

UNIT Eleven

Alterations in the Skeletal and Integumentary Systems

CHAPTER

41

Structure and Function of the Skeletal System

Characteristics of Skeletal Tissue

Cartilage

Bone

- Types of Bone

- Bone Cells

- Periosteum and Endosteum

Bone Growth and Remodeling

Hormonal Control of Bone Formation and

Metabolism

- Parathyroid Hormone

- Calcitonin

- Vitamin D

Skeletal Structures

Classification of Bones

Tendons and Ligaments

Joints and Articulations

- Synarthroses

- Diarthroses

- Blood Supply and Innervation

- Bursae

- Intra-articular Menisci

Without the skeletal system, movement in the external environment would not be possible. The bones of the skeletal system serve as a framework for the attachment of muscles, tendons, and ligaments. The skeletal system protects and maintains soft tissues in their proper position, provides stability for the body, and maintains the body's shape. The bones act as a storage reservoir for calcium, and the central cavity of some bones contains the hematopoietic connective tissue in which blood cells are formed.

The skeletal system consists of the axial and appendicular skeleton. The axial skeleton, which is composed of the bones of the skull, thorax, and vertebral column, forms the axis of the body. The appendicular skeleton consists of the bones of the upper and lower extremities, including the shoulder and hip. For our purposes, the skeletal system is considered to include the bones and cartilage of the axial and appendicular skeleton, as well as the connective tissue structures (*i.e.*, ligaments and tendons) that connect the bones and join muscles to bone.

CHARACTERISTICS OF SKELETAL TISSUE

Two types of connective tissue are found in the skeletal system: cartilage and bone. Each of these connective tissue types consists of living cells, nonliving intercellular protein fibers, and an amorphous (shapeless) ground substance. The tissue cells are responsible for secreting and maintaining the intercellular substances in which they are housed. These substances provide the structural characteristics of the tissue. For example,

KEY CONCEPTS**THE SKELETAL SYSTEM**

- The skeletal system consists of the bones of the skull, thorax, and vertebral column, which form the axial skeleton, and the bones of the upper and lower extremities, which form the appendicular skeleton.
- Two types of connective tissue are found in the skeletal system: (1) cartilage, a semirigid and slightly flexible structure that plays an essential role in prenatal and childhood development of the skeleton and as a surface for the articulating ends of skeletal joints; and (2) bones, which provide for the firm structure of the skeleton and serve as a reservoir for calcium and phosphate storage.
- Both bone and cartilage are composed of living cells and a nonliving intercellular matrix that is secreted by the living cells.
- Bone matrix is maintained by three types of cells: osteoblasts, which synthesize and secrete the constituents of bone; osteoclasts, which resorb surplus bone and are required for bone remodeling; and the osteocytes, which make up the osteoid tissue of bone.

the intercellular matrix of bone is impregnated with calcium salts, providing the hardness that is characteristic of this tissue.

Two main types of intercellular fibers are found in skeletal tissue: collagenous and elastic. Collagen is an inelastic and insoluble fibrous protein. Because of its molecular configuration, collagen has great tensile strength; the breaking point of collagenous fibers found in human tendons is reached with a force of several hundred kilograms per square centimeter. Fresh collagen is colorless, and tissues that contain large numbers of collagenous fibers generally appear white. The collagen fibers in tendons and ligaments give these structures their white color. Elastin is the major component of elastic fibers that allows them to stretch several times their length and rapidly return to their original shape when the tension is released. Ligaments and structures that must undergo repeated stretching contain a high proportion of elastic fibers.

Cartilage

Cartilage is a firm but flexible type of connective tissue consisting of cells and intercellular fibers embedded in an amorphous, gel-like material. It has a smooth and resilient surface and a weight-bearing capacity exceeded only by that of bone.

Cartilage is essential for growth before and after birth. It is able to undergo rapid growth while maintaining a considerable degree of stiffness. In the embryo, most of the axial and appendicular skeleton is formed first as a cartilage model and is replaced by bone. In postnatal life, cartilage continues to play an essential role in the growth of long bones and persists as articular cartilage in the adult.

There are three types of cartilage: elastic cartilage, hyaline cartilage, and fibrocartilage. *Elastic cartilage* contains some elastin in its intercellular substance. It is found in areas, such as the ear, where some flexibility is important. Pure cartilage is called *hyaline cartilage* (from a Greek word meaning “glass”) and is pearly white. It is the type of cartilage seen on the articulating ends of fresh soup bones found in the supermarket. *Fibrocartilage* has characteristics that are intermediate between dense connective tissue and hyaline cartilage. It is found in the intervertebral disks, in areas where tendons are connected to bone, and in the symphysis pubis.

Hyaline cartilage is the most abundant type of cartilage. It forms much of the cartilage of the fetal skeleton. In the adult, hyaline cartilage forms the costal cartilages that join the ribs to the sternum and vertebrae, many of the cartilages of the respiratory tract, the articular cartilages, and the epiphyseal plates.

Cartilage cells, which are called *chondrocytes*, are located in lacunae. These lacunae are surrounded by an uncalcified, gel-like intercellular matrix of collagen fibers and ground substance. Cartilage is devoid of blood vessels and nerves. The free surfaces of most hyaline cartilage, with the exception of articular cartilage, are covered by a layer of fibrous connective tissue called the *perichondrium*.

It has been estimated that approximately 65% to 80% of the wet weight of cartilage is water held in its gel structure. Because cartilage has no blood vessels, this tissue fluid allows the diffusion of gases, nutrients, and wastes between the chondrocytes and blood vessels outside the cartilage. Diffusion cannot take place if the cartilage matrix becomes impregnated with calcium salts, and cartilage dies if it becomes calcified.

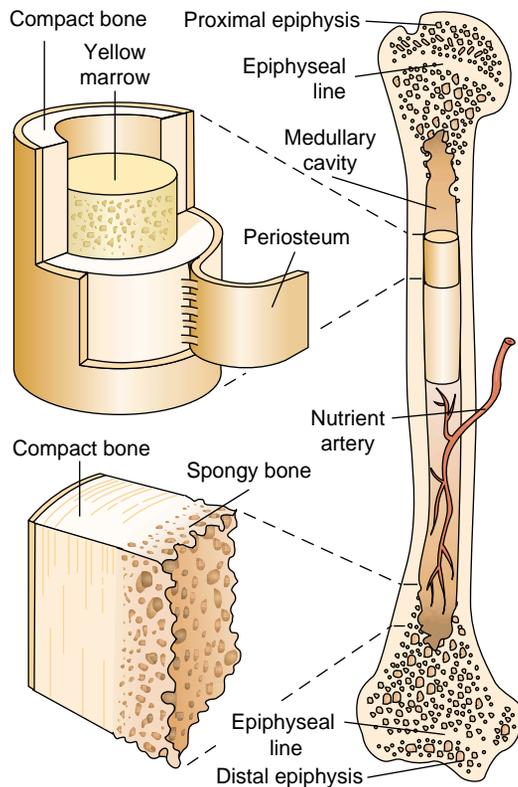
Bone

Bone is connective tissue in which the intercellular matrix has been impregnated with inorganic calcium salts so that it has great tensile and compressible strength but is light enough to be moved by coordinated muscle contractions. The intercellular matrix is composed of two types of substances—organic matter and inorganic salts. The organic matter, including bone cells, blood vessels, and nerves, constitutes approximately one third of the dry weight of bone; the inorganic salts make up the other two thirds.

The organic matter consists primarily of collagen fibers embedded in an amorphous ground substance. The inorganic matter consists of hydroxyapatite, an insoluble macrocrystalline structure of calcium phosphate salts, and small amounts of calcium carbonate and calcium fluoride. Bone may also take up lead and other heavy metals, thereby removing these toxic substances from the circulation. This can be viewed as a protective mechanism. The antibiotic tetracycline is readily bound to calcium deposited in newly formed bones and teeth. When tetracycline is given during pregnancy, it can be deposited in the teeth of the fetus, causing discoloration and deformity. Similar changes can occur if the drug is given for long periods to children younger than 6 years of age.

Types of Bone

There are two types of mature bones, cancellous and compact bone (Fig. 41-1). Both types are formed in layers and thus are called *lamellar bone*. Cancellous (spongy) bone is found in the



■ **FIGURE 41-1** ■ A long bone shown in longitudinal section.

interior of bones and is composed of *trabeculae*, or *spicules*, of bone that form a latticelike pattern. These latticelike structures are lined with osteogenic cells and filled with red or yellow bone marrow. Cancellous bone is relatively light, but its structure is such that it has considerable tensile strength and weight-bearing properties. Compact (cortical) bone, which forms the outer shell of a bone, has a densely packed calcified intercellular matrix that makes it more rigid than cancellous bone. The relative quantity of compact and cancellous bone varies in different types of bones throughout the body and in different parts of the same bone, depending on the need for strength and lightness. Compact bone is the major component of tubular bones. It is also found along the lines of stress on long bones and forms an outer protective shell on other bones.

Bone Cells

Four types of bone cells participate in the formation and maintenance of bone tissue: osteogenic cells, osteoblasts, osteocytes, and osteoclasts (Table 41-1).

Osteogenic Cells. The undifferentiated osteogenic cells are found in the periosteum, endosteum, and epiphyseal plate of growing bone. These cells differentiate into osteoblasts and are active during normal growth; they may also be activated in adult life during healing of fractures and other injuries. Osteogenic cells also participate in the continual replacement of worn-out bone tissue.

Osteoblasts. The osteoblasts, or bone-building cells, are responsible for the formation of the bone matrix. Bone formation

TABLE 41-1 Function of Bone Cells

Type of Bone Cell	Function
Osteogenic cells	Undifferentiated cells that differentiate into osteoblasts. They are found in the periosteum, endosteum, and epiphyseal growth plate of growing bones.
Osteoblasts	Bone-building cells that synthesize and secrete the organic matrix of bone. Osteoblasts also participate in the calcification of the organic matrix.
Osteocytes	Mature bone cells that function in the maintenance of bone matrix. Osteocytes also play an active role in releasing calcium into the blood.
Osteoclasts	Bone cells responsible for the resorption of bone matrix and the release of calcium and phosphate from bone.

occurs in two stages: ossification and calcification. Ossification involves the formation of osteoid, or prebone. Calcification of bone involves the deposition of calcium salts in the osteoid tissue. The osteoblasts synthesize collagen and other proteins that make up osteoid tissue. They also participate in the calcification process of the osteoid tissue, probably by controlling the availability of calcium and phosphate. Osteoblasts secrete the enzyme *alkaline phosphatase*, which is thought to act locally in bone tissue to raise calcium and phosphate levels to the point at which precipitation occurs. The activity of the osteoblasts undoubtedly contributes to the increase in serum levels of alkaline phosphatase that follows bone injury and fractures.

Osteocytes. The osteocytes are mature bone cells that are actively involved in maintaining the bony matrix. Death of the osteocytes results in the resorption of this matrix. The osteocytes lie in a small lake filled with extracellular fluid, called a *lacuna*, and are surrounded by a calcified intercellular matrix. Extracellular fluid-filled passageways permeate the calcified matrix and connect with the lacunae of adjacent osteocytes. These passageways are called *canaliculi*. Because diffusion does not occur through the calcified matrix of bone, the canaliculi serve as communicating channels for the exchange of nutrients and metabolites between the osteocytes and the blood vessels on the surface of the bone layer.

The osteocytes, together with their intercellular matrix, are arranged in layers, or lamellae. In compact bone, 4 to 20 lamellae are arranged concentrically around a central haversian canal, which runs essentially parallel to the long axis of the bone. Each of these units is called a *haversian system*, or *osteon*. The haversian canals contain blood vessels that carry nutrients and wastes to and from the canaliculi (Fig. 41-2). The blood vessels from the periosteum enter the bone through tiny openings called *Volkmann's canals* and connect with the haversian systems. Cancellous bone is also composed of lamellae, but its trabeculae usually are not penetrated by blood vessels. Instead, the bone cells of cancellous bone are nourished by diffusion from the endosteal surface through canaliculi, which interconnect their lacunae and extend to the bone surface.

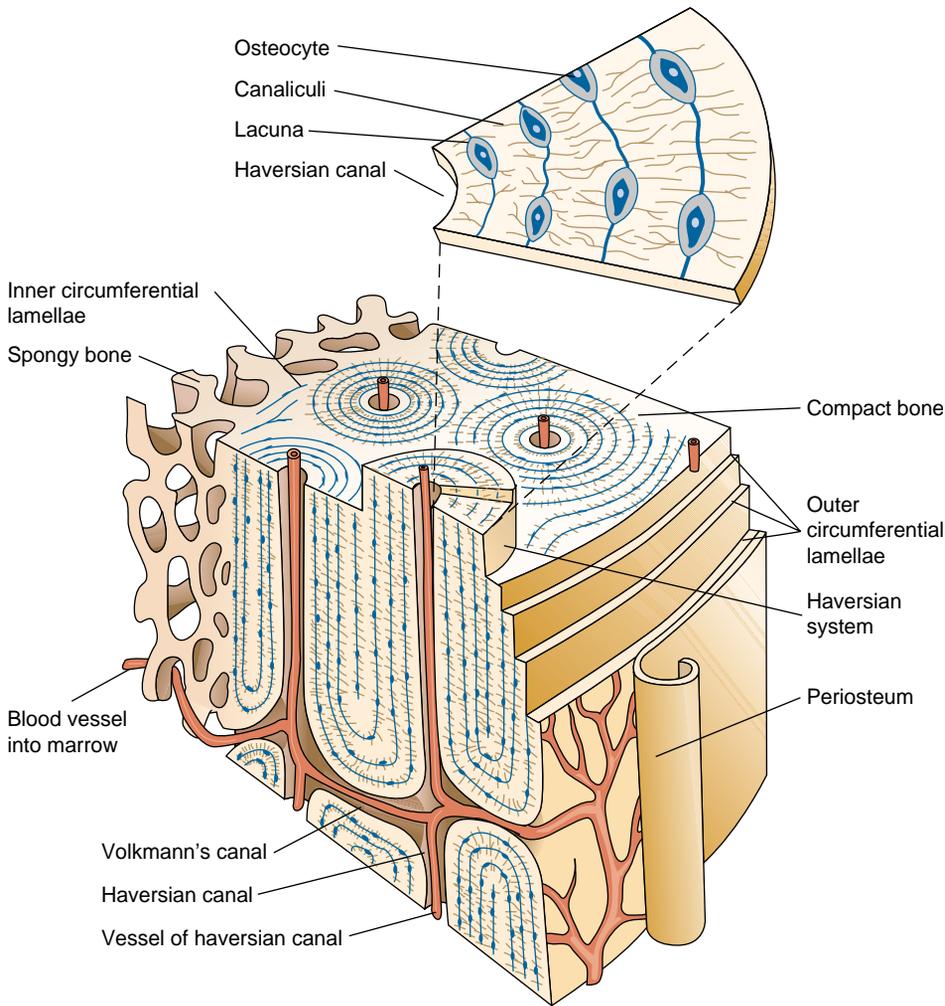


FIGURE 41-2 Haversian systems as seen in a wedge of compact bone tissue. The periosteum has been peeled back to show a blood vessel entering one of Volkmann's canals. (Upper right) Osteocytes lying within lacunae; canaliculi permit interstitial fluid to reach each lacuna.

Osteoclasts. Osteoclasts are “bone-chewing” cells that function in the resorption of bone, removing the mineral content and the organic matrix. They are large phagocytic cells of monocyte/macrophage lineage. Although the mechanism of osteoclast formation and activation remains elusive, it is known that parathyroid hormone (PTH) increases the number and resorptive function of the osteoclasts. Calcitonin is thought to reduce the number and resorptive function of the osteoclasts. Estrogen also reduces the number and function of the osteoclasts; thus, the decrease in estrogen levels that occur at menopause results in increased reabsorption of bone. The mechanism whereby osteoclasts exert their resorptive effect on bone is unclear. These cells may secrete an acid that removes calcium from the bone matrix, releasing the collagenic fibers for digestion by osteoclasts or mononuclear cells. The osteoclastic cells, by virtue of their phagocytic lineage, also imbibe minute particles of bone matrix and crystals, eventually dissolving and releasing them into the blood.

Periosteum and Endosteum

Bones are covered, except at their articular ends, by a membrane called the *periosteum* (see Fig. 41-1). The periosteum has an outer fibrous layer and an inner layer that contains the osteogenic cells needed for bone growth and development. The peri-

osteum contains blood vessels and acts as an anchorage point for vessels as they enter and leave the bone. The endosteum is the membrane that lines the spaces of spongy bone, the marrow cavities, and the haversian canals of compact bone. It is composed mainly of osteogenic cells. These osteogenic cells contribute to the growth and remodeling of bone and are necessary for bone repair.

Bone Growth and Remodeling

The skeletal system develops from the mesoderm, the thin middle layer of embryonic tissue. Development of the vertebrae of the axial skeleton begins at approximately the fourth week in the embryo; during the ninth week, ossification begins with the appearance of ossification centers in the lower thoracic and upper lumbar vertebrae. The paddle-shaped limb buds of the lower extremities make their appearance late in the fourth week. The hand pads are developed by days 33 to 36, and the finger rays are evident on days 41 to 43 of embryonic development.¹

During the first two decades of life, the skeleton undergoes general overall growth. The long bones of the skeleton, which grow at a relatively rapid rate, are provided with a specialized structure called the *epiphyseal growth plate*. As long bones grow

in length, the deeper layers of cartilage cells in the growth plate multiply and enlarge, pushing the articular cartilage farther away from the metaphysis and diaphysis of the bone.² As this happens, the mature and enlarged cartilage cells at the metaphyseal end of the plate become metabolically inactive and are replaced by bone cells (Fig. 41-1). This process allows bone growth to proceed without changing the shape of the bone or causing disruption of the articular cartilage. The cells in the growth plate stop dividing at puberty, at which time the epiphysis and metaphysis fuse.

Several factors can influence the growth of cells in the epiphyseal growth plate. Epiphyseal separation can occur in children as the result of trauma. The separation usually occurs in the zone of the mature enlarged cartilage cells, which is the weakest part of the growth plate. The blood vessels that nourish the epiphysis pass through the growth plate. These vessels are ruptured when the growth plate separates. This can cause cessation of growth and a shortened extremity.

The growth plate also is sensitive to nutritional and metabolic changes. Scurvy (*i.e.*, vitamin C deficiency) impairs the formation of the organic matrix of bone, causing slowing of growth at the epiphyseal plate and cessation of diaphyseal growth. In rickets (*i.e.*, vitamin D deficiency), calcification of the newly developed bone on the metaphyseal side of the growth plate is impaired. Thyroid and growth hormones are required for normal growth. Alterations in these and other hormones can affect growth (see Chapter 31).

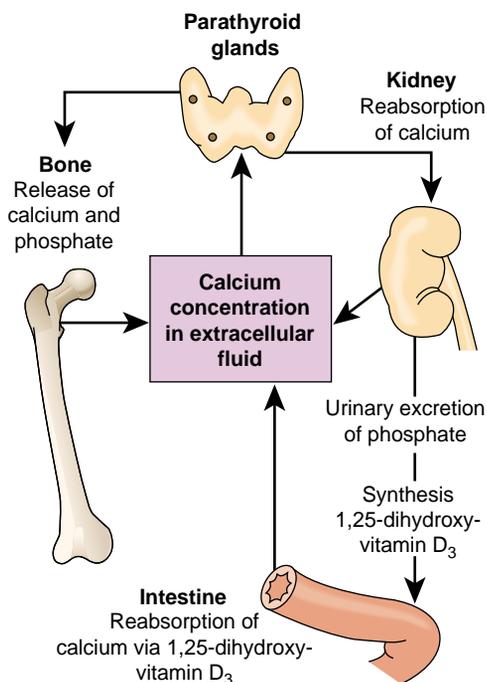
Growth in the diameter of bones occurs as new bone is added to the outer surface of existing bone along with an accompanying resorption of bone on the endosteal or inner surface. Such oppositional growth allows for widening of the marrow cavity while preventing the cortex from becoming too thick and heavy. In this way, the shape of the bone is maintained. As a bone grows in diameter, concentric rings are added to the bone surface, much as rings are added to a tree trunk; these rings form the lamellar structure of mature bone. Osteocytes, which develop from osteoblasts, become buried in the rings. Haversian channels form as periosteal vessels running along the long axis become surrounded by bone.

Hormonal Control of Bone Formation and Metabolism

The process of bone formation and mineral metabolism is complex. It involves the interplay among the actions of PTH, calcitonin, and vitamin D. Other hormones, such as cortisol, growth hormone, thyroid hormone, and the sex hormones, also influence bone formation directly or indirectly.

Parathyroid Hormone

PTH is one of the important regulators of calcium and phosphate levels in the blood. PTH prevents serum calcium levels from falling below and serum phosphate levels from rising above normal physiologic concentrations (see Chapter 31). The secretion of PTH is regulated by negative feedback levels of ionized calcium. PTH maintains serum calcium levels by initiation of calcium release from bone, by conservation of calcium by the kidney, by enhanced intestinal absorption of calcium through activation of vitamin D, and by reduction of serum phosphate levels (Fig. 41-3). PTH also increases the movement of calcium and phosphate from bone into the



■ FIGURE 41-3 ■ Regulation and actions of parathyroid hormone.

extracellular fluid. Calcium is immediately released from the canaliculi and bone cells; a more prolonged release of calcium and phosphate is mediated by increased osteoclast activity. In the kidney, PTH stimulates tubular reabsorption of calcium while reducing the reabsorption of phosphate. The latter effect ensures that increased release of phosphate from bone during mobilization of calcium does not produce an elevation in serum phosphate levels. This is important because an increase in calcium and phosphate levels could lead to crystallization in soft tissues. PTH increases intestinal absorption of calcium because of its ability to stimulate activation of vitamin D by the kidney.

Calcitonin

Whereas PTH increases blood calcium levels, the hormone calcitonin lowers blood calcium levels. Calcitonin, sometimes called *thyrocalcitonin*, is secreted by the parafollicular, or C, cells of the thyroid gland. Calcitonin inhibits the release of calcium from bone into the extracellular fluid. It is thought to act by causing calcium to become sequestered in bone cells and by inhibiting osteoclast activity. Calcitonin also reduces the renal tubular reabsorption of calcium and phosphate; the decrease in serum calcium level that follows administration of pharmacologic doses of calcitonin may be related to this action.

The major stimulus for calcitonin synthesis and release is an increase in serum calcium. The role of calcitonin in overall mineral homeostasis is uncertain. There are no clearly definable syndromes of calcitonin deficiency or excess, which suggests that calcitonin does not directly alter calcium metabolism. It has been suggested that the physiologic actions of calcitonin are related to the postprandial handling and processing of dietary calcium. This theory proposes that after meals, calcitonin maintains parathyroid secretion at a time when it normally would be reduced by calcium entering the blood from the

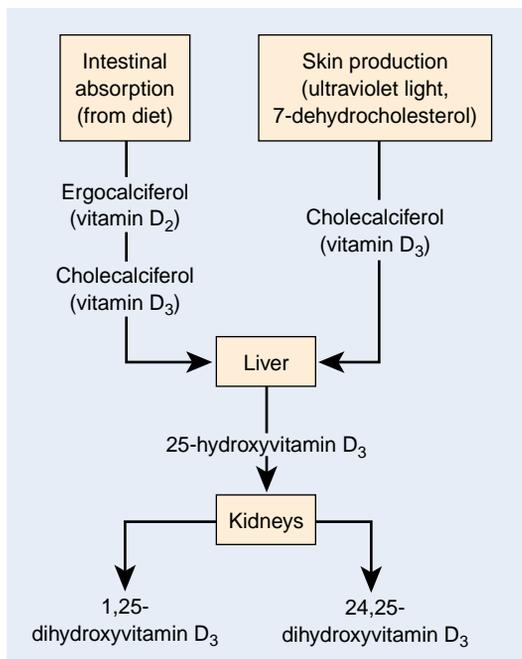
digestive tract. Although excess or deficiency states associated with alterations in physiologic levels of calcitonin have not been observed, it has been shown that pharmacologic doses of the hormone reduce osteoclastic activity. Because of this action, calcitonin has proved effective in the treatment of Paget's disease (see Chapter 43). The hormone is also used to reduce serum calcium levels during hypercalcemic crises.

Vitamin D

Vitamin D and its metabolites are not vitamins but steroid hormones. There are two forms of vitamin D: vitamin D₂ (ergocalciferol) and vitamin D₃ (cholecalciferol). The two forms differ by the presence of a double bond, but they have identical biologic activity. The term *vitamin D* is used to indicate both forms.

Vitamin D has little or no activity until it has been metabolized to compounds that mediate its activity. Figure 41-4 depicts sources of vitamin D and pathways for activation. The first step of the activation process occurs in the liver, where vitamin D is hydroxylated to form the metabolite 25-hydroxyvitamin D₃ [25-(OH)D₃]. From the liver, 25-(OH)D₃ is transported to the kidneys, where it undergoes conversion to 1,25-dihydroxyvitamin D₃ [1,25-(OH)₂D₃] or 24,25-dihydroxyvitamin D₃ [24,25-(OH)₂D₃]. Other metabolites of vitamin D have been and still are being discovered.

There are two sources of vitamin D: intestinal absorption and skin production. Intestinal absorption occurs mainly in the jejunum and includes vitamin D₂ and vitamin D₃. The most important dietary sources of vitamin D are fish, liver, and irradiated milk. Because vitamin D is fat soluble, its absorption is mediated by bile salts and occurs by means of the lymphatic vessels. In the skin, ultraviolet radiation from sunlight spontaneously converts 7-dehydrocholesterol provitamin D₃ to vitamin D₃. A circulating vitamin D-binding protein provides a mechanism to remove vitamin D from the skin and make it available to the rest of the body.



■ FIGURE 41-4 ■ Sources and pathway for activation of vitamin D.

With adequate exposure to sunlight, the amount of vitamin D that can be produced by the skin is usually sufficient to meet physiologic requirements. The importance of sunlight exposure is evidenced by population studies that report lower vitamin D levels in countries, such as England, that have less sunlight than the United States. Elderly persons who are housebound or institutionalized frequently have low vitamin D levels. The deficiency often goes undetected until there are problems such as pseudofractures or electrolyte imbalances. Seasonal variations in vitamin D levels probably reflect changes in sunlight exposure.

The most potent of the vitamin D metabolites is 1,25-(OH)₂D₃. This metabolite increases intestinal absorption of calcium and promotes the actions of PTH on resorption of calcium and phosphate from bone. Bone resorption by the osteoclasts is increased, and bone formation by the osteoblasts is decreased; there is also an increase in acid phosphatase and a decrease in alkaline phosphatase. Intestinal absorption and bone resorption increase the amount of calcium and phosphorus available to the mineralizing surface of the bone. The role of 24,25-(OH)₂D₃ is less clear. There is evidence that 24,25-(OH)₂D₃, in conjunction with 1,25-(OH)₂D₃, may be involved in normal bone mineralization.

The regulation of vitamin D activity is influenced by several hormones. PTH and prolactin stimulate 1,25-(OH)₂D₃ production by the kidney. States of hyperparathyroidism are associated with increased levels of 1,25-(OH)₂D₃, and hypoparathyroidism leads to lowered levels of this metabolite. Prolactin may have an ancillary role in regulating vitamin D metabolism during pregnancy and lactation. Calcitonin inhibits 1,25-(OH)₂D₃ production by the kidney. In addition to hormonal influences, changes in the concentration of ions such as calcium, phosphate, hydrogen, and potassium exert an effect on 1,25-(OH)₂D₃ and 24,25-(OH)₂D₃ production. Under conditions of deprivation of phosphate and calcium, 1,25-(OH)₂D₃ levels are increased, whereas hyperphosphatemia and hypercalcemia decrease the levels of metabolite.

In summary, skeletal tissue is composed of two types of connective tissue: cartilage and bone. These skeletal structures are composed of similar tissue types; each has living cells and nonliving intercellular fibers and ground substance that is secreted by the cells. Cartilage is a firm, flexible type of skeletal tissue that is essential for growth before and after birth. There are three types of cartilage: elastic, hyaline, and fibrocartilage. Hyaline cartilage, which is the most abundant type, forms the costal cartilages that join the ribs to the sternum and vertebrae, many of the cartilages of the respiratory tract, and the articular cartilages.

The characteristics of the various skeletal tissue types are determined by the intercellular matrix. In bone, this matrix is impregnated with calcium salts to provide hardness and strength. There are four types of bone cells: osteocytes, or mature bone cells; osteoblasts, or bone-building cells; osteoclasts, which function in bone resorption; and osteogenic cells, which differentiate into osteoblasts. Densely packed compact bone forms the outer shell of a bone, and latticelike cancellous bone forms the interior. The periosteum, the membrane that covers bones, contains blood vessels and acts as an anchorage point for vessels as they

enter and leave the bone. The endosteum is the membrane that lines the spaces of spongy bone, the marrow cavities, and the haversian canals of compact bone.

The process of bone formation and mineral metabolism involves the interplay among the actions of PTH, calcitonin, and vitamin D. PTH acts to maintain serum levels of ionized calcium; it increases the release of calcium and phosphate from bone, the conservation of calcium and elimination of phosphate by the kidney, and the intestinal reabsorption of calcium through vitamin D. Calcitonin inhibits the release of calcium from bone and increases renal elimination of calcium and phosphate, thereby serving to lower serum calcium levels. Vitamin D functions as a hormone in regulating body calcium. It increases absorption of calcium from the intestine and promotes the actions of PTH on bone.

SKELETAL STRUCTURES

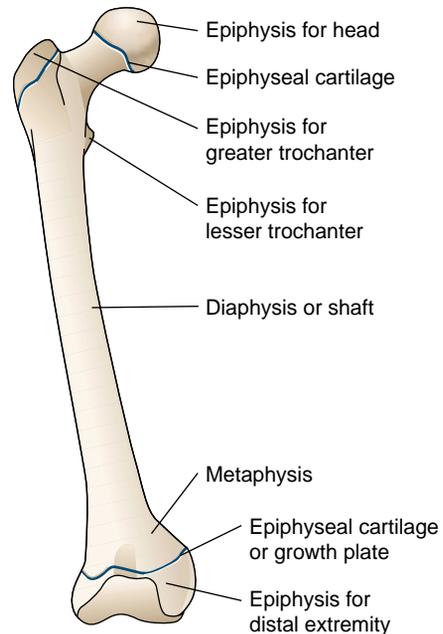
Classification of Bones

Bones are classified by shape as long, short, flat, and irregular. Long bones are found in the upper and lower extremities. Short bones are irregularly shaped bones located in the ankle and the wrist. Except for their surface, which is compact bone, these bones are spongy throughout. Flat bones are composed of a layer of spongy bone between two layers of compact bone. They are found in areas such as the skull and rib cage, where extensive protection of underlying structures is needed, or, as in the scapula, where a broad surface for muscle attachment must be provided. Irregular bones, because of their shapes, cannot be classified in any of the previous groups. This group includes bones such as the vertebrae and the bones of the jaw.

A typical long bone has a shaft, or *diaphysis*, and two ends, called *epiphyses*. Long bones usually are narrow in the midportion and broad at the ends so that the weight they bear can be distributed over a wider surface. The shaft of a long bone is formed mainly of compact bone roughly hollowed out to form a marrow-filled medullary canal. The ends of long bones are covered with articular cartilage that rests on a bony plate, the subchondral bone.

In growing bones, the part of the bone shaft that funnels out as it approaches the epiphysis is called the *metaphysis* (Fig. 41-5). It is composed of bony trabeculae that have cores of cartilage. In the child, the epiphysis is separated from the metaphysis by the cartilaginous growth plate. After puberty, the metaphysis and epiphysis merge, and the growth plate is obliterated.

Bone marrow occupies the medullary cavities of the long bones throughout the skeleton and the cavities of cancellous bone in the vertebrae, ribs, sternum, and flat bones of the pelvis. The cellular composition of the bone marrow varies with age and skeletal location. Red bone marrow contains developing red blood cells and is the site of blood cell formation. Yellow bone marrow is composed largely of adipose cells. At birth, nearly all of the marrow is red and hematopoietically active. As the need for red blood cell production decreases during postnatal growth, red marrow is gradually replaced with yellow



■ FIGURE 41-5 ■ A femur, showing epiphyseal cartilages for the head, metaphysis, trochanters, and distal end of the bone.

bone marrow in most of the bones. In the adult, red marrow persists in the vertebrae, ribs, sternum, and ilia.

Tendons and Ligaments

In the skeletal system, tendons and ligaments are dense connective tissue structures that connect muscles and bones. Tendons connect muscles to bone, and ligaments connect the movable bones of joints. Tendons can appear as cordlike structures or as flattened sheets, called *aponeuroses*, such as in the abdominal muscles.

The dense connective tissue found in tendons and ligaments has a limited blood supply and is composed largely of intercellular bundles of collagen fibers arranged in the same direction and plane. This type of connective tissue provides great tensile strength and can withstand tremendous pull in the direction of fiber alignment. At the sites where tendons or ligaments are inserted into cartilage or bone, a gradual transition from pure dense connective tissue to bone or cartilage occurs. In cartilage, this transitional tissue is called *fibrocartilage*.

Tendons that may rub against bone or other friction-generating surfaces are enclosed in double-layered sheaths. An outer connective tissue tube is attached to the structures surrounding the tendon, and an inner sheath encloses the tendon and is attached to it. The space between the inner and outer sheath is filled with a fluid similar to synovial fluid.

Joints and Articulations

Articulations, or joints, are areas where two or more bones meet. The term *arthro* is the prefix used to designate a joint. For example, *arthrology* is the study of joints, and *arthroplasty* is the repair of a joint. There are two classes of joints, based on movement and the presence of a joint cavity: *synarthroses* and *diarthroses*.

KEY CONCEPTS**SKELETAL JOINTS**

- Joints, or articulations, are sites where two or more bones meet to hold the skeleton together and give it mobility.
- There are two types of joints: synarthroses, which are immovable joints, and diarthroses, which are freely movable joints.
- All limb joints are synovial diarthrodial joints, which are enclosed in a joint cavity containing synovial fluid.
- The articulating surfaces of synovial joints are covered with a layer of avascular cartilage that relies on oxygen and nutrients contained in the synovial fluid.
- Regeneration of articular cartilage of synovial joints is slow, and the healing of injuries often is slow and unsatisfactory.

Synarthroses

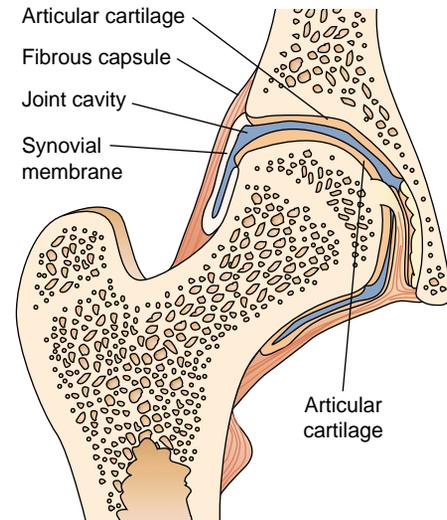
Synarthroses are joints that lack a joint cavity and move little or not at all. There are three types of synarthroses: *synostoses*, *synchondroses*, and *syndesmoses*. *Synostoses* are nonmovable joints in which the surfaces of the bones are joined by dense connective tissue or bone. The bones of the skull are joined by *synostoses*; they are joined by dense connective tissue in children and young adults and by bone in older persons. *Synchondroses* are joints in which bones are connected by hyaline cartilage and have limited motion. The ribs are attached to the sternum by this type of joint. *Syndesmoses* permit a certain amount of movement; they are separated by a fibrous disk and joined by interosseous ligaments. The symphysis pubis of the pelvis and the bodies of the vertebrae that are joined by intervertebral disks are examples of *syndesmoses*.

Diarthroses

Diarthrodial joints (*i.e.*, synovial joints) are freely movable joints. Most joints in the body are of this type. Although they are classified as freely movable, their movement ranges from almost none (*e.g.*, sacroiliac joint), to simple hinge movement (*e.g.*, interphalangeal joint), to movement in many planes (*e.g.*, shoulder or hip joint). The bony surfaces of these joints are covered with thin layers of articular cartilage, and the cartilaginous surfaces of these joints slide past each other during movement. As discussed in Chapter 43, diarthrodial joints are the joints most frequently affected by rheumatic disorders.

In a diarthrodial joint, the articulating ends of the bones are not connected directly but are indirectly linked by a strong fibrous capsule (*i.e.*, joint capsule) that surrounds the joint and is continuous with the periosteum (Fig. 41-6). This capsule supports the joint and helps to hold the bones in place. Additional support may be provided by ligaments that extend between the bones of the joint.

The joint capsule consists of two layers: an outer fibrous layer and an inner membrane, the synovium. The synovium



■ **FIGURE 41-6** ■ Diarthrodial joint, showing the articular cartilage, fibrous joint capsule, joint cavity, and synovial membrane.

surrounds the tendons that pass through the joints and the free margins of other intra-articular structures, such as ligaments and menisci. The synovium forms folds that surround the margins of articulations but do not cover the weight-bearing articular cartilage. These folds permit stretching of the synovium so that movement can occur without tissue damage.

The synovium secretes a slippery fluid with the consistency of egg white called *synovial fluid*. This fluid acts as a lubricant and facilitates the movement of the articulating surfaces of the joint. Normal synovial fluid is clear or pale yellow, does not clot, and contains fewer than 100 cells/mm³. The cells are predominantly mononuclear cells derived from the synovium. The composition of the synovial fluid is altered in many inflammatory and pathologic joint disorders. Aspiration and examination of the synovial fluid play an important role in the diagnosis of joint diseases.

The articular cartilage is an example of hyaline cartilage and is unique in that its free surface is not covered with perichondrium. It has only a peripheral rim of perichondrium, and calcification of the portion of cartilage abutting the bone may limit or preclude diffusion from blood vessels supplying the subchondral bone. Articular cartilage is apparently nourished by the diffusion of substances contained in the synovial fluid bathing the cartilage. Regeneration of most cartilage is slow; it is accomplished primarily by growth that requires the activity of perichondrium cells. In articular cartilage, which has no perichondrium, superficial injuries heal slowly.

Blood Supply and Innervation

The blood supply to a joint arises from blood vessels that enter the subchondral bone at or near the attachment of the joint capsule and form an arterial circle around the joint. The synovial membrane has a rich blood supply, and constituents of plasma diffuse rapidly between these vessels and the joint cavity. Because many of the capillaries are near the surface of the synovium, blood may escape into the synovial fluid after relatively minor injuries. Healing and repair of the synovial membrane usually are rapid and complete. This is important be-

cause synovial tissue is injured in many surgical procedures that involve the joint.

The nerve supply to joints is provided by the same nerve trunks that supply the muscles that move the joints. These nerve trunks also supply the skin over the joints. As a rule, each joint of an extremity is innervated by all the peripheral nerves that cross the articulation; this accounts for the referral of pain from one joint to another. For example, hip pain may be perceived as pain in the knee.

The tendons and ligaments of the joint capsule are sensitive to position and movement, particularly stretching and twisting. These structures are supplied by the large sensory nerve fibers that form proprioceptor endings (see Chapter 38). The proprioceptors function reflexively to adjust the tension of the muscles that support the joint and are particularly important in maintaining muscular support for the joint. For example, when a weight is lifted, there is a proprioceptor-mediated reflex contraction and relaxation of appropriate muscle groups to support the joint and protect the joint capsule and other joint structures. Loss of proprioception and reflex control of muscular support leads to destructive changes in the joint.

The synovial membrane is innervated only by autonomic fibers that control blood flow. It is relatively free of pain fibers, as evidenced by the fact that surgical procedures on the joint are often done under local anesthesia. The joint capsule and the ligaments have pain receptors; these receptors are more easily stimulated by stretching and twisting than are other joint structures. Pain arising from the capsule tends to be diffuse and poorly localized.

Bursae

In some diarthrotic joints, the synovial membrane forms closed sacs that are not part of the joint. These sacs, called *bursae*, contain synovial fluid. Their purpose is to prevent friction on a tendon. Bursae occur in areas where pressure is exerted because of close approximation of joint structures (Fig. 41-7). Such conditions occur when tendons are deflected over bone or where skin must move freely over bony tissue. Bursae may

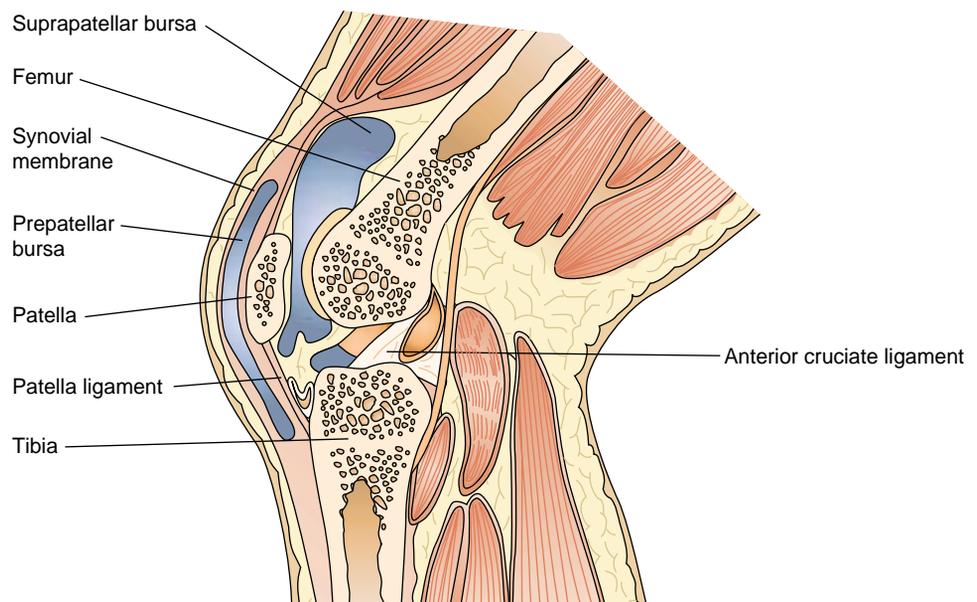
become injured or inflamed, causing discomfort, swelling, and limitation in movement of the involved area. A bunion is an inflamed bursa of the metatarsophalangeal joint of the great toe.

Intra-articular Menisci

Intra-articular menisci are fibrocartilage structures that develop from portions of the articular disk that occupied the space between articular cartilage surfaces during fetal development. Menisci may extend part way through the joint and have a free inner border, as at the lateral and medial articular surfaces of the knee, or they may extend through the joint, separating it into two separate cavities, as in the sternoclavicular joint. The menisci of the knee joint may be torn as the result of an injury (see Chapter 42).

In summary, bones are classified on the basis of their shape as long, short, flat, or irregular. Long bones are found in the upper and lower extremities; short bones in the ankle and wrist; flat bones in the skull and rib cage; and irregular bones in the vertebrae and jaw. Tendons and ligaments are dense connective skeletal tissue that connect muscles and bones. Tendons connect muscles to bones, and ligaments connect the movable bones of joints.

Articulations, or joints, are areas where two or more bones meet. Synarthroses are joints in which bones are joined together by fibrous tissue, cartilage, or bone; they lack a joint cavity and have little or no movement. Diarthrodial or synovial joints are freely movable. The surfaces of the articulating ends of bones in diarthrodial joints are covered with a thin layer of articular cartilage, and they are enclosed in a fibrous joint capsule. The joint capsule consists of two layers: an outer fibrous layer and an inner membrane, the synovium. The synovial fluid, which is secreted by the synovium into the joint capsule, acts as a lubricant and facilitates movement of the joint's articulating surfaces. Bursae, which are closed sacs containing synovial fluid, prevent friction in areas where tendons



■ **FIGURE 41-7** ■ Sagittal section of knee joint, showing prepatellar and suprapatellar bursae.

are deflected over bone or where skin must move freely over bony tissue.

Menisci are fibrocartilaginous structures that develop from portions of the articular disk that occupied the space between the articular cartilage during fetal development. The menisci may have a free inner border, or they may extend through the joint, separating it into two cavities. The menisci in the knee joint may be torn as a result of injury.

- Explain why pain is often experienced in all the joints of an extremity when only a single joint is affected by a disease process.
- Describe the structure and function of a bursa.



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REVIEW QUESTIONS

- Cite the common components of cartilage and bone.
- Compare the properties of the intercellular collagen and elastic fibers of skeletal tissue.
- Cite the characteristics and name at least one location of elastic cartilage, hyaline cartilage, and fibrocartilage.
- State the function of parathyroid hormone, calcitonin, and vitamin D in terms of bone formation and metabolism.
- State the location and function of the periosteum and the endosteum.
- State the characteristics of tendons and ligaments.
- State the difference between synarthrodial and diarthrodial joints.

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