **periosteum** and sprouting loops of capillaries.

- **Osteoblasts** develop, line the wall of the tunnels, and begin to secrete osteoid in a cyclic manner, forming the concentric lamellae of bone with trapped **osteocytes**.

- In healthy adults
- 5%-10% of the bone turns over annually
Histology of Muscular System

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Muscle Tissue

• **Muscle tissue** is composed of cells that have property of **contractility**.

• **Actin and myosin microfilaments** are associated proteins that generate the forces necessary for the muscle contraction.

• Origin of all muscle cells is the **mesoderm**.
Muscle Tissue

- **sarcoplasm** is the cytoplasm of muscle cells.
- **The sarcoplasmic reticulum (SR)** is a membrane-bound structure found within muscle cells, that is similar to the endoplasmic reticulum in other cells. The main function of the SR is to store calcium (Ca\(^{2+}\)). Calcium levels are kept relatively constant, with the concentration of calcium within a cell being 100,000 times smaller than the concentration of calcium outside the cell.
- **sarcolemma** is the muscle cell membrane.
sarcoplasmic reticulum is a network of tubules that extend throughout muscle cells, wrapping around the myofibrils (contractile units of the cell). Cardiac and skeletal muscle cells, contain structures called transverse tubules (T-tubules), which are extensions of the cell membrane that travel into the centre of the cell. T-tubules are closely associated with a specific region of the SR, known as the terminal cisternae in cardiac muscle or junctional SR in skeletal muscle, with a distance of roughly 12 nanometers, separating them. This is the primary site of calcium release. The longitudinal SR are thinner projects, that run between the terminal cisternae/junctional SR, and are the location where ion channels necessary for calcium absorption are most abundant. These processes are fundamental for the process of excitation-contraction coupling in skeletal, cardiac and smooth muscle.
Section of skeletal muscle, showing t-tubules running deep into the centre of the cell between two terminal cisternae/junctional SR. The thinner projections, running horizontally between two terminal cisternae are the longitudinal sections of the SR.
Muscle Tissue

• **Characteristics**
  – Contracts or shortens with force
  – Moves entire *body and pumps* blood

• **Types**
  – **Skeletal**
    • Striated and voluntary
  – **Cardiac**
    • Striated and involuntary
  – **Smooth**
    • Non striated and involuntary
Skeletal Muscle

- Skeletal *(striated)* muscle consists of bundles of very long, cylindrical multinucleated cells with cross-striations.

- Their contraction is *quick, forceful*, and usually under *voluntary* control.

- Elongated nuclei are found peripherally just under the *sarcolemma*, a characteristic nuclear location unique to skeletal muscle fibers (cells).
Skeletal Muscle

- During embryonic muscle development, **mesenchymal myoblasts** fuse, forming **myotubes** with many nuclei.

- **Myotubes** then further differentiate to form striated muscle fibers.

- A small population of reserve progenitor cells (**Satellite cells**) remains adjacent to most fibers of differentiated skeletal muscle.
Organization of a Skeletal Muscle

Thin layers of connective tissue surround and organize the contractile fibers in skeletal muscle.

- The epimysium
- The perimysium
- The endomysium
Organization of a Skeletal Muscle

The **epimysium**, an external sheath of **dense connective tissue**, surrounds the entire muscle.

**Septa** of this tissue extend inward, carrying the larger nerves, blood vessels, and lymphatics of the muscle.
Organization of a Skeletal Muscle

The **perimysium** is a thin connective tissue layer that immediately surrounds each bundle of muscle fibers termed a **fascicle**.

Each **fascicle** of muscle fibers makes up a functional unit in which the fibers work together.

Nerves, blood vessels, and lymphatics penetrate the **perimysium** to supply each **fascicle**.
The **endomysium**, very thin, delicate layer of reticular fibers and scattered fibroblasts, surrounds the external lamina of individual muscle fibers. Exist within **fascicles**.

Capillaries form a rich network in the **endomysium** bringing O\textsubscript{2} to the muscle fibers.
**Organization of a Skeletal Muscle**

Collagen in the connective tissue layers of muscle transmit the mechanical Forces generated by the contracting muscle cells (fibers).

Some skeletal muscles taper at their ends, where the epimysium is continuous with the dense regular connective tissue of a tendon at myotendinous junctions.
Organization Within Muscle Fibers

- Internally each muscle fiber is filled with myofibrils, composed of thousands of thick myosin filaments and thin actin filaments, highly organized into contractile units called sarcomeres.

- The thick and thin filaments interdigitate

- Troponin is the protein controlling the sliding filaments
The sarcomeric subunits of one myofibril are in nearly perfect alignment with those of the myofibrils next to it. This alignment gives rise to certain optical properties which cause the cell to appear striped or striated.

In smooth muscle cells, this alignment is absent, hence there are no apparent striations and the cells are called smooth.