This chapter focuses on two highly specialized types of connective tissues—bone and cartilage. In addition, the functional characteristics of cartilage and a comparison of cartilage and bone are discussed later in the chapter.

Other types of tissue in the skeletal system include fibrous and loose connective tissue, blood, nervous tissue, epithelium, lymphatic tissue, myeloid tissue (bone marrow), and adipose, or fat, tissue.

Individual bones, which are considered separate, discrete organs, are discussed in Chapter 8. Articulations, or joints, are points of contact between bones that make movement possible and are considered in Chapter 9.

**TYPES OF BONES**

Structurally, we can name four types of bones. Their names suggest their shapes: long bones, short bones, flat bones, and irregular bones. Figure 7-1 gives an illustration of each type. Bones serve differing needs, and their size, shape, and appearance will vary to meet those needs. Some bones must bear great weight; others serve a protective function or serve as delicate support structures for the fingers and toes. Bones differ in size and shape and also in the amount and proportion of two different types of bone tissue that comprise them. **Compact bone** is dense and “solid” in appearance; **cancellous, or spongy, bone** is characterized by open space partially filled by an assemblage of needle-like structures. Both types are discussed when the microscopic structure of bone is described later in the chapter.

All four types of bone discussed below have varying amounts of cancellous and compact bone in their structure.

**Long bones** are easily identified by their extended longitudinal axes and expanded and often uniquely shaped articular ends. The femur of the thigh and humerus of the arm are examples.

**Short bones** are often described as cube- or box-shaped structures, which are about as broad as they are long. Examples include the wrist (carpals) and ankle (tarsal) bones.
Flat bones are generally broad and thin with a flattened and often curved surface. Certain bones of the skull, the shoulder blades (scapulae), ribs, and breastbone (sternum) are typical flat bones. Red marrow fills the spaces in the cancellous bone inside a few flat bones—the sternum is one example. To help in the diagnosis of leukemia and certain other diseases, a physician may decide to perform a needle puncture of one of these bones. In this type of diagnostic procedure a needle is inserted through the skin and compact bone into the red marrow, and a small amount of the marrow is then aspirated and examined under the microscope for normal or abnormal blood cells. The procedure, called an aspiration biopsy, is discussed on p. 550.

Irregular bones are often clustered in groups and come in various sizes and shapes. The vertebral bones that form the spine and the facial bones are good examples. Unique irregular bones, which often appear singly rather than in groups, are called sesamoid bones. There are only a few sesamoid bones in the body and they are generally found embedded in the substance of tendons close to the joints. The kneecap, or patella, is a good example.

**Figure 7-1** Types of bones. Examples of bone types include A, long bones (humerus); B, flat bones (scapula); C, short bones (phalanx); and D, irregular bones (vertebra).

**PARTS OF A LONG BONE**

A long bone consists of the following structures visible to the naked eye: diaphysis, epiphyses, articular cartilage, periosteum, medullary (marrow) cavity, and endosteum. Identify each of these structures in the tibia shown in Figure 7-2, A. The tibia is the longer, stronger, and more medially located of the two leg bones.

1. **Diaphysis** (di-AF-i-sis). Main shaftlike portion. Its hollow, cylindrical shape and the thick compact bone that composes it adapt the diaphysis well to its function of providing strong support without cumbersome weight.

2. **Epiphyses** (e-PIF-i-sis). Both ends of a long bone. Epiphyses have a bulbous shape that provides generous space near joints for muscle attachments and also gives stability to joints. Look at Figure 7-2 to note the innumerable small spaces in the bone of the epiphysis. They make this kind of bone look a little like a sponge—hence its name, spongy, or cancellous, bone. A specialized type of soft connective tissue, called red marrow, fills the spaces within this spongy bone. Early in development, epiphyses are separated from the diaphysis by a layer of cartilage, the epiphyseal plate. The region between epiphyses and diaphysis (in a mature bone) or the epiphyseal plate region (in a growing bone) is called the metaphysis (me-TAF-I-sis).

3. **Articular cartilage.** Thin layer of hyaline cartilage that covers articular or joint surfaces of epiphyses. Resiliency of this material cushions jolts and blows.

4. **Periosteum** (pair-ee-OS-tee-um). Dense, white fibrous membrane that covers bone except at joint surfaces, where articular cartilage forms the covering. Many of the periosteum’s fibers penetrate the underlying bone, welding these two structures to each other. In addition, muscle tendon fibers interlace with periosteal fibers, thereby anchoring muscles firmly to bone. The periosteum is a critically important membrane that, depending on its location, also contains bone forming and destroying cells, and blood vessels that become incorporated into bones during their initial growth or subsequent remodeling and repair. This important membrane is essential for bone cell survival and for bone formation, a process that continues throughout life.

5. **Medullary (or marrow) cavity.** A tubelike hollow space in the diaphysis of a long bone. In the adult the medullary cavity is filled with connective tissue rich in fat—a substance called yellow marrow.

6. **Endosteum** (end-OS-tee-um). A thin epithelial membrane that lines the medullary cavity of long bones.

**BONE TISSUE**

Bone (osseous) tissue is perhaps the most distinctive form of connective tissue in the body. It is typical of other connective tissues in that it consists of cells, fibers, and extracellular material, or matrix. However, its extracellular components are hard and calcified. In bone the extracellular material, or matrix, predominates. It is much more abundant than the bone cells, and it contains many fibers of collagen (the body’s most abundant protein). The rigidity of bone enables it to serve supportive and protective functions.

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1. Name the two major types of connective tissue found in the skeletal system.

2. Name the two different types of bone tissue.
As a tissue, bone is ideally suited to its functions, and the concept that structure and function are interrelated is apparent in this highly specialized tissue. It has a tensile strength nearly equal to cast iron but at less than one third the weight. Bone is organized so that its great strength and minimal weight result from the interrelationships of its structural components. The relationship of structure to function is apparent in its chemical, cellular, tissue, and organ levels of organization.

**COMPOSITION OF BONE MATRIX**

The extracellular bone matrix can be subdivided into two principal chemical components: inorganic salts and organic matrix.

**Inorganic Salts**

The calcified nature and thus the hardness of bone results from the deposition of highly specialized chemical crystals of calcium and phosphate, called hydroxyapatite. The process is called calcification. The needle-like apatite crystals are about 300 Å in length by 20 Å in thickness. They are oriented in the microscopic spaces between the collagen fibers in the bone matrix so that they can most effectively resist stress and mechanical deformation. In addition to calcium and phosphate, other mineral constituents such as magnesium, sodium, sulfate, and fluoride are also found in bone.

**Measuring Bone Mineral Density**

Osteoporosis (OSS-tee-oh-pore-OH-sis) (see Mechanisms of Disease, p. 205) is an age-related skeletal disease that is characterized by loss of bone mineral density, increased bone fragility, and susceptibility to fractures—especially of the spine, forearm, and hip. The disease affects nearly 45% of untreated women during the first 10 years after menopause. During this time they may lose as much as 4% to 8% of their bone density on a yearly basis. Of this group, and white women are particularly susceptible, about 40% will suffer some type of osteoporotic fracture and 15% will break a hip, resulting in costly and devastating medical outcomes.

Treatment of osteoporosis using estrogen (hormone replacement therapy—HRT), bone-building nonhormonal drugs such as Fosamax (alendronate sodium) or other so-called "designer estrogens," or Miacalcin (calcitonin) is required if nutritional calcium supplements and weight-bearing exercise are ineffective in maintaining bone mineral density.

Unfortunately, regular x-rays do not detect significant reductions in bone mineral content until 30% or more of total bone mass has been lost. In the past, only a limited number of large medical centers had the complex and expensive equipment needed to accurately measure bone mineral density—a requirement for effective screening and treatment programs. These devices, using technology called single photon absorptiometry (SPA), dual energy x-ray absorptiometry (DXA), or varieties of quantitative computed tomography (QCT), although becoming more available than in the past, are still only available on a regular basis to physicians in large practice settings or in academic medical centers. Recently, however, advances in an old technique called radiographic absorptiometry (RA) allows use of a plain x-ray of the hand,
wrist, or heel, taken with a standardized wedge of aluminum, to make an accurate assessment of bone mineral density. Using this and other now routinely available tests has resulted in more effective and widespread screening and treatment of osteoporosis in larger numbers of individuals.

**Organic Matrix**

The organic matrix of bone and other connective tissues is a composite of collagenous fibers and an amorphous mixture of protein and polysaccharides called ground substance. The ground substance of bone provides support and adhesion between cellular and fibrous elements and also serves an active role in many cellular metabolic functions necessary for growth, repair, and remodeling. Connective tissue cells secrete the gel-like and homogeneous ground substance that surrounds the fibers found in bone matrix.

**Chondroitin** (kon-DROY-tin) sulfate is an important component of ground substance in both bone and cartilage. Chemically, it is a compound with a tongue-twister name: glucosaminoglycan (gly-COE-ah-MEE-no-GLY-can) or GAG. Chondroitin sulfate and a chemical component called glucosamine (glu-COE-ah-meen) are both required for repair and maintenance of bone and cartilage. As a result, they are now being used extensively as dietary supplements intended to facilitate healing and reduce the “wear and tear” pain of osteoarthritis (see Box 7-1 and Mechanisms of Disease, p. 204).

Components of the organic matrix not only add to overall strength but also give bone some degree of plastic-like resilience so that applied stress—within reasonable limits—does not result in frequent crush or fracture injuries.

**MICROSCOPIC STRUCTURE OF BONE**

The basic structural components and cell types of bone were described briefly in Chapter 5. In the paragraphs that follow, additional information about bone structure and cell types will serve as a basis for learning the functional characteristics of this important tissue. Understanding how a bone forms and grows, how it repairs itself after injury, and how it interacts with other tissues and organs in maintaining various important homeostatic mechanisms is based on knowledge of its basic structure—a structure as unique as its chemical composition.

**COMPACT BONE**

Compact bone contains many cylinder-shaped structural units called osteons (OS-tee-ahns), or Haversian systems (in honor of Clopton Havers, a seventeenth-century English anatomist who first described them). Note in Figure 7-3 that each osteon surrounds a canal that runs lengthwise through the bone. Living bone cells in these units are literally cemented together to constitute the structural framework of compact bone. The unique structure of the osteon permits delivery of nutrients and removal of waste products from metabolically active but imprisoned bone cells.

Four types of structures make up each osteon, or Haversian canal: lamellae, lacunae, canaliculi, and a Haversian canal. As you read the following definitions, identify each structure in Figure 7-3.

- Lacunae (la-KYOO-nay) (Latin for “little lakes”). Small spaces containing tissue fluid in which bone cells lie imprisoned between the hard layers of the lamellae.
- Canaliculi (CAN-uh-LIK-you-lye). Ultrasmall canals radiating in all directions from the lacunae and connecting them to each other and into a larger canal, the Haversian canal.
- Haversian canal. Extends lengthwise through the center of each Haversian system; contains blood vessels, lymphatic vessels, and nerves from the Haversian canal; nutrients and oxygen move through canaliculi to the lacunae and their bone cells—a short distance of about 0.1 mm or less.

Lengthwise-running Haversian canals are connected to each other by transverse Volkmann’s canals. These communicating canals contain nerves and vessels that carry blood and lymph from the exterior surface of the bone to the osteons.

**CANCELLOUS BONE**

Cancellous, or spongy, bone differs in microscopic structure from compact bone. As you recall, the structural unit of compact bone is the highly organized osteon, or Haversian system. There are no osteons in cancellous bone. Instead, it consists of needle-like bony spicules called trabeculae. Bone
cells are found within the trabeculae. Nutrients are delivered to the cells and waste products are removed by diffusion through tiny canaliculi that extend to the surface of the very thin spicules.

Note that the cancellous bone shown in Figure 7-3, C, lies between two layers of compact bone, much like the filling in a sandwich. The middle layer of spongy bone is called the diploe (DIP-low-ee). This layered organization is typical of

**Figure 7-3** Structure of compact and cancellous bone. A, Longitudinal section of a long bone showing both cancellous and compact bone. B, A magnified view of compact bone.
flat bones such as those found in the skull. The placement of trabeculae in spongy bone is not as random and unorganized as it might first appear. The bony spicules are actually arranged along lines of stress, and their orientation will therefore differ between individual bones according to the nature and magnitude of the applied load (Figure 7-4). This feature greatly enhances a bone’s strength and is yet another example of the relationship between structure and function.

Locked within a seemingly lifeless calcified matrix, bone cells are active metabolically. They must, like all living cells, continually receive food and oxygen and excrete their wastes, so blood supply to bone is both important and abundant. One or more arteries supply the bone marrow in the internal medullary cavity and provide nutrients to areas of cancellous bone. In addition, blood vessels from the periosteum, when they eventually become covered by new bone in the development process, become incorporated into the bone itself and then, by way of Volkman’s canals and by connections with other vessels in adjacent Haversian systems, ultimately serve the nutrient needs of cells that, because of their own secretions, have become surrounded by calcified matrix in compact bone. The mechanism by which periosteal blood vessels become “imprisoned” by the deposition of new bone during growth and remodeling is shown in Figure 7-12 and described on p. 201.

Figure 7-3, cont’d  C, Section of a flat bone. Outer layers of compact bone surround cancellous bone. Note the fine structure of compact and cancellous bone.

Figure 7-4  Orientation of trabeculae. Longitudinal section of a long bone showing trabeculae oriented along lines of stress.
TYPES OF BONE CELLS

Three major types of cells are found in bone: osteoblasts (bone-forming cells), osteoclasts (bone-reabsorbing cells), and osteocytes (mature bone cells). All bone surfaces are covered with a continuous layer of cells that is critical to the survival of bone. This layer is composed of relatively large numbers of osteoblasts interspersed with a much smaller population of osteoclasts.

Osteoblasts (OS-tee-oh-blasts) are small cells that synthesize and secrete a specialized organic matrix, called osteoid, that is an important part of the ground substance of bone. Collagen fibrils line up in regular arrays in the osteoid and serve as a framework for the deposition of calcium and phosphate. The process ultimately results in accumulation of mineralized bone. Osteogenic (os-tee-oh-JEN-ik) stem cells, found in the endosteum and lining the Haversian canals, undergo cell division to form osteoblasts.

Osteoclasts (OS-tee-oh-clasts) are giant multinucleate cells (Figure 7-5) that are responsible for the active erosion of bone minerals. They are formed by fusion of several precursor cells and contain large numbers of mitochondria and lysosomes. Each 24-hour period sees an alternation of primarily osteoblast, then osteoclast, activity. For this reason, bone is a highly active, dynamic tissue that undergoes continuous change and remodeling.

Osteocytes (OS-tee-oh-sites) are mature, nondividing osteoblasts that have become surrounded by matrix and now lie within lacunae. Figure 7-6 is a scanning electron micrograph showing a mature osteocyte within a lacuna. Note that a cytoplasmic process from the cell is extending into a canaliculus below. Numerous collagen fibers are seen in the ground substance and mineralized bone surrounding the osteocyte.

The way in which these cell types work together to produce bone is described in detail when the development of bone is discussed later in this chapter.

BONE MARROW

Bone marrow is a specialized type of soft, diffuse connective tissue called myeloid tissue. It serves as the site for production of blood cells and is found in the medullary cavities of certain long bones and in the spaces of spongy bone in some areas.

During the lifetime of an individual, two types of marrow exist. In an infant’s or child’s body, virtually all of the bones contain red marrow. This is named for its function in the production of red blood cells. As an individual ages the red marrow is gradually replaced by yellow marrow. In yellow marrow the marrow cells have become saturated with fat and, as a result, are inactive in blood cell production.

The main bones in an adult that still contain red marrow include the ribs, bodies of the vertebrae and the ends of the humerus in the upper arm, the pelvis and the femur, or thigh, bone. During times of decreased blood supply, yellow marrow in an adult can alter to become red marrow. Such a transition may occur during periods of prolonged anemia caused by chronic blood loss, exposure to radiation or toxic chemicals, and certain diseases.

If the bone marrow is severely damaged, a bone marrow transplant can be a life-saving treatment. In this procedure red marrow from a compatible donor is introduced into the recipient intravenously. If the recipient’s immune system does not reject the new tissue, which is always a danger in tissue transplants, the donor cells may establish a colony of new, healthy tissue in the bone marrow.
FUNCTIONS OF BONE

Bones perform five functions for the body. Each one is important for maintaining homeostasis and for optimal body function.

1. Support. Bones serve as the supporting framework of the body, much as steel girders are the supporting framework of our modern buildings. They contribute to the shape, alignment, and positioning of the body parts.

2. Protection. Hard, bony "boxes" serve to protect the delicate structures they enclose. For example, the skull protects the brain, and the rib cage protects the lungs and the heart.

3. Movement. Bones with their joints constitute levers. Muscles are anchored firmly to bones. As muscles contract and shorten, they pull on bones, thereby producing movement at a joint. This process is discussed further in Chapter 9.

4. Mineral storage. Bones serve as the major reservoir for calcium, phosphorus, and certain other minerals. Homeostasis of blood calcium concentration—essential for healthy survival—depends largely on changes in the rate of calcium movement between the blood and bones. If, for example, blood calcium concentration increases above normal, calcium moves more rapidly out of the blood into bones and more slowly in the opposite direction. The result? Blood calcium concentration decreases—usually to its homeostatic level.

5. Hematopoiesis. Hematopoiesis, or blood cell formation, is a vital process carried on in red bone marrow, or myeloid tissue. Myeloid tissue, in the adult, is located primarily in the ends, or epiphyses, of certain long bones, in the flat bones of the skull, in the pelvis, and in the sternum and ribs.

REGULATION OF BLOOD CALCIUM LEVELS

The bones of the skeletal system serve as a storehouse for about 98% of the body calcium reserves. As the major reservoir for this physiologically important body mineral, bones play a key role in maintaining constancy of blood-calcium levels. To maintain homeostasis of blood-calcium levels within a very narrow range, calcium is mobilized and moves into and out of the blood during the continuous remodeling of bone. It is the balance between deposition of bone by osteoblasts and the breakdown and resorption of bone matrix by osteoclasts that helps regulate blood calcium levels. During bone formation, osteoblasts serve to remove calcium from blood, thus lowering its circulating levels. However, when osteoclasts are active and breakdown of bone predominates, calcium is released into the blood and circulating levels will increase.

Homeostasis of calcium ion concentration is essential not only for bone formation, which is described below, but also for normal blood clotting, transmission of nerve impulses, and maintenance of skeletal and cardiac muscle contraction. The primary homeostatic mechanisms involved in the regulation of blood calcium levels involve secretion of two hormones: (1) parathyroid hormone by the parathyroid glands and (2) calcitonin by the thyroid gland.

MECHANISMS OF CALCIUM HOMEOSTASIS

Parathyroid Hormone

The actions of parathyroid hormone are fully discussed in Chapter 16. However, the importance of this hormone as the primary regulator of calcium homeostasis and its effect on bone remodeling warrant a brief description here. When the level of calcium in blood passing through the parathyroid glands decreases below its normal homeostatic "set point" level, osteoclasts are stimulated to initiate increased breakdown of bone matrix, which results in the release of calcium into the blood and the return of calcium levels to normal. In addition, parathyroid hormone also increases renal absorption of calcium from the urine, thus reducing its loss from the body. Another effect of parathyroid hormone is to stimulate vitamin D synthesis, which increases the efficiency of absorption of calcium from the intestine. If blood passing through the parathyroid glands has an elevated calcium level, osteoclast activity will be suppressed, thus reducing the breakdown of bone matrix and the level of calcium circulating in the blood. The multiple effects of this type of hormonal control permit the body to precisely regulate a number of homeostatic mechanisms that have an effect both directly and indirectly on blood levels of this important mineral.

Parathyroid hormone is the most critical factor in homeostasis of blood calcium levels. As a result of its actions and the ability of the body to regulate its formation and release, bones remain strong and calcium levels are maintained within normal limits during both bone formation and resorption.

Calcitonin

Calcitonin, also discussed in Chapter 16, is a protein hormone produced by specialized cells in the thyroid gland. It is produced in response to high blood calcium levels and functions to stimulate bone deposition by osteoblasts and inhibit osteoclast activity. As a result, calcium will move into the bones from the blood and circulating levels will decrease. A specialized nasal spray containing calcitonin (Miacalcin) is now available to treat postmenopausal osteoporosis. Although calcitonin does play a role in the homeostasis of blood calcium levels, it is far less important than parathyroid hormone.

DEVELOPMENT OF BONE

When the skeleton begins to form in an infant before its birth, it consists of not bones but of cartilage and fibrous structures shaped like bones. Gradually these cartilage "models" become transformed into real bones when the cartilage is replaced with calcified bone matrix. This process of constantly "remodeling" a growing bone as it changes from a
small cartilage model to the characteristic shape and proportion of the adult bone requires continuous activity by the bone-forming osteoblasts and bone-resorbing osteoclasts. The laying down of calcium salts in the gel-like matrix of the forming bones is an ongoing process. This calcification process is what makes bones as “hard as bone.” The combined action of the osteoblasts and osteoclasts sculpts bones into their adult shapes. The term osteogenesis is used to describe this process.

“Sculpting” by the bone-forming and bone-resorbing cells allows bones to respond to stress or injury by changing size, shape, and density. The stresses placed on certain bones during exercise increase the rate of bone deposition. For this reason, athletes or dancers may have denser, stronger bones than less active people.

Most bones of the body are formed from cartilage models in a process called endochondral ossification, meaning “formed in cartilage.” A few flat bones are formed within fibrous membrane, rather than cartilage, in the process of intramembranous ossification. Figure 7-7 illustrates osseous development of the infant at birth.

**INTRAMEMBRANOUS OSSIFICATION**

Intramembranous ossification takes place, as its name implies, within a connective tissue membrane. The flat bones of the skull, for example, begin to take shape when groups of osteogenic stem cells within the membrane differentiate into osteoblasts. These clusters of osteoblasts are called centers of ossification. They secrete matrix material and collagenous fibrils. The Golgi apparatus in an osteoblast specializes in synthesizing and secreting carbohydrate compounds of the type called mucopolysaccharides, and its endoplasmic reticulum makes and secretes collagen, a protein. In time, relatively large amounts of the mucopolysaccharide substance, or ground substance, accumulate around each osteoblast. Numerous bundles of collagenous fibers then become embedded in the ground substance. Together, the ground substance and collagenous fibers constitute the organic bone matrix. Calcification of the organic bone matrix occurs when complex calcium salts are deposited in it.

As calcification of bone matrix continues, the trabeculae appear and join in a network to form spongy bone. In time the core layer of spongy bone (diploe) will be covered on each side by plates of compact, or dense, bone. Once formed, a flat bone grows in size by the addition of osseous tissue to its outer surface. The process is called appositional growth. Flat bones cannot grow by interior expansion as is the case with endochondral bone growth described in the following section.

**ENDOCHONDRAL OSSIFICATION**

Most bones of the body are formed from cartilage models, with bone formation spreading essentially from the center to the ends. The steps of endochondral ossification are illustrated in Figure 7-8. The cartilage model of a typical long bone, such as the tibia, can be identified early in embryonic life (Figure 7-8, A). The cartilage model then develops a periossteum (Figure 7-8, B) that soon enlarges and produces a ring, or collar, of bone. Bone is deposited by osteoblasts, which differentiate from cells on the inner surface of the covering periosteum. Soon after the appearance of the ring of bone, the cartilage begins to calcify (Figure 7-8, C) and a primary ossification center forms when a blood vessel enters the rapidly changing cartilage model at the midpoint of the diaphysis. Endochondral ossification progresses from the diaphysis toward each epiphysis (see Figure 7-8, D) and the bone grows in length. Eventually, secondary ossification centers appear in the epiphyses (see Figure 7-8, E), and bone growth proceeds toward the diaphysis from each end (Figure 7-8, F).

Until bone growth in length is complete, a layer of the cartilage, known as the epiphyseal plate, remains between each epiphysis and the diaphysis. During periods of growth, proliferation of epiphyseal cartilage cells brings about a thickening of this layer. Ossification of the additional cartilage nearest the diaphysis follows—that is, osteoblasts synthesize organic bone matrix, and the matrix undergoes calcification. As a result, the bone becomes longer. It is the epiphyseal plate that allows the diaphysis of a long bone to increase in length.

The epiphyseal plate shown in Figure 7-9, B, is composed of four layers of cells. The top layer of cells closest to the epiphysis is composed of “resting” cartilage cells. These cells are not proliferating or undergoing change. This layer serves
Figure 7-8  Endochondral bone formation. A, Cartilage model. B, Subperiosteal bone collar formation. C, Development of primary ossification center and entrance of blood vessel. D, Prominent medullary cavity, with thickening and lengthening of collar. E, Development of secondary ossification centers in epiphyseal cartilage. F, Enlargement of secondary ossification centers, with bone growth proceeding toward the diaphysis from each end. G, With cessation of bone growth, lower, then upper, epiphyseal plates disappear.
as a point of attachment firmly joining the outer end, or epiphysis, of a bone to the shaft.

The second layer of cells shown in Figure 7-9, B, is called the *proliferating zone*. It is composed of cartilage cells, which are undergoing active mitosis. As a result of mitotic division and increased cellular activity the layer thickens and the plate as a whole increases in length.

The third layer of cells, called the *zone of hypertrophy*, is composed of older, enlarged cells, which are undergoing degenerative changes associated with calcium deposition.

**Figure 7-9 Epiphyseal plate.** A, Localization of epiphyseal plate between epiphyses and diaphyses of a long bone. B, Zones of the epiphyseal plate. C, Composite showing steps in ossification on either side of the epiphyseal plate.
The layer closest to the diaphysis is a thin layer composed of dead or dying cartilage cells undergoing rapid calcification. As the process of calcification progresses, this layer becomes fragile and disintegrates. The resulting space is soon filled with new bone tissue, and the bone as a whole grows in length.

When epiphyseal cartilage cells stop multiplying and the cartilage has become completely ossified, bone growth ends. Radiographs can reveal any epiphyseal cartilage still present. When bones have grown their full length, the epiphyseal cartilage disappears—bone has replaced it and is then continuous between epiphysis and diaphysis. The point of articulation between the epiphysis and diaphysis of a growing long bone, however, is susceptible to injury if overstressed—especially in a young child or preadolescent athlete. In these individuals the epiphyseal plate can be separated from the diaphysis or epiphysis, causing an epiphyseal fracture (Figure 7-10).

**BONE GROWTH AND RESORPTION**

Bones grow in diameter by the combined action of two of the three bone cell types: osteoblasts and osteoclasts. Osteoclasts enlarge the diameter of the medullary cavity by eating away the bone of its walls. At the same time, osteoblasts from the periosteum build new bone around the outside of the bone. By this dual process, a bone with a larger diameter and larger medullary cavity is produced from a smaller bone with a smaller medullary cavity.

This remodeling activity of osteoblasts (deposition of new bone) and osteoclasts (removal of old bone) is important in homeostasis of blood calcium levels. It also permits bones to grow in length and diameter and to change their overall shape and the size of the marrow cavity (Figure 7-11).

The formation of bone tissue continues long after bones have stopped growing. Throughout life, bone formation (ossification) and bone destruction (resorption) proceed concurrently. These opposing processes balance each other during adulthood’s early to middle years. The rate of bone formation equals the rate of bone destruction. Bones, therefore, neither grow nor shrink. They stay constant in size. Not so in the earlier years. During childhood and adolescence, ossification occurs at a faster rate than bone resorption.
Bone gain outstrips bone loss, and bones grow larger. But between the ages of 35 and 40 years, the process reverses, and from that time on, bone loss exceeds bone gain. Bone gain occurs slowly at the outer, or periosteal, surfaces of bones. Bone loss, on the other hand, occurs at the inner, or endosteal, surfaces and occurs at a somewhat faster pace. More bone is lost on the inside than gained on the outside, and inevitably bones become remodeled as the years go by.

Remodeling in compact bone involves the formation of new Haversian systems (osteons). The process begins when osteoclasts in the covering periosteum are activated and erode the outer surface of the bone, forming grooves. Periosteal blood vessels lie in these grooves, which are eventually surrounded by new bone formed as a result of osteoblast activity. As the grooves are transformed into tunnels, additional layers of bone are deposited by osteoblasts in the lining endosteum. With the passage of time, new lamellae are added and osteon formation occurs (Figure 7-12).

**Box 7-2 SPORTS AND FITNESS**

**Exercise and Bone Density**

Walking, jogging, and other forms of exercise subject bones to stress. They respond by laying down more collagen fibers and mineral salts in the bone matrix. This, in turn, makes bones stronger. But inactivity and lack of exercise tend to weaken bones because of decreased collagen formation and excessive calcium withdrawal. To prevent these changes, as well as many others, astronauts regularly perform special exercises in space because of the lack of gravity. Regular weight-bearing exercise is also an important part of the prevention and treatment of osteoporosis.

**REPAIR OF BONE FRACTURES**

The term fracture is defined as a break in the continuity of a bone. Types of bone fractures are discussed in Chapter 8, pp. 248-249. Fracture healing is considered the prototype of bone repair. The complex bone tissue repair process that follows a fracture is apparently initiated by bone death or by damage to periosteal and Haversian system blood vessels.

A bone fracture invariably tears and destroys blood vessels that carry nutrients to osteocytes. It is this vascular damage that initiates the repair sequence. Eventually, dead bone is either removed by osteoclastic resorption or serves as a scaffolding or framework for the deposition of a specialized repair tissue called callus.

The process of fracture healing is shown in Figure 7-13, A to D. Vascular damage occurring immediately after a frac-
ture results in hemorrhage and the pooling of blood at the point of injury. The resulting blood clot is called a fracture hematoma (Figure 7-13, B). As the hematoma is resorbed, the formation of specialized callus tissue occurs. It serves to bind the broken ends of the fracture on both the outside surface and along the marrow cavity internally. The rapidly growing callus tissue effectively “collars” the broken ends and stabilizes the fracture so that healing can proceed (Figure 7-13, C). If the fracture is properly aligned and immobilized and if complications do not develop, callus tissue will be actively “modeled” and eventually replaced with normal bone as the injury heals completely (Figure 7-13, D).

A new synthetic skeletal repair material called vitos is now available to facilitate fracture repair. It consists of a calcium spongelike matrix material riddled with microscopic holes. Vitos assists callus tissue in stabilizing the fracture site and in movement of bone repair cells and nutrients into the injured area. This new synthetic material is useful not only in treatment of fractures, but also in reducing the need for expensive and often surgically difficult bone grafts. Unlike metal stabilizers, vitos “patches” degrade naturally in the body after repair and do not require surgical removal.

CARTILAGE

TYPES OF CARTILAGE

Cartilage is classified as connective tissue and consists of three specialized types called hyaline (HI-ah-lin), elastic, and fibrocartilage. As a tissue, cartilage both resembles and differs from bone. Innumerable collagenous fibers reinforce the matrix of both tissues, and, as with bone, cartilage consists more of extracellular substance than of cells. However, in cartilage the fibers are embedded in a firm gel instead of in a calcified cement substance. Hence cartilage has the flexibility of a firm plastic material, whereas bone has the rigidity of cast iron. Another difference is that no canal system and no blood vessels penetrate the cartilage matrix. Cartilage is avascular and bone is abundantly vascular. Nevertheless, cartilage cells, as with bone cells, lie in lacunae. However, because no canals and blood vessels interlace cartilage matrix, nutrients and oxygen can reach the scattered, isolated chondrocytes (cartilage cells) only by diffusion. They diffuse through the matrix gel from capillaries in the fibrous covering of the cartilage—the perichondrium—or from synovial fluid, in the case of articular cartilage.

The three cartilage types differ from one another largely by the amount of matrix material that is present and also by the relative amounts of elastic and collagenous fibers that are embedded in them. Hyaline is the most abundant type, and both elastic and fibrocartilage varieties are considered modifications of the hyaline type. Collagenous fibers are present in all three types but are most numerous in fibrocartilage. Hence it has the greatest tensile strength. Elastic cartilage matrix contains elastic fibers, as well as collagenous fibers, and so has elasticity, as well as firmness.

Cartilage is an excellent skeletal support tissue in the developing embryo. It forms rapidly and yet retains a significant degree of rigidity, or stiffness. A majority of the bones that eventually form the axial and the appendicular skeleton described in Chapter 8 first appear as cartilage models. Skeletal maturation involves replacement of the cartilage models with bone.

After birth there is a decrease in the total amount of cartilage tissue present in the body. However, it continues to play an important role in the growth of long bones until skeletal maturity and is found throughout life as the material that covers the articular surfaces of bones in joints. The three types of cartilage also serve numerous specialized functions throughout the body.

Hyaline Cartilage

Hyaline, in addition to being the most common type of cartilage, serves many specialized functions. It resembles milk glass in appearance (Figure 7-14, A). In fact, its name is derived from the Greek word meaning “glassy.” Sometimes called gristle, it is semitransparent and has a bluish, opalescent cast.

In the embryo hyaline cartilage forms from differentiation of specialized mesenchymal cells that become crowded together in so-called centers of chondrification. As the cells enlarge, they secrete matrix material that surrounds the delicate collagen fibrils. Eventually, the continued production of matrix separates and isolates the cells, or chondrocytes, into compartments, which, as in bone, are called lacunae. Like bone, the organic matrix of hyaline cartilage is a mixture of ground substance and collagenous fibers. The ground substance is rich in both chondroitin sulfate and a unique gel-like polysaccharide. Both substances are secreted from chondrocytes in much the same way protein and carbohydrates are secreted from glandular cells.

In addition to covering the articular surfaces of bones, hyaline cartilage forms the costal cartilages that connect the anterior ends of the ribs with the sternum, or breastbone. It also forms the cartilage rings in the trachea, bronchi of the lungs, and tip of the nose.
**Elastic Cartilage**

Elastic cartilage gives form to the external ear, the epiglottis that covers the opening of the respiratory tract when swallowing, and the eustachian, or auditory, tubes that connect the middle ear and nasal cavity. The collagenous fibers of hyaline cartilage are also present—but in fewer numbers—in elastic cartilage. Large numbers of easily stained elastic fibers confer the elasticity and resiliency typical of this form of cartilage. In most stained sections elastic cartilage has a yellowish color and has a greater opacity than does the hyaline variety (Figure 7-14, B).

**Fibrocartilage**

Fibrocartilage is characterized by small quantities of matrix and abundant fibrous elements (Figure 7-14, C). It is strong, rigid, and most often associated with regions of dense connective tissue in the body. It occurs in the symphysis pubis, intervertebral disks, and near the points of attachment of some large tendons to bones.

**HISTOPHYSIOLOGY OF CARTILAGE**

The gristle-like nature of cartilage permits it to sustain great weight when covering the articulating surfaces of bones or when serving as a shock-absorbing pad between articulating bones in the spine. In other areas, such as the external ear, nose, or respiratory passages, cartilage provides a strong yet pliable support structure that resists deformation or collapse of tubular passageways. Cartilage permits growth in length of long bones and is largely responsible for their adult shape and size.

**GROWTH OF CARTILAGE**

The growth of cartilage occurs in two ways:

1. Interstitial growth
2. Appositional growth

During interstitial growth, cartilage cells within the substance of the tissue mass divide and begin to secrete additional matrix. Internal division of chondrocytes is possible because of the soft, pliable nature of cartilage tissue. This form of growth is most often seen during childhood and early adolescence, when a majority of cartilage is still soft and capable of expansion from within.

Appositional growth occurs when chondrocytes in the deep layer of the perichondrium begin to divide and secrete additional matrix. The new matrix is then deposited on the surface of the cartilage, causing it to increase in size. Appositional growth is unusual in early childhood but, once initiated, continues beyond adolescence and throughout an individual’s life.

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**Figure 7-14 Types of cartilage.**


1. Name three specialized types of cartilage.
2. Identify the primary type of cartilage cell.
3. List the two mechanisms of cartilage growth.
This chapter focused on the changes that occur in bone and cartilage tissue from the time before birth to advanced old age. For instance, we have outlined in some detail the process by which the soft cartilage and membranous skeleton become ossified during a period of years. By the time a person is a young adult in the mid-twenties, the skeleton has become fully ossified. A few areas of soft tissue—the cartilaginous areas of the nose and ears, for example—may continue to grow and ossify very slowly throughout adulthood, so that by advanced old age, some structural changes are apparent.

Changes in skeletal tissue that occur during adulthood usually result from specific conditions. For example, the mechanical stress of weight-bearing exercise can trigger dramatic increases in the density and strength of bone tissue. Pregnancy, nutritional deficiencies, and illness can all cause a loss of bone density accompanied by a loss of structural strength.

In advanced adulthood, degeneration of bone and cartilage tissue becomes apparent. Replacement of hard bone matrix by softer connective tissue results in a loss of strength that increases susceptibility to injury. This is especially true in older women who suffer from osteoporosis. Fortunately, even very light exercise by elderly individuals can counteract some of the skeletal tissue degeneration associated with old age.

The homeostatic function of skeletal tissues is beautifully illustrated by the role they play in mineral storage and release. For example, regulation of blood calcium levels is important in such diverse areas as nerve transmission, muscle contraction, and normal clotting of the blood. Because they contain red marrow, the bones also serve in the important role of hematopoiesis, or blood cell formation. This function ties skeletal tissues to such diverse homeostatic functions as regulation of body pH and the transport of respiratory gases and vital nutrients. By viewing skeletal tissues in such a broad and interrelated functional context, you can more readily sense the ‘connectedness’ that unites these otherwise seemingly isolated body structures to the ‘big picture’ of overall health and survival.

Osteosarcoma (osteogenic sarcoma) is the most common primary malignant tumor of skeletal tissue and is often the most fatal. It appears more frequently in men, with its peak age of incidence between 10 and 25 years. Common sites of involvement are the tibia, femur, and humerus. Roughly 10% of patients experience metastases to the lungs, and, if left untreated, the course can involve widespread metastases and death within 1 year. Therapy commonly involves surgery followed with chemotherapy.

Chondrosarcoma is a malignant tumor of hyaline cartilage arising from chondroblasts. It is a large, bulky, slow-growing tumor occurring most frequently in middle-age persons. Common sites of involvement include the femur, spine, pelvis, ribs, or scapula. Large excisions or amputation of the affected extremity can improve survival rates. Chemotherapy has not been proven to be effective.
Metabolic Bone Diseases

Metabolic bone diseases are disorders of bone remodeling. 

Osteoporosis is one of the most common and serious of all bone diseases. It is characterized by excessive loss of calcified matrix, bone mineral, and collagenous fibers that cause a reduction in total bone mass (see p. 191).

Because estrogen and testosterone serve important roles in stimulating osteoblast activity after puberty, decreasing levels of these hormones in the elderly reduce new bone growth and maintenance of existing bone mass. In women decreasing estrogen levels associated with menopause cause accelerated bone resorption. Inadequate intake of calcium or vitamin D, necessary for normal bone mineralization, during a period of years, can also result in decreased bone mass and the development of osteoporosis.

In osteoporosis bones become porous, brittle, and fragile, fracturing easily under stress. As a result, they are often characterized by pathological changes in the mass or chemical composition of skeletal tissue. The result is a dangerous pathological condition resulting in increased susceptibility to “spontaneous fractures” and pathological curvature of the spine. Osteoporosis occurs most frequently in elderly white women. Although requiring specialized equipment, the dual energy x-ray absorptiometry scan (DXA) remains the “method of choice” to measure bone mineral density in the spine and hip. Bone density is expressed in grams per square centimeter and results are available in minutes. Advances in radiographic absorptiometry (RA) are now making this more economical test the choice for determining bone density at the wrist. It is used to determine bone mineral density in growing numbers of osteoporosis patients and in screening programs intended to detect the disease in “at risk” individuals.

Osteomalacia is a metabolic bone disease characterized by inadequate mineralization of bone. A large amount of osteoid (organic bone matrix) does not calcify in patients with this disease. Risk factors for development of osteomalacia include malabsorption problems, vitamin D and calcium deficiencies, chronic renal failure, and inadequate exposure to sunlight. Symptoms, though subtle, may include muscle weakness, fractures, generalized bone pain and tenderness in the extremities, and lower back pain. Treatment includes dietary supplements of vitamin D and calcium. In addition, exposure to sunlight may be instituted to promote vitamin D synthesis in the body.

Paget’s disease, also known as osteitis deformans, is a disorder affecting older adults. It is characterized by proliferation of osteoclasts and compensatory increased osteoblastic activity. The result is rapid and disorganized bone remodeling. The bones formed are poorly constructed and weakened. It commonly affects the skull, femur, vertebra, and pelvic bones. Clinical manifestations may include bone pain, tenderness, and fractures. However, the majority of patients experience minimal changes and never know they have the disease. No treatment is recommended in the asymptomatic patient.

Osteomyelitis is a bacterial infection of the bone and marrow tissue. Infections of the bone are often more difficult to treat than are soft-tissue infections because of the decreased blood supply and density of the bone. Bacteria, viruses, fungi, and other pathogens may cause osteomyelitis. Staphylococcus bacteria are the most common pathogens. Osteomyelitis is associated with extension of another infection (e.g., bacteremia, urinary tract infection, vascular ulcer) or direct bone contamination (e.g., gunshot wound, open fracture). Patients who are elderly, poorly nourished, or diabetic are also at risk. Thrombosis of blood vessels in osteomyelitis often results in ischemia and bone necrosis. As a result, infection can extend under the periosteum and spread to adjacent soft tissues and joints. Signs and symptoms may include an area swollen, warm, tender to touch, and painful. Early recognition of infection and antimicrobial management are required. Sometimes patients may require 6 weeks of antibiotics.
### CASE STUDY

Johnny, age 5, was riding his tricycle when he fell and injured one of his long bones. He was taken to the emergency room where an x-ray revealed a fracture through the epiphyseal plate.

1. Which one of the following bones did Johnny most likely fracture?
   - A. Wrist (carpals)
   - B. Tibia
   - C. Clavicle
   - D. Pelvis

### CHAPTER SUMMARY

#### TYPES OF BONES

A. Structurally, there are four types of bones (Figure 7-1)
   1. Long bones
   2. Short bones
   3. Flat bones
   4. Irregular bones

B. Bones serve various needs, and their size, shape, and appearance will vary to meet those needs

C. Bones vary in proportion of compact and cancellous (spongy) bone; compact bone is dense and solid in appearance, whereas cancellous bone is characterized by open space partially filled with needle-like structures

D. Parts of a long bone (Figure 7-2)
   1. Diaphysis
      - a. Main shaft of long bone
      - b. Hollow, cylindrical shape and thick compact bone
      - c. Function is to provide strong support without cumbersome weight
   2. Epiphyses
      - a. Both ends of a long bone, made of cancellous bone filled with marrow
      - b. Bulbous shape
      - c. Function is to provide attachments for muscles and give stability to joints
   3. Articular cartilage
      - a. Layer of hyaline cartilage that covers the articular surface of epiphyses
      - b. Function is to cushion jolts and blows
   4. Periosteum
      - a. Dense, white fibrous membrane that covers bone
      - b. Attaches tendons firmly to bones
      - c. Contains cells that form and destroy bone
      - d. Contains blood vessels important in growth and repair
      - e. Contains blood vessels that send branches into bone
      - f. Essential for bone cell survival and bone formation

#### BONE TISSUE

A. Most distinctive form of connective tissue

B. Extracellular components are hard and calcified

C. Rigidity of bone allows it to serve its supportive and protective functions

D. Tensile strength nearly equal to cast iron at less than one third the weight

E. Composition of bone matrix
   1. Inorganic salts
      - a. Hydroxyapatite—highly specialized chemical crystals of calcium and phosphate contribute to bone hardness
      - b. Slender needle-like crystals are oriented to most effectively resist stress and mechanical deformation
      - c. Magnesium and sodium are also found in bone
   2. Measuring bone mineral density
   3. Organic matrix
      - a. Composite of collagenous fibers and an amorphous mixture of protein and polysaccharides called ground substance
      - b. Ground substance is secreted by connective tissue cells
      - c. Adds to overall strength of bone and gives some degree of resilience to the bone
MICROSCOPIC STRUCTURE OF THE BONE (Figure 7-3)

A. Compact bone
   1. Contains many cylinder-shaped structural units called osteons, or Haversian systems
   2. Osteons surround canals that run lengthwise through bone and are connected by transverse Volkmann's canals
   3. Living bone cells are located in these units that constitute the structural framework of compact bone
   4. Osteons permit delivery of nutrients and removal of waste products
   5. Four types of structures make up each osteon
      a. Lamella—concentric, cylinder-shaped layers of calcified matrix
      b. Lacunae—small spaces containing tissue fluid in which bone cells are located between hard layers of the lamella
      c. Canaliculi—ultrasmall canals radiating in all directions from the lacunae and connecting them to each other and to the Haversian canal
      d. Haversian canal—extends lengthwise through the center of each osteon and contains blood vessels and lymphatic vessels

B. Cancellous bone (Figure 7-4)
   1. No osteons in cancellous bone; instead, it has trabeculae
   2. Nutrients are delivered and waste products removed by diffusion through tiny canaliculi
   3. Bony spicules are arranged along lines of stress, enhancing the bone's strength

C. Blood supply
   1. Bone cells are metabolically active and need a blood supply, which comes from the bone marrow in the internal medullary cavity of cancellous bone
   2. Compact bone, in addition to bone marrow and blood vessels from the periosteum, penetrate bone and then, by way of Volkmann's canals, connect with vessels in the Haversian canals

D. Types of bone cells
   1. Osteoblasts
      a. Bone-forming cells found in all bone surfaces
      b. Small cells synthesize and secrete osteoid, an important part of the ground substance
      c. Collagen fibrils line up in osteoid and serve as a framework for the deposition of calcium and phosphate
   2. Osteoclasts (Figure 7-5)
      a. Giant multinucleate cells
      b. Responsible for the active erosion of bone minerals
      c. Contain large numbers of mitochondria and lysosomes
   3. Osteocytes—mature, nondividing osteoblast surrounded by matrix, lying within lacunae (Figure 7-6)

BONE MARROW

A. Specialized type of soft, diffuse connective tissue; called myeloid tissue
B. Site for the production of blood cells
C. Found in medullary cavities of long bones and in the spaces of spongy bone
D. Two types of marrow occur during a person's lifetime
   1. Red marrow
      a. Found in virtually all bones in an infant's or child's body
      b. Functions to produce red blood cells
   2. Yellow marrow
      a. As an individual ages, red marrow is replaced by yellow marrow
      b. Marrow cells become saturated with fat and are no longer active in blood cell production

E. The main bones in an adult that still contain red marrow include the ribs, bodies of the vertebrae, the humerus, the pelvis, and the femur
F. Yellow marrow can alter to red marrow during times of decreased blood supply, such as anemia, exposure to radiation, and certain diseases

FUNCTIONS OF BONE

A. Support—bones form the framework of the body and contribute to the shape, alignment, and positioning of the body parts
B. Protection—bony “boxes” protect the delicate structures they enclose
C. Movement—bones with their joints constituting levers that move as muscles contract
D. Mineral storage—bones are the major reservoir for calcium, phosphorus, and other minerals
E. Hematopoiesis—blood cell formation is carried out by myeloid tissue

REGULATION OF BLOOD CALCIUM LEVELS

A. Skeletal system serves as a storehouse for about 98% of body calcium reserves
   1. Helps maintain constancy of blood calcium levels
      a. Calcium is mobilized and moves into and out of blood during bone remodeling
      b. During bone formation, osteoblasts remove calcium from blood and lower circulating levels
      c. During breakdown of bone, osteoclasts release calcium into blood and increase circulating levels
   2. Homeostasis of calcium ion concentration essential for the following:
      a. Bone formation, remodeling, and repair
      b. Blood clotting
      c. Transmission of nerve impulses
      d. Maintenance of skeletal and cardiac muscle contraction
B. Mechanisms of calcium homeostasis
   1. Parathyroid hormone
      a. Primary regulator of calcium homeostasis
      b. Stimulates osteoclasts to initiate breakdown of bone matrix and increase blood calcium levels
      c. Increases renal absorption of calcium from urine
      d. Stimulates vitamin D synthesis
   2. Calcitonin
      a. Protein hormone produced in the thyroid gland
      b. Produced in response to high blood calcium levels
      c. Stimulates bone deposition by osteoblasts
      d. Inhibits osteoclast activity
      e. Far less important in homeostasis of blood calcium levels than parathyroid hormone

DEVELOPMENT OF BONE
A. Osteogenesis—development of bone from small cartilage model to an adult bone
B. Intramembranous ossification
   1. Occurs within a connective tissue membrane
   2. Flat bones begin when groups of cells differentiate into osteoblasts
   3. Osteoblasts are clustered together in centers of ossification
   4. Osteoblasts secrete matrix material and collagenous fibrils
   5. Large amounts of ground substance accumulate around each osteoblast
   6. Collagenous fibers become embedded in the ground substance and constitute the bone matrix
   7. Bone matrix calcifies when calcium salts are deposited
   8. Trabeculae appear and join in a network to form spongy bone
   9. Apposition growth occurs by adding osseous tissue
C. Endochondral ossification (Figure 7-8)
   1. Most bones begin as a cartilage model with bone formation spreading essentially from the center to the ends
   2. Periosteum develops and enlarges, producing a collar of bone
   3. Primary ossification center forms
   4. Blood vessel enters the cartilage model at the mid-point of the diaphysis
   5. Bone grows in length as endochondral ossification progresses from the diaphysis toward each epiphysis
   6. Secondary ossification centers appear in the epiphysis, and bone growth proceeds toward the diaphysis
   7. Epiphyseal plate remains between diaphysis and each epiphysis until bone growth in length is complete (Figure 7-10)
   8. Epiphyseal plate is composed of four layers (Figure 7-9)
      a. “Resting” cartilage cells—point of attachment joining the epiphysis to the shaft
      b. Zone of proliferation—cartilage cells undergoing active mitosis, causing the layer to thicken and the plate to increase in length
      c. Zone of hypertrophy—older, enlarged cells undergoing degenerative changes associated with calcium deposition
      d. Zone of calcification—dead or dying cartilage cells undergoing rapid calcification

BONE GROWTH AND RESORPTION
(Figures 7-11 and 7-12)
A. Bones grow in diameter by the combined action of osteoclasts and osteoblasts
B. Osteoclasts enlarge the diameter of the medullary cavity
C. Osteoblasts from the periosteum build new bone around the outside of the bone

REPAIR OF BONE FRACTURES
A. Fracture—break in the continuity of a bone
B. Fracture healing (Figure 7-13)
   1. Fracture tears and destroys blood vessels that carry nutrients to osteocytes
   2. Vascular damage initiates repair sequence
   3. Callus—specialized repair tissue that binds the broken ends of the fracture together
   4. Fracture hematoma—blood clot occurring immediately after the fracture, is then resorbed and replaced by callus

CARTILAGE
A. Characteristics
   1. Avascular connective tissue
   2. Fibers of cartilage are embedded in a firm gel
   3. Has the flexibility of firm plastic
   4. No canal system or blood vessels
   5. Chondrocytes receive oxygen and nutrients by diffusion
   6. Perichondrium—fibrous covering of the cartilage
B. Types of cartilage (Figure 7-14)
   1. Hyaline cartilage
      a. Most common type
      b. Covers the articular surfaces of bones
      c. Forms the costal cartilages, cartilage rings in the trachea, bronchi of the lungs, and the tip of the nose
      d. Forms from specialized cells in centers of chondrification, which secrete matrix material
      e. Chondrocytes are isolated into lacunae
   2. Elastic cartilage
      a. Forms external ear, epiglottis, and eustachian tubes
      b. Large number of elastic fibers confers elasticity and resiliency
   3. Fibrocartilage
      a. Occurs in symphysis pubis and intervertebral disks
b. Small quantities of matrix and abundant fibrous elements
c. Strong and rigid

C. Histophysiology of cartilage
1. Gristle-like nature permits cartilage to sustain great weight or serve as a shock absorber
2. Strong yet pliable support structure
3. Permits growth in length of long bones

D. Growth of cartilage
1. Interstitial or endogenous growth
   a. Cartilage cells divide and secrete additional matrix
   b. Seen during childhood and early adolescence while cartilage is still soft and capable of expansion from within
2. Appositional or exogenous growth
   a. Chondrocytes in the deep layer of the perichondrium divide and secrete matrix
   b. New matrix is deposited on the surface, increasing its size
   c. Unusual in early childhood, but, once initiated, continues throughout life

CYCLE OF LIFE: SKELETAL TISSUES
A. Skeleton fully ossified by mid-twenties
   1. Soft tissue may continue to grow—ossifies more slowly
B. Adults—changes occur from specific conditions
   1. Increased density and strength from exercise
   2. Decreased density and strength from pregnancy, nutritional deficiencies, and illness
C. Advanced adulthood—apparent degeneration
   1. Hard bone matrix replaced by softer connective tissue
   2. Exercise can counteract degeneration

**REVIEW QUESTIONS**

1. Describe the microscopic structure of bone and cartilage.
2. Describe the structure of a long bone.
3. Explain the functions of the periosteum.
4. Describe the two principal chemical components of extracellular bone.
5. List and discuss each of the major anatomical components that together constitute an osteon.
6. Compare and contrast the three major types of cells found in bone.
7. Discuss and discriminate between the sequence of steps characteristic of fracture healing.
8. Compare and contrast the basic structural elements of bone and cartilage.
9. Compare the structure and function of the three types of cartilage.

**CRITICAL THINKING QUESTIONS**

1. Cancer treatment may generate a need for a bone marrow transplant. Osteoporosis is a condition characterized by an excessive loss of calcium in bone. These two conditions are disruptions or failures of two bone functions. Identify these two functions and explain what their normal functioning should be.
2. Compare and contrast bone formation in intramembranous and endochondral ossification.
3. Can you make a distinction between the growth processes of cartilage and bone?
4. Explain why a bone fracture along the epiphyseal plate may have serious implications among children and young adults.
5. During the aging process, adults face the issue of a changing skeletal framework. Describe these changes and explain how these skeletal framework changes affect the health of older adults.