7. Skeletal System: Bone Structure and Function

For the next two chapters (7 and 9) we will study the skeletal system. Although the major feature of this system is the bones, the skeletal system also consists of cartilage, ligaments, tendons, and other structures that hold the bones together and stabilize them. As we study Chapter 7 the focus will be on bones. By the way, specific bones, as described in Chapter 8, will be studied primarily in the laboratory. That is why Chapter 8 is not part of the lecture.

I. Bone: The Major Organ of the Skeletal System
Every bone in your skeletal system is considered an organ. We’ll begin our study of bones with general functions and classification of bones.

General functions
A. Support and protection. The skeletal system provides structural support for the entire body. Skeletal elements protect various vital organs, such as the brain and the heart.

B. Movement. Bones function as levers for the muscles to provide movement of the body.

C. Hemopoiesis. Formed elements of the blood are produced in red marrow of the bones.

D. Storage of mineral and energy reserves. Bones provide an important reserve supply of calcium and phosphate; they also store lipids, which are an energy reserve, in yellow marrow.

Classification of bones
There are 206 named bones in the human skeleton, and they can be divided between two major regions of the skeleton: the axial skeleton consists of the skull, vertebral column, and rib cage; the appendicular skeleton consists of the arms, pectoral girdles, legs, and pelvic girdle.

Bones can also be classified according to their general shapes (Fig. 7.2):

A. **Long bones** are long and relatively slender, *e.g.*, the femur, the humerus, and the phalanges.

B. **Short bones** are boxy in shape, *e.g.*, the carpals and tarsals.

C. **Flat bones** are thin and broad in shape, *e.g.*, the scapula, ribs, and the sternum. They are not necessarily truly flat. These bones either serve for protection or provide an extensive surface for muscle attachment.

D. **Irregular bones** have complex shapes, and they do not fit the other categories. Examples are the vertebrae and sphenoid bone.

Gross anatomy of bones
Each bone contains two types of **osseous tissue** (bone tissue): (1) **Compact bone** is very dense and solid, and it is always found on the surface of the bone. (2) **Spongy bone** has a relatively porous structure, and it is found in the interior of bones. The relative amounts of compact and spongy bone are related to the function of the bone.
With the exception of surfaces found within joint cavities, the surfaces of bones are wrapped with connective tissue called the **periosteum**. The periosteum consists of a fibrous outer layer and a cellular inner layer. Its functions are (1) to separate the bone from surrounding tissues, (2) to provide a pathway for circulatory and nervous supply, and (3) to assist in bone growth and repair. The periosteum also is essential in forming joints, as it is contiguous with tendons and ligaments. Fibers of the periosteum, called **perforating fibers**, actually penetrate the bone itself and anchor the periosteum to the bone.

The **endosteum** lines the marrow cavity, trabeculae of the spongy bone, and the inner surfaces of the central canals.

We will review some additional aspects of bone structure by examining features of two bones that are more or less at the extreme ends of bone structure: the humerus (a long bone) and the parietal bone (a flat bone).

The humerus is a representative long bone (Fig. 7.3). The shaft is referred to as the **diaphysis**, and each swollen end is referred to as an **epiphysis**. A hole, called the **nutrient foramen**, allows nerve fibers and blood vessels to enter the diaphysis. Inside the diaphysis is a space called the **medullary** (or “marrow”) **cavity**. The medullary cavity contains **bone marrow**, which is a loose connective tissue. **Yellow bone marrow** consists mainly of fat cells, and **red bone marrow** consists of a mixture of mature and immature blood cells. Each epiphysis may form a joint, in which case it is covered with a thin layer of hyaline cartilage, called the **articular cartilage**. An **epiphyseal line** marks the border between each epiphysis and the diaphysis. The epiphyseal line is the remnant of the **epiphyseal plate**, a layer of cartilage that is important for growth of the long bone during development.

The parietal bone is a representative flat bone (Fig. 7.4). Two parallel layers of compact bone surround a flat layer of spongy bone, like a sandwich. The spongy bone of a flat bone is called the **diploë**. Bone marrow is present in the spongy bone, but not in a defined marrow cavity.

**Microscopic anatomy: bone connective tissue**

Remember that osseous tissue is a type of connective tissue. The matrix is very dense owing to deposits of calcium salts around the matrix proteins. There are four main cell types in bone tissue (Fig. 7.6):

1. **Osteoprogenitor cells** are stem cells that divide and give rise to the next type of cell, the osteoblast.

2. **Osteoblasts** generate new bone matrix in a process called **osteogenesis**. As the tissue surrounding the osteoblast matures into bone, the osteoblast develops into an osteocyte.

3. **Osteocytes**, which are mature bone cells, are the most numerous. They reside within pockets in the matrix called **lacunae**. **Canaliculi** are passages between the lacunae and nearby blood vessels. Osteocytes project cytoplasmic extensions into the canaliculi, and gap junctions connect neighboring osteocytes. Both of these features aid in the transport of nutrients throughout the bone. Osteocytes are responsible for maintaining and monitoring the protein and mineral content of the matrix, and they participate in the repair of damaged bone.
4. **Osteoclasts** are giant, multinucleate cells that remove bone matrix from the bone. Unlike other bone cells, they are derived from monocytes. Osteoclasts use acids and enzymes to dissolve the matrix and release stored minerals in a process called **osteolysis**. The actions of osteoblasts and osteoclasts must be properly balanced to maintain proper strength of the bones.

**Composition of the bone matrix**

Nearly all the mass of a bone is matrix; cellular elements make up very little of the mass of a bone. Bone matrix consists of two major components: the organic component and the inorganic component.

The organic component accounts for about 1/3 of the mass of a bone, and it is called the **osteoid**. Collagen fibers are the major component of the osteoid.

The inorganic component accounts for about 2/3 the mass of a bone, and it consists mainly of a substance called **hydroxyapatite**. The major chemical in hydroxyapatite is **calcium phosphate** ($\text{Ca}_3(\text{PO}_4)_2$).

Hydroxyapatite provides strength and resistance to compression. The collagen fibers provide resistance to tensile forces. This arrangement is similar to “reinforced concrete,” which is used in construction of large buildings, bridges, etc. Reinforced concrete consists of concrete poured around steel rods. The concrete (like hydroxyapatite) provides resistance to compression. The steel rods (like collagen fibers) provide resistance to tensile forces.

**Comparison of compact and spongy bone microscopic anatomy**

**Compact bone**

The basic functional unit of compact bone is the **osteon**, or **Haversian system** (Figs. 7.7 and 7.8). Each osteon contains osteocytes arranged in concentric layers, called **lamellae**, around a **central canal**, which contains one or more blood vessels. Central canals generally run parallel to the bone surface. **Perforating canals** run perpendicular to the central canals and link the central canals. The lamellae arranged around the central canals are called **concentric lamellae**, **interstitial lamellae** fill in the spaces between the osteons, and **circumferential lamellae** can be found along the bone surface.

The function of compact bone is to provide strength. Osteons are particularly good at resisting forces applied along their axes. In long bones, the osteons of the diaphysis are aligned parallel to the long axis of the bone. This makes the shaft resistant to compression and tension.

**Spongy bone**

The matrix in spongy bone forms struts and plates called **trabeculae** (Fig. 7.8c). This arrangement creates a considerable amount of open space within the bone. Spongy bone is found where the bone does not receive a great deal of stress or where the stresses may arrive from many directions. The presence of spongy bone also reduces the weight of the bone and provides an environment for other tissues, such as the bone marrow.
II. Bone Growth and Bone Remodeling

Bone growth
There are two main ways that bones grow, once they have formed:

A. Interstitial growth
Long bones grow in length with help from the epiphyseal plates (Fig. 7.12). Chondroblasts create more hyaline cartilage in the plates. This leads to growth in both directions as the epiphyses move away from the center of the diaphysis. Older cartilage in the plates is invaded by osteoclasts and osteoblasts, which eat away the cartilage and replace it with bone. Eventually, the cartilage stops growing and is completely replaced by bone. What structure replaces the epiphyseal plate at that time? In the space below, draw how the bone increases in length at the epiphyseal plates.

B. Appositional growth
**Appositional growth** is an increase in size in all directions (Fig. 7.13). This process occurs in all bones. Basically, osteoblasts deposit new bone matrix all over the surface of the bone, and this thickens the bone. Meanwhile, inside the bone, osteoclasts eat away at bone matrix. As the bone increases in size, old compact bone on the inside is replaced by spongy bone. Why is this important? In the case of a long bone, osteoclasts eat away at spongy bone to increase the size of the medullary cavity.
Bone remodeling
Although bones appear to be static organs, they are actually quite dynamic. Approximately 6% of the bone mass of an adult is recycled on a weekly basis. Spongy bone is entirely replaced about every 3-4 years, and compact bone is entirely replaced about every 10 years.

The continuing processes of bone deposition and bone removal constitute **bone remodeling**. In an adult, bone deposition and bone removal generally occur at equal rates, which keeps the overall mass of a bone constant.

Bone deposition is accomplished by osteoblasts. Deposition of new matrix begins with the production of osteoid. After about a week, the osteoid becomes mineralized as crystals of hydroxyapatite form.

Bone removal is accomplished by the osteoclasts. Osteoclasts move along the bone surface and dig pits or grooves into the surface of the bone. Enzymes secreted into the matrix digest the osteoid, and acids secreted into the matrix dissolve the hydroxyapatite.

Bone remodeling is also affected by use of the bones. Mechanical stress on the bones encourages bone growth (or inhibits bone destruction) at the points of greatest stress. For example, weightlifters and people who do a lot of manual labor will have extra deposits of bone where the muscles attach to the bones.

III. Regulating Blood Calcium Levels

Review what you should have learned in Chapter 6 about vitamin D and calcitriol.

Bone remodeling is carefully regulated, primarily by two hormones: **parathyroid hormone (PTH)** and **calcitonin** (Fig. 7. 15). However, this regulation is directed at keeping the amount of calcium in the blood constant, rather than keeping the structure of bone constant!

When the blood calcium level decreases below normal, PTH is released by the parathyroid glands. PTH stimulates activity of osteoclasts, which then break down bone and release calcium into the bloodstream.

When the blood calcium level rises above normal, calcitonin is released by the thyroid gland. Calcitonin inhibits bone removal and encourages the deposition of calcium in the bones.

What will happen to bones if blood calcium levels are chronically low?