A  Overview of The Skeletal System

1. Definition:
Anatomically the SKELETAL SYSTEM consists of bones, cartilages, ligaments and joints.

2. Bones are organs consisting of several tissues:
- bone (osseous tissue), cartilage, fibrous connective tissue (in the surface layer or periosteum), hemopoietic (blood forming) tissue (in the red marrow) and adipose tissue (in the yellow marrow).

3. Functions (see unit 2)
The SKELETAL SYSTEM has the following functions:
- support
- body shape
- protection of vital organs
- movement (bones form attachment sites for muscles; bones and joints create levers which allow movements when muscles pull on bones)
- mineral storage (Ca/P) in bone matrix
- fat storage in yellow marrow
- hemopoiesis in red marrow

4. Cartilage vs Bone Tissue:
Cartilage and bone differ in several respects and are distributed in the skeletal system according to their properties.

<table>
<thead>
<tr>
<th>Cartilage</th>
<th>Bone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Properties of resiliency and strength</td>
<td>Properties of rigidity, hardness and strength</td>
</tr>
<tr>
<td>Non – calcified matrix-firm but not rigid</td>
<td>Calcified matrix- hard and rigid</td>
</tr>
<tr>
<td>Mature cartilage cells are chondrocytes</td>
<td>Mature bone cells are osteocytes</td>
</tr>
<tr>
<td>Non vascular, thus thin &amp; slow to heal</td>
<td>Vascular (vessels run in canals)</td>
</tr>
<tr>
<td>Grows by appositional (surface) &amp; interstitial (internal) growth</td>
<td>Grows by appositional growth only, due to its calcified matrix</td>
</tr>
<tr>
<td>Forms most of the embryonic skeleton: In adults found mainly at joints and in the upper respiratory tract</td>
<td>In development bone gradually replaces cartilage to form the major tissue of all adult bones</td>
</tr>
</tbody>
</table>
4. **Types of Cartilage.** There are three types of cartilage (hyaline, elastic and fibrous cartilage). Only fibrous and hyaline cartilage occur in the skeletal system. The three types differ as follows:

<table>
<thead>
<tr>
<th>Hyaline Cartilage</th>
<th>Elastic Cartilage</th>
<th>Fibrous Cartilage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matrix appears smooth but has many thin collagen fibers</td>
<td>Matrix has many elastic fibers</td>
<td>Matrix has many thick parallel collagen fibers</td>
</tr>
<tr>
<td>Provides firmness, resiliency, strength and a smooth surface for joints</td>
<td>Provides elastic support</td>
<td>Provides extreme strength</td>
</tr>
<tr>
<td>Found in</td>
<td>Found in</td>
<td>Found in</td>
</tr>
<tr>
<td>• articular surfaces of bones</td>
<td>• ear, epiglottis, larynx</td>
<td>• pubic symphysis, intervertebral disks, joint cartilages (menisci)</td>
</tr>
<tr>
<td>• embryonic skeleton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• costal cartilages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• upper respiratory system</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

B **Bone Tissue**

1. Bone tissue is a connective tissue in which the extracellular matrix secreted by bone cells consists of an organic component (osteoid) and a hardened inorganic component.

- The organic component (osteoid) consists of collagen fibers in a firm glycoprotein ground substance; this provides strength to withstand tensile forces (due to stretching, bending and twisting) without breaking.

- The inorganic component consists mainly of hydroxyapatite (Ca$_5$(PO$_4$)$_3$OH), a hard mineral which provides hardness and rigidity to withstand compression forces without bending.

- Mature bone cells (osteocytes) are connected to each other and to the nearest blood supply via many cytoplasmic processes which run through tiny canals (canaliculi) in the matrix. Unlike cartilage the matrix itself is impermeable and does not allow diffusion.
2. Two types of bone tissue occur, **Compact Bone** and **Spongy Bone**. These differ as follows:

<table>
<thead>
<tr>
<th>Compact Bone</th>
<th>Spongy (Cancellous) Bone</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No marrow</strong> spaces</td>
<td>Contains many spaces with <strong>marrow</strong></td>
</tr>
<tr>
<td></td>
<td>Spongy bone reduces the weight of bones and</td>
</tr>
<tr>
<td></td>
<td>(where it contains <strong>red marrow</strong>) is a source of blood cells.</td>
</tr>
<tr>
<td></td>
<td>Red marrow occurs in the proximal epiphyses of the femur and humerus, in flat bones</td>
</tr>
<tr>
<td></td>
<td>(e.g. sternum) and some irregular bones (e.g. pelvic bones).</td>
</tr>
<tr>
<td>Contains <strong>Haversian Systems (osteons)</strong></td>
<td>Has <strong>lamellae</strong> but <strong>no osteons</strong></td>
</tr>
<tr>
<td>consisting of <strong>concentric layers (lamellae)</strong></td>
<td></td>
</tr>
<tr>
<td>of bone tissue surrounding a central</td>
<td></td>
</tr>
<tr>
<td><strong>(Haversian) canal</strong> containing blood vessels.</td>
<td></td>
</tr>
<tr>
<td>Radiating canaliculi connect the osteocytes with</td>
<td></td>
</tr>
<tr>
<td>the central canal.</td>
<td></td>
</tr>
<tr>
<td>Parallel osteons resist forces primarily in one</td>
<td></td>
</tr>
<tr>
<td>direction</td>
<td></td>
</tr>
<tr>
<td><strong>Has no trabeculae</strong></td>
<td><strong>Consists of irregular bony bars or struts</strong></td>
</tr>
<tr>
<td></td>
<td><em>(trabeculae)</em> aligned to withstand forces from many directions.</td>
</tr>
<tr>
<td>Occurs <strong>externally</strong> on bones</td>
<td><strong>Occurs internally</strong> in bones</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
C. Structure of a Long Bone

- Long bones consist of a diaphysis (or shaft) the walls of which are mostly of compact bone. The shaft of a long bone withstands forces mainly parallel to the bone. The diaphysis contains interstitial and circumferential lamellae as well as concentric lamellae.

- Perforating or Volkmann’s canals connect the Haversian canals to the main blood supply.

- The diaphysis is hollow with a marrow cavity containing fatty yellow marrow.

- An expanded end at each end of the diaphysis called the epiphysis. This forms joints with other bones and contains spongy bone so is able to withstand forces from many directions. Yellow or red marrow occurs in the spaces between trabeculae.

- In adults red marrow occurs in the proximal epiphyses of the femur and humerus.

- The epiphysis is covered by a thin cortex of compact bone and, at the joint surfaces by an articular cartilage (hyaline cartilage).

- The metaphysis is the junction between diaphysis and epiphysis.

- During growth years a layer of hyaline cartilage occurs on the epiphyseal side of the metaphysis called the epiphyseal plate. This is responsible for longitudinal growth (lengthening of long bones) until maturity by interstitial growth of cartilage and appositional growth of bone. At maturity the epiphyseal plate is completely ossified and is now called the epiphyseal line

- The external surfaces of bones (except at joint surfaces) are covered by the periosteum. This has two layers, an outer collagenous fibrous layer and an inner cellular layer.

  - The outer fibrous layer of the periosteum protects bones and binds tendons and ligaments to bones (via perforating or Sharpey’s fibers).

  - The inner cellular layer of the periosteum is osteogenic, i.e. functions in appositional growth, remodelling and repair of bones. It therefore contains stem cells (osteoprogenitor cells) and osteoblasts which are the source of new bone tissue and osteoclasts which destroy bone tissue.

- Internally the cavities of bones are lined with a thin cellular endosteum which functions similarly to the cellular layer of the periosteum.
Structure of a Long Bone

Fig. 6-2, Martini & Bartholomew; Figs. 6-2, 6-11, Martini
**Types of Bone cells**

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

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

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

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

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**Periosteum & Endoisteum**

(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.

(b) The endosteum is an incomplete cellular layer containing epithelial cells, osteoblasts, osteopenotinor cells, and osteoclasts.
OSSIFICATION, GROWTH AND REMODELING OF THE SKELETON

1. Two types of growth occur in skeletal tissues **appositional growth** and **interstitial growth**.

2. **Appositional growth** means growth at a surface by cell division of osteogenic (or chondrogenic) cells in the periosteum or endosteum of bone or in the perichondrium of cartilage.

3. **Interstitial growth** means internal growth by cell division and production of new matrix internally, thus expanding the tissue from within. This occurs in cartilage but not in bone since its matrix is calcified (i.e. hardened).

4. Because bone tissue has a calcified matrix it can only grow by appositional growth. **Appositional growth** occurs in bone tissue as follows:

   - Osteogenic (bone – forming) cells in the periosteum or endosteum are called **osteoblasts**.
   - Osteoblasts exchange chemicals via cytoplasmic processes connecting the cells
   - Osteoblasts secrete the **organic matrix** first and then create the alkaline environment causing precipitation of the **inorganic matrix** of hydroxyapatite around themselves.
   - The osteoblasts are now mature non-dividing cells called osteocytes and are imprisoned within their **lacunae** in the **calcified matrix** and connected to their blood supply via canaliculi.

5. **Ossification** is the formation of bone tissue by appositional growth which occurs
   - during the growth of the skeleton to maturity
   - during remodelling of bone throughout life and
   - in the repair of bones.

6. In the embryo most bones are first formed as hyaline cartilage bone “models” which are gradually replaced by bone (osseous) tissue at maturity in a process called **endochondral ossification**. A few bones however, are formed instead as fibrous membrane models (most skull bones and the clavicle) in a different process called **intramembranous ossification**.

7. In both types of ossification centers of bone forming tissue (called **ossification centers**) are formed within the model in a vascularised environment. Osteoblasts first secrete the **organic matrix** followed by **calcification**. Ossification then proceeds by **appositional growth** away from the ossification center.

8. **INTRAMEMBRANOUS OSSIFICATION** In intramembranous ossification embryonic mesenchyme cells differentiate to become osteoblasts (bone forming cells) within a fibrous membrane under the skin. Osteoblasts then form **spongy bone** to which is added **compact bone**, externally, beneath the newly formed periosteum.
**ENDOCHONDRAL OSSIFICATION**

9. For most bones embryonic mesenchyme cells first differentiate to become chondroblasts surrounded by a perichondrium. **Hyaline cartilage is formed** which grows by interstitial and appositional methods forming a **cartilage bone “model”**.

10. In **endochondral ossification** calcification of the hyaline cartilage bone model occurs which causes death of most chondrocytes. The bone model is then invaded by vascularised tissue which form **ossification centers** within the model. **Cartilage is replaced by spongy bone** tissue as ossification spreads by appositional growth away from the ossification centers.

**STEPS IN ENDOCHONDRAL OSSIFICATION**

11. **Endochondral ossification** in long bones occurs as follows:

- In the center of the diaphysis the **cartilage model calcifies** and **chondrocytes die**.

- Increased **vascularisation** of the **perichondrium** forms a **peristeum** which forms an external **collar of compact bone** around the **diaphysis** of the cartilage model. This collar spreads along the diaphysis.

- Vascularised bone - forming tissue from the peristeum (a **periosteal bud**) invades the center of the diaphysis forming a **primary ossification center**.

- **Osteoclasts** digest away the calcified cartilage while **osteoblasts** form new **spongy bone** around the remnants of the cartilage within the diaphysis.

- **Calcification of cartilage** continues within the diaphysis and ossification follows this, spreading along the diaphysis.

- **Osteoclasts** erode the newly formed spongy bone to create a **marrow cavity** in the center of the diaphysis which spreads along the diaphysis.

- **Calcification of cartilage** then occurs in each **epiphysis** at or after birth, followed by invasion by a **periosteal bud**, forming a **secondary ossification center** in each **epiphysis**.

- Ossification forms **spongy bone** in each epiphysis between a layer of **epiphyseal cartilage** (the **epiphyseal plate**) and **articular cartilage**.

- Epiphyseal plate cartilage continue to grow by **interstitial growth** as fast as it replaced by bone tissue on the diaphyseal side of the plate. Therefore the long bone continues to grow in length until maturity when the epiphyseal plate is completely ossified (“**closure of epiphyses**”) forming an **epiphyseal line**.

- After this stage no further lengthening of bones can occur but bones continue to increase in thickness.
Endochondral Ossification

STEP 1:

STEP 2:

STEP 3:

STEP 4:

STEP 5:

STEP 6:

Fig. 6-5, Martini & Bartholomew; Fig. 6-8, Martini Fig. 6-8
**BONE REMODELING**

1. **Bone remodeling** refers to the changes in shape and thickness of bones throughout life due to two antagonistic processes, **bone deposition** and **bone resorption** at the **periosteum** and **endosteum**. Bone deposition and resorption also occur in response to the need for a constant blood calcium level, in response to mechanical stresses, for repair of fractures and during bone growth to maturity.

2. **Bone deposition** means **appositional growth** of new bone tissue by the activity of **osteoblasts**. These first secrete the **organic matrix** then the **inorganic matrix**. Formation of inorganic matrix is catalysed by locally increased concentrations of Ca\(^{2+}\) and PO\(_4\)\(^{3-}\) and by the creation of an alkaline environment for enzymes secreted by the osteoblasts.

3. **Bone resorption** refers to the digestion of bone matrix by enzymes and acids secreted by **osteoclasts** which also phagocytose the cellular products.

4. Bone is a living tissue and is constantly responding to the needs of the body:
   - to resist mechanical stress
   - for adequate blood levels of Ca\(^{2+}\) and PO\(_4\)\(^{3-}\)

5. **Wolff’s law** states that bones respond to the level of mechanical stress by structural changes (e.g. trabeculae of spongy bones form along lines which will resist the most stress). Thus the fetal skeleton is relatively featureless, athletes show increased bone mass and astronauts and bedridden patients show a loss of bone mass (atrophy of disuse). Thus bone remodeling occurs in response to the mechanical stresses placed upon bones.

6. Two antagonistic hormones (**parathyryroid hormone, PTH** and **calcitonin**) respond to the needs for adequate blood calcium and therefore affect bone remodeling.

7. **PTH** is released when blood calcium levels fall. It increases the activity of osteoclasts so causing **increased bone resorption**. Thus **PTH raises blood calcium levels**.

8. **Calcitonin** is released when blood calcium levels rise. It decreases osteoclast activity allowing **osteoblasts** to cause **increased bone deposition**, thus **calcitonin lowers blood calcium levels**.
Function of Parathyroid Hormone (PTH)

- **Intestine**
- **Extracellular fluid**
  - **PTH (with calcitriol)**
  - Rate of intestinal absorption increases
- **Bone**
  - PTH
    - Osteoclasts stimulated to increase release of stored calcium ions
- **Kidney**
  - PTH
    - Kidneys retain calcium ions

(a) Factors that increase blood calcium levels

Function of Calcitonin

- **Intestine**
- **Extracellular fluid**
  - **Calcitonin**
    - Kidneys allow calcium loss
- **Bone**
  - Calcitonin
    - Osteoclasts inhibited while osteoclasts continue to lock calcium ions in bone matrix

(b) Factors that decrease blood calcium levels
FACTORS AFFECTING GROWTH OF THE SKELETON

1. **Growth of the skeleton** requires extrinsic factors and intrinsic factors.

2. **Extrinsic growth factors** include vitamin D (for calcium absorption, sunlight (for synthesis of vitamin D), vitamin C (for collagen synthesis), dietary protein (for synthesis of organic matrix), dietary calcium and phosphorus (for formation of inorganic matrix) and carbohydrate (for energy).

3. **Intrinsic growth factors** include genes, growth hormone, thyroid hormones and sex hormones.

   ![Extrinsic Growth Factors](image1)

   ![Intrinsic Growth Factors](image2)

   **HORMONES AFFECTING GROWTH**

4. **Growth hormone (GH)** causes protein synthesis and cell division of osteogenic cells throughout the growing years. **Growth Hormone** causes the juvenile growth spurt and general growth of the skeleton to maturity (pituitary dwarf has short stature with normal skeletal proportions)

5. **Thyroid hormones (thyroxine)** causes energy release for bone growth and controls the changes in skeletal proportions as bones grow. **Thyroid hormones (thyroxine)** works synergistically with GH to cause skeletal growth and controls changes in skeletal proportions (thyroid dwarf has short stature and infantile skeletal proportions)

6. **Sex hormones (androgens and estrogens)** cause the growth spurt of puberty, the ossification ("closure") of the epiphyseal plates at the end of puberty and the secondary sexual skeletal changes as well as bone deposition throughout life (preventing osteoporosis).
CHANGES IN THE HUMAN SKELETON WITH AGE

1. **Bone mass** is not constant but increases and decreases during life due to two processes, **deposition and resorption** of bone.

   - During **growth years** (0 - 20) the rate of deposition exceeds the rate of resorption and there is a net increase in bone mass.
   - During **adulthood** (ages 20 - 35 in females; 20 - 60 in males) the rate of deposition equals the rate of resorption and bone mass is fairly constant.
   - During **later years** (35+ in females; 60+ in males) the rate of deposition is less than the rate of absorption and there is a net decrease in bone mass.

2. The following **specific skeletal changes** occur during growth to maturity

   a. **Changes in Body Proportions**

      - **skull** becomes proportionately smaller
      - **face** becomes proportionately larger
      - **cranium** becomes proportionately smaller
      - **legs** become proportionately longer
      - **trunk** becomes proportionately smaller
      - **female pelvis** widens (during puberty)
      - **thorax** changes shape (from round to elliptical)

   b. **Ossification (Closure) of Epiphyseal Plates** (by 18 in females; 21 in males).

   c. Appearance of **Secondary Spinal Curvatures** (cervical curvature by 3 months; lumbar curvature by 1 year).

   d. Closure of Fontanels of Skull and formation of **Sutures** (these fuse in old age).

3. **Hormones** help control these skeletal changes (along with diet and normal bone use).
Effect of Age and Hormones on the Skeleton

Relative importance of hormones in human growth at various ages.

Normal and abnormal growth. Hypothyroid dwarfs retain their infantile proportions, whereas dwarfs of the constitutional type and, to a lesser extent, of the hypopituitary type have proportions characteristic of their chronological age.
Changing Growth Rates in the Skeleton with Age (Marieb Fig. 7.34)

Human newborn

Human adult

Newborn  2 yrs.  5 yrs.  15 yrs.  Adult
Developmental Changes in the Skeleton

Human embryo 7 weeks old. The skeleton consists entirely of cartilage and membrane.

1 YEAR
- Bone
- Cartilage
- Flesh

5 YEARS
- Shaft getting bigger
- Growing bone
- Protecting cartilage

10 YEARS
- Cartilage less
- Changing joint shape
- Bone ends larger

15 YEARS
- Knee looks adult
- Cartilage almost all bone
- End close to shaft

Repair of Bone Fractures
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**Fig. 6-5, Martini & Bartholomew; Fig. 6-7, Martini Fig. 6-14**

**STEP 1:**
Immediately after the fracture, extensive bleeding occurs. Over a period of several hours, a large blood clot, or fracture hematoma, develops.

**STEP 2:**
An internal callus forms as a network of spongy bone unites the inner surfaces, and an external callus of cartilage and bone stabilizes the outer edges.

**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.

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