Chapter 6: Osseous Tissue and Bone Structure

I. An Introduction to the Skeletal System, p. 180

Objective: Describe the functions of the skeletal system

The skeletal system includes:
- bones of the skeleton
- cartilages, ligaments and other stabilizing connective tissues

The 5 primary functions of the skeletal system are:
1. Support
2. Storage of minerals (calcium) and lipids (yellow marrow)
3. Blood cell production (red marrow)
4. Protection
5. Leverage (force of motion)

II. The Gross Anatomy of Bones, p. 180

Objectives:
1. Classify bones according to shapes and internal tissues.
2. Identify the major types of bone markings.

Bone Shapes, p. 180

The 6 major bone shapes are:
1. Long bones
2. Flat bones
3. Sutural bones
4. Irregular bones
5. Short bones
6. Sesamoid bones

*Figure 6-1a*
Long bones are long and thin. They are found in arms, legs, hands, feet, fingers and toes.

*Figure 6-1b*
Flat bones are thin with parallel surfaces. They are found in the skull, sternum, ribs and scapula.

*Figure 6-1c*
Sutural bones are small, irregular bones between the flat bones of the skull.

*Figure 6-1d*
Irregular bones are complex shapes such as spinal vertebrae and pelvic bones.
Figure 6-1e
Short bones are small and thick, including ankle and wrist bones.

Figure 6-1f
Sesamoid bones are small, flat bones that develop inside tendons near joints of knees, hands and feet.

Bone Markings, p. 181

The surface features of bones include depressions or grooves where tendons, ligaments and neighboring bones attach, and tunnels where blood and nerves enter the bone.

Table 6-1 describes 19 types of surface features and their functions.

Bone Structure, p. 183

Figure 6-2a
The femur is a long bone.
   The long shaft is the diaphysis.
   The wide part at each end, where the femur articulates with other bones, is the epiphysis.
   The area where the two connect is the metaphysis.

The heavy wall of the diaphysis is made of compact or dense bone. Inside is a central space called the marrow cavity.

The epiphysis is made mostly of spongy (cancellous) bone with an open network structure, covered with a thin layer of compact bone called the cortex.

Figure 6-2b
The parietal bone of the skull is a flat bone, consisting of a sandwich of spongy bone between 2 layers of compact bone.

III. Bone Histology, p. 184

Objectives:
1. Identify cell types and functions in bone
2. Compare structures and functions of compact bone and spongy bone

Osseous tissue is dense, supportive connective tissue containing specialized cells. The matrix of bone tissue is solid because of the calcium salts deposited around protein fibers in its ground substance.

The 4 characteristics of bone tissue are:
   1. Dense matrix containing deposits of calcium salts
2. The matrix contains bone cells within lacunae, which are organized around blood vessels.

3. Canaliculi form pathways for blood vessels to exchange nutrients and wastes.

4. Outer surfaces of bones are covered by periosteum consisting of outer fibrous and inner cellular layers.

*The Matrix of Bone, p. 184*

Two-thirds of bone matrix is made of calcium phosphate, Ca$_3$(PO$_4$)$_2$, which reacts with calcium hydroxide, Ca(OH)$_2$ to form crystals of hydroxyapatite, Ca$_{10}$(PO$_4$)$_6$(OH)$_2$, which incorporates other calcium salts and ions as it crystallizes.

About 1/3 of bone is protein fibers (collagen).

Bone cells are only about 2% of bone mass.

*The Cells of Bone, p. 184*

Bone contains 4 types of cells:

1. osteocytes
2. osteoblasts
3. osteoprogenitor cells
4. osteoclasts

*Figure 6-3a*

Osteocytes are mature bone cells that maintain the bone matrix.

Each osteocyte lives in a lacuna between layers (lamellae) of matrix.

Canaliculi through the lamellae allow osteocytes to connect at gap junctions between cytoplasmic extensions.

Osteocytes do not divide.

The main functions of osteocytes are:

1. To maintain the protein and mineral content of the matrix.
2. To help repair damaged bone (can revert to osteoblast or osteoprogenitor).

Osteoblasts are immature bone cells that secrete the matrix by the process of osteogenesis (secretion of proteins and other inorganic compounds of the matrix).

Before calcium salts are deposited (forming bone), the matrix is called osteoid.

When osteoblasts are surrounded by bone, they become osteocytes.

Osteoprogenitor cells are mesenchymal stem cells that divide to produce osteoblasts.

Located in the inner, cellular layer of periosteum (endosteum).

Assist in repairing bone fractures.

Osteoclasts are giant, multinucleate cells that secrete acids and protein-digesting enzymes which dissolve bone matrix and release stored minerals (the process of osteolysis).
Osteoclasts are derived from the stem cells that produce macrophages.

Bone building and bone recycling must be kept in balance. When osteoclasts break down bone faster than osteocytes build bone, bones become weak. Bones get stronger with exercise, which causes osteocytes to build bone.

*The Structure of Compact Bone, p. 185*

**Figure 6-5**

The basic unit of mature compact bone is a longitudinal unit called the osteon, in which osteocytes are arranged in concentric circles (concentric lamellae) around a central canal containing blood vessels.

Perpendicular to the central canal are perforating canals which carry blood vessels deep into the bone and bone marrow.

All osteons in long bones run the length of the bone, strengthening the bone in that direction.

A layer of circumferential lamellae wraps around the circumference of the long bone and binds all together.

*The Structure of Spongy Bone, p. 186*

**Figure 6-6**

Spongy bone does not have osteons. Its matrix forms an open network of trabeculae.

Spongy bone has no blood vessels in its trabeculae. The space between trabeculae is filled with another tissue, red bone marrow, which has blood vessels and supplies nutrients to the osteocytes.

Red bone marrow is red because it forms red blood cells. In other bones, spongy bone may hold yellow bone marrow, which is yellow because it stores fat.

**Figure 6-7**

The femur transfers weight from the hip joint along its length to the knee joint, causing stretching or tension on the outside of the shaft (lateral), and compression on the inside (medial).

*The Periosteum and Endosteum, p. 188*

**Figure 6-8**

The periosteum covers all bones except the parts of joints enclosed within the joint capsule. It has an outer fibrous layer and an inner cellular layer.
The collagen fibers of the periosteum connect the collagen fibers of the bone with those of joint capsules, attached tendons and ligaments (perforating fibers).

The periosteum has 3 functions:
1. isolates bone from surrounding tissues
2. provides a route for circulatory and nervous supply
3. participates in bone growth and repair

**Figure 6-8b**
Endosteum is an incomplete cellular layer covering the trabeculae of spongy bone in the marrow cavity, and line central canals. Endosteum contains osteoblasts, osteoprogenitor cells and osteoclasts, and is active in bone growth and repair.

IV. Bone Formation and Growth, p. 189

Objectives:
1. Compare intramembranous ossification and endochondral ossification
2. The timing of bone formation and growth, and differences in internal structure of adult bones

Human bones grow until about age 25. The process of replacing other tissues with bone (bone formation or osteogenesis) is called **ossification**. The process of depositing calcium salts (calcification) occurs during ossification and in other tissues.

The 2 main forms of ossification are:
1. intramembranous ossification
2. endochondral ossification

**Intramembranous Ossification, p. 189**

**Figure 6-9**
Intramembranous ossification, also called dermal ossification because it occurs in the dermis, produces dermal bones such as the mandible and clavicle.

There are 3 main steps in intramembranous ossification:
1. Mesenchymal cells aggregate, differentiate into osteoblasts, and begin ossification. The location where ossification begins is the **ossification center**, from which developing bone grows out in projections called spicules.
2. Blood vessels grow into the area to supply the osteoblasts. Spicules connect, trapping blood vessels inside bone.
3. Spongy bone develops, which can be remodeled into osteons of compact bone, periosteum or marrow cavities.

**Endochondral Ossification, p. 191**
Most bones originate as hyaline cartilage which becomes ossified through the process of endochondral ossification.

**Figure 6-10a (steps 1-6)**
The growth and ossification of a long bone occurs in 6 steps:
1. Chondrocytes in the center of the hyaline cartilage enlarge and form struts which begin to calcify. The enlarged chondrocytes die, leaving cavities in the cartilage.
2. Blood vessels grow around the edges of the cartilage. Cells in the perichondrium change to osteoblasts, producing a layer of superficial bone around the shaft which will continue to grow and become compact bone (appositional growth).
3. Blood vessels enter the cartilage, bringing fibroblasts that become osteoblasts. Spongy bone develops at the primary ossification center.
4. Remodeling creates a marrow cavity. Bone replaces cartilage at the metaphyses.
5. Capillaries and osteoblasts enter the epiphyses, creating secondary ossification centers.
6. The epiphyses fill with spongy bone. The cartilage remaining within the joint cavity is the articulation cartilage. The cartilage at the metaphysis is the epiphyseal cartilage.

**Figure 6-11**
When the long bone stops growing, after puberty, the epiphyseal cartilage disappears -- but its location is visible on X-rays as an epiphyseal line.

**Figure 6-10a (step 2)**
**Appositional Growth:**
The growth of compact bone on the surface (periosteum) of the bone, continues to thicken and strengthen the long bone with layers of circumferential lamellae.

_The Blood and Nerve Supplies, p. 193_

**Figure 6-12**
As the long bone matures, osteoclasts enlarge the marrow cavity, and osteons form around blood vessels in the compact bone.

Three major sets of blood vessels develop:
1. The nutrient artery and vein: a single pair of large blood vessels that enter the diaphysis through the nutrient foramen. (The femur has more than 1 pair.)
2. Metaphyseal vessels supply the epiphyseal cartilage, where bone growth occurs.
3. Periosteal vessels provide blood to the superficial osteons and the secondary ossification centers.

The periosteum also contains networks of lymphatic vessels and sensory nerves.

_V. The Dynamic Nature of Bone, p. 194_
Objectives:
1. The remodeling and homeostatic mechanisms of the skeletal system
2. The effects of nutrition, hormones, exercise and aging on bone.
3. The types of fractures and how they heal.

The adult skeleton must maintain itself and replace mineral reserves. The process that recycles and renews bone matrix is remodeling.

Bone remodeling involves osteocytes, osteoblasts and osteoclasts.

Key
Bone is continually remodeled, recycled and replaced. The rate of turnover varies. When deposition is greater than removal, bones get stronger. When removal is faster than replacement, bones get weaker.

Effects of Exercise on Bone, p. 194
Mineral recycling allows bones to adapt to stress. Heavily stressed bones become thicker and stronger.

Degenerative changes in the skeleton occur after relatively short periods of inactivity. Up to 1/3 of bone mass can be lost in just a few weeks without stress.

Key
What you don’t use, you lose. The stresses applied to bones during physical activity are essential to maintaining bone strength and mass.

Hormonal and Nutritional Effects on Bone, p. 194
Normal bone growth and maintenance requires some nutritional and hormonal factors:
1. A dietary source of calcium and phosphate salts, plus small amounts of magnesium, fluoride, iron and manganese.
2. The hormone calcitriol, made in the kidneys, is essential to proper absorption of calcium and phosphorus by the digestive tract. Calcitriol synthesis requires vitamin D3 (cholecalciferol).
4. Growth hormone and thyroxine stimulate bone growth.
5. Sex hormones: Estrogens and androgens stimulate osteoblasts for bone growth.
6. Calcitonin and parathyroid hormone regulate calcium and phosphate levels in body fluids.

Table 6-2 shows the major hormones involved in bone growth and maintenance.

The Skeleton as a Calcium Reserve, p. 196
**Figure 6-13**
Our bones are storage areas for many metabolically active minerals, particularly calcium.

Calcium (stored in bones) is the most abundant mineral in the body. Calcium ions are important to membranes and to the intracellular activities of neurons and muscle cells, especially heart cells. Calcium ion concentrations in body fluids must be closely regulated.

Calcium ion homeostasis is maintained by the hormones calcitonin and parathyroid hormone, which control calcium ion storage, absorption and excretion.

Three sites are controlled:
1. bones, where calcium is stored
2. digestive tract, where calcium is absorbed
3. kidneys, where calcium is excreted

**Figure 6-14a**
Parathyroid hormone (PTH), produced by parathyroid glands located in the neck, increases calcium ion levels in body fluids by:
1. stimulating osteoclasts (release calcium stored in bone)
2. increasing intestinal absorption of calcium ions (through its effect on calcitriol)
3. decreasing the rate of calcium excretion at the kidneys.

**Figure 6-14b**
Calcitonin, secreted by C cells (parafollicular cells) in the thyroid, decreases calcium ion levels in body fluids by:
1. inhibiting osteoclast activity
2. increasing calcium ion excretion at the kidneys

**Key**
Calcium and phosphate ions circulating in the blood are constantly being lost in the urine. These ions must be replaced to maintain homeostasis. If they aren’t obtained from the diet, they will be released from storage in the skeleton, making bones weaker. Exercise and a diet with plenty of calcium are necessary to keep bones strong.

*Fracture Repair, p. 198*
Fractures are cracks or breaks in bones caused by physical stress.

Fractures are repaired in 4 steps:

**Figure 6-15a**
1. Bleeding produces a clot called the fracture hematoma, establishing a fibrous network. Bone cells in the area die.

**Figure 6-15b**
2. Cells of the endosteum and periosteum divide and migrate into the fracture zone. **Calluses** stabilize the break: A collar of cartilage and bone (external callus) surrounds the break, and an **internal callus** develops in the marrow cavity.

**Figure 6-15c**
3. Osteoblasts replace the central cartilage of the external callus with spongy bone.

**Figure 6-15d**
4. Osteoblasts and osteocytes continue to remodel the fracture for up to a year, reducing the bone calluses.

**Figure 6-16**
The major types of fractures are:
1. Pott’s fracture
2. comminuted fractures
3. transverse fractures
4. spiral fractures
5. displaced fractures
6. Colles’ fracture
7. greenstick fracture
8. epiphyseal fractures
9. compression fractures

**VI. Aging and the Skeletal System, p. 199**
Objective:
1. The effects of the aging process on the skeletal system

The bones of the skeleton become thinner and weaker with age. Reduction in bone mass (osteopenia) begins between ages 30 and 40. Women lose about 8% of bone mass per decade, men about 3%.

Epiphyses, vertebrae and jaws are most affected, resulting in fragile limbs, reduction in height, and tooth loss.

**Osteoporosis** is the condition of severe bone loss, extensive enough to impair normal function. Over age 45, 29% of women and 18% of men have osteoporosis.

Estrogens and androgens contribute to maintaining bone mass. Bone loss in women accelerates after menopause.

Cancerous tissues release a chemical (**osteoclast-activating factor**) that stimulates osteoclasts and produces severe osteoporosis.

**SUMMARY**
In chapter 6 we learned about:
- Bone shapes, markings and structure.
- The matrix of osseous tissue.
- Types of bone cells.
- The structures of compact bone.
- The structures of spongy bone.
- The periosteum and endosteum.
- The processes of ossification and calcification.
- Intramembranous ossification.
- Endochondrial ossification.
- Blood and nerve supplies to bone.
- Bone minerals, recycling and remodeling.
- The effects of exercise on bone.
- Hormonal and nutritional effects on bone.
- The skeleton as calcium storage.
- Fracture repair.
- The effects of aging on the skeletal system.