chapter 6

The Skeletal System

Anterior view of the bones in the right hand and wrist of an adult as shown by X ray.

chapter outline & learning objectives

After you have studied this chapter, you should be able to:

6.1 Skeleton: Overview (p. 84)

- Name at least five functions of the skeleton.
- Explain a classification of bones based on their shapes.
- Describe the anatomy of a long bone.
- Describe the growth and development of bones.
- Name and describe six types of fractures, and state the four steps in fracture repair.

6.2 Axial Skeleton (p. 89)

- Distinguish between the axial and appendicular skeletons.
- Name the bones of the skull, and state the important features of each bone.
- Describe the structure and function of the hyoid bone.
- Name the bones of the vertebral column and the thoracic cage. Be able to label diagrams of them.
- Describe a typical vertebra, the atlas and axis, and the sacrum and coccyx.
- Name the three types of ribs and the three parts of the sternum.

6.3 Appendicular Skeleton (p. 97)

- Name the bones of the pectoral girdle and the pelvic girdle. Be able to label diagrams of them.
- Name the bones of the upper limb (arm and forearm) and the lower limb (thigh and leg). Be able to label diagrams that include surface features.
- Cite at least five differences between the female and male pelvises.

6.4 Joints (Articulations) (p. 104)

- Explain how joints are classified, and give examples of each type of joint.
- List the types of movements that occur at synovial joints.

6.5 Effects of Aging (p. 107)

- Describe the anatomical and physiological changes that occur in the skeletal system as we age.

6.6 Homeostasis (p. 108)

- List and discuss six ways the skeletal system contributes to homeostasis. Discuss ways the other systems assist the skeletal system.

Medical Focus

Osteoporosis (p. 88)

What's New

Coaxing the Chondrocytes for Knee Repair (p. 107)

6.1 Skeleton: Overview

The skeletal system consists of the bones (206 in adults) and joints, along with the cartilage and ligaments that occur at the joints.

Functions of the Skeleton

The skeleton has the following functions:

The skeleton supports the body. The bones of the lower limbs support the entire body when we are standing, and the pelvic girdle supports the abdominal cavity.

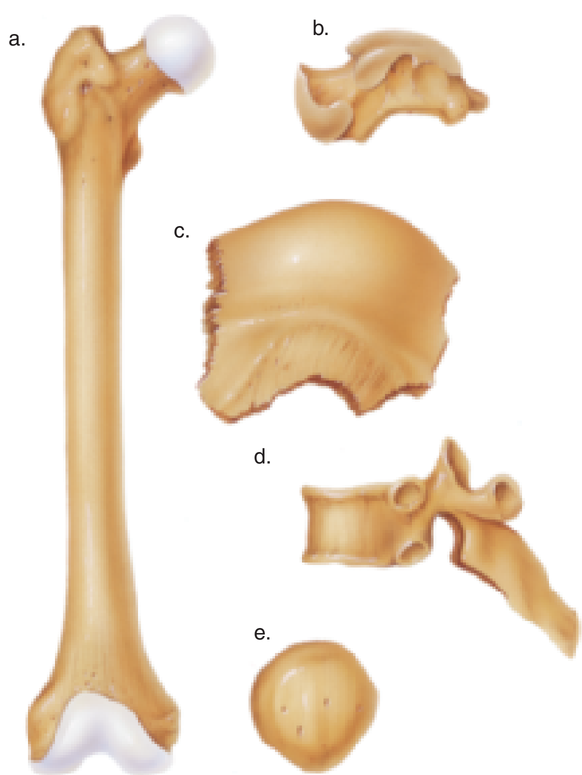
The skeleton protects soft body parts. The bones of the skull protect the brain; the rib cage protects the heart and lungs.

The skeleton produces blood cells. All bones in the fetus have red bone marrow that produces blood cells. In the adult, only certain bones produce blood cells.

The skeleton stores minerals and fat. All bones have a matrix that contains calcium phosphate, a source of calcium ions and phosphate ions in the blood. Fat is stored in yellow bone marrow.

The skeleton, along with the muscles, permits flexible body movement. While articulations (joints) occur between all the bones, we associate body movement in particular with the bones of the limbs.

Figure 6.1 Classification of bones. **a.** Long bones are longer than they are wide. **b.** Short bones are cube shaped; their lengths and widths are about equal. **c.** Flat bones are platelike and have broad surfaces. **d.** Irregular bones have varied shapes with many places for connections with other bones. **e.** Round bones are circular.



Anatomy of a Long Bone

Bones are classified according to their shape. Long bones are longer than they are wide. Short bones are cube shaped—that is, their lengths and widths are about equal. Flat bones, such as those of the skull, are platelike with broad surfaces. Irregular bones have varied shapes that permit connections with other bones. Round bones are circular in shape (Fig. 6.1).

A long bone, such as the one in Figure 6.2, can be used to illustrate certain principles of bone anatomy. The bone is enclosed in a tough, fibrous, connective tissue covering called the **periosteum,** which is continuous with the ligaments and tendons that anchor bones. The periosteum contains blood vessels that enter the bone and service its cells. At both ends of a long bone is an expanded portion called an **epiphysis;** the portion between the epiphyses is called the **diaphysis.**

As shown in the section of an adult bone in Figure 6.2, the diaphysis is not solid but has a **medullary cavity** containing yellow marrow. Yellow marrow contains large amounts of fat. The medullary cavity is bounded at the sides by compact bone. The epiphyses contain spongy bone. Beyond the spongy bone is a thin shell of compact bone and, finally, a layer of hyaline cartilage called the **articular cartilage.** Articular cartilage is so named because it occurs where bones articulate (join). **Articulation** is the joining together of bones at a joint. The medullary cavity and the spaces of spongy bone are lined with *endosteum,* a thin, fibrous membrane.

Compact Bone

Compact bone, or dense bone, contains many cylinder-shaped units called osteons. The osteocytes (bone cells) are in tiny chambers called *lacunae* that occur between concentric layers of matrix called *lamellae.* The matrix contains collagenous protein fibers and mineral deposits, primarily of calcium and phosphorus salts.

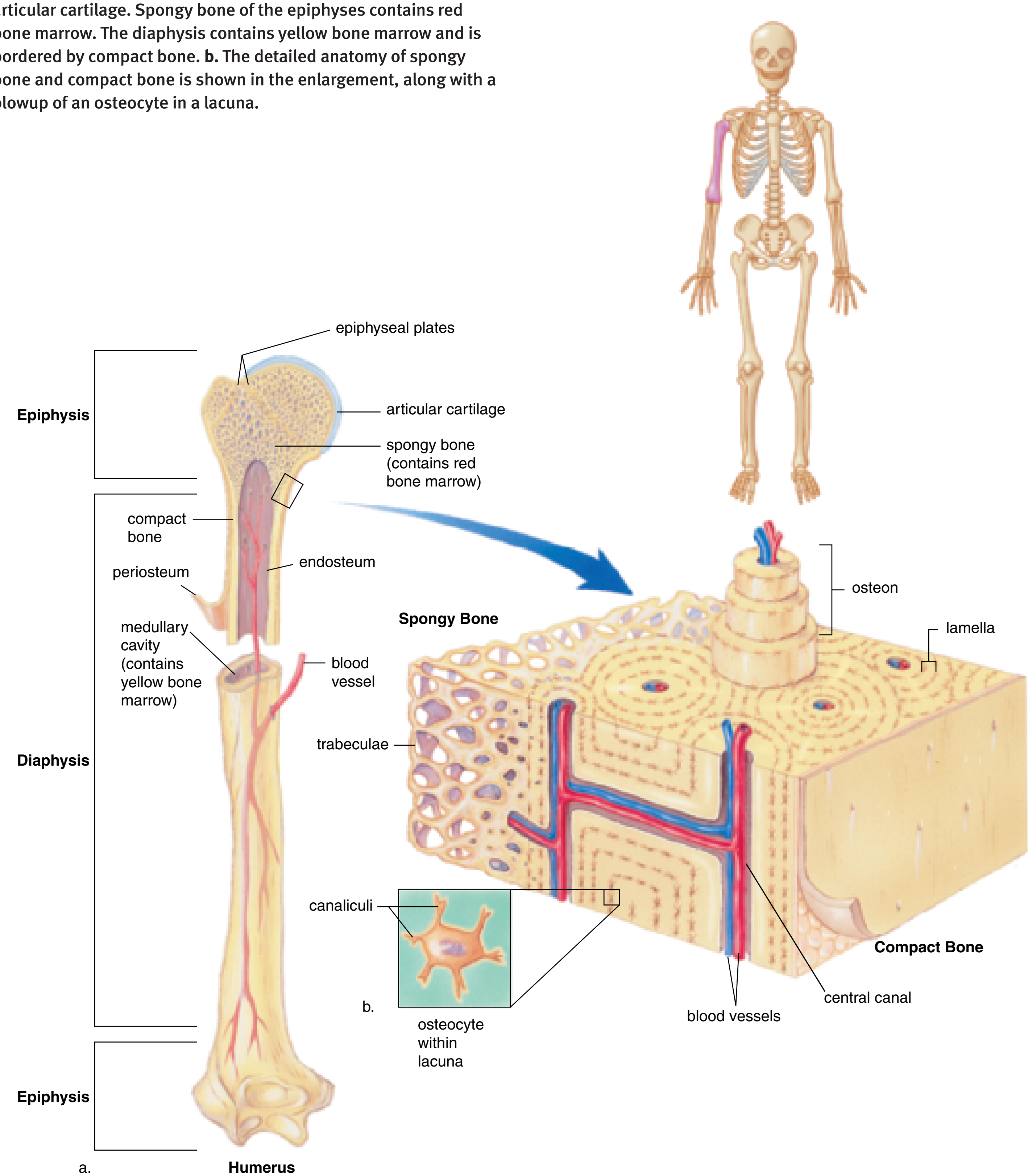
In each osteon, the lamellae and lacunae surround a single central canal. Blood vessels and nerves from the periosteum enter the central canal. The osteocytes have extensions that extend into passageways called *canaliculi,* and thereby the osteocytes are connected to each other and to the central canal.

Spongy Bone

Spongy bone, or cancellous bone, contains numerous bony bars and plates, called *trabeculae.* Although lighter than compact bone, spongy bone is still designed for strength. Like braces used for support in buildings, the trabeculae of spongy bone follow lines of stress.

In infants, **red bone marrow,** a specialized tissue that produces blood cells, is found in the cavities of most bones. In adults, red blood cell formation, called **hematopoiesis,** occurs in the spongy bone of the skull, ribs, sternum (breastbone), and vertebrae, and in the ends of the long bones.

Figure 6.2 Anatomy of a long bone. **a.** A long bone is encased by the periosteum except at the epiphyses, which are covered by articular cartilage. Spongy bone of the epiphyses contains red bone marrow. The diaphysis contains yellow bone marrow and is bordered by compact bone. **b.** The detailed anatomy of spongy bone and compact bone is shown in the enlargement, along with a blowup of an osteocyte in a lacuna.



Bone Growth and Repair

Bones are composed of living tissues, as exemplified by their ability to grow and undergo repair. Several different types of cells are involved in bone growth and repair:

Osteoprogenitor cells are unspecialized cells present in the inner portion of the periosteum, in the endosteum, and in the central canal of compact bone.

Osteoblasts are bone-forming cells derived from osteoprogenitor cells. They are responsible for secreting the matrix characteristic of bone.

Osteocytes are mature bone cells derived from osteoblasts. Once the osteoblasts are surrounded by matrix, they become the osteocytes in bone.

Osteoclasts are thought to be derived from monocytes, a type of white blood cell present in red bone marrow. Osteoclasts perform bone resorption; that is, they break down bone and assist in depositing calcium and phosphate in the blood. The work of osteoclasts is important to the growth and repair of bone.

Bone Development and Growth

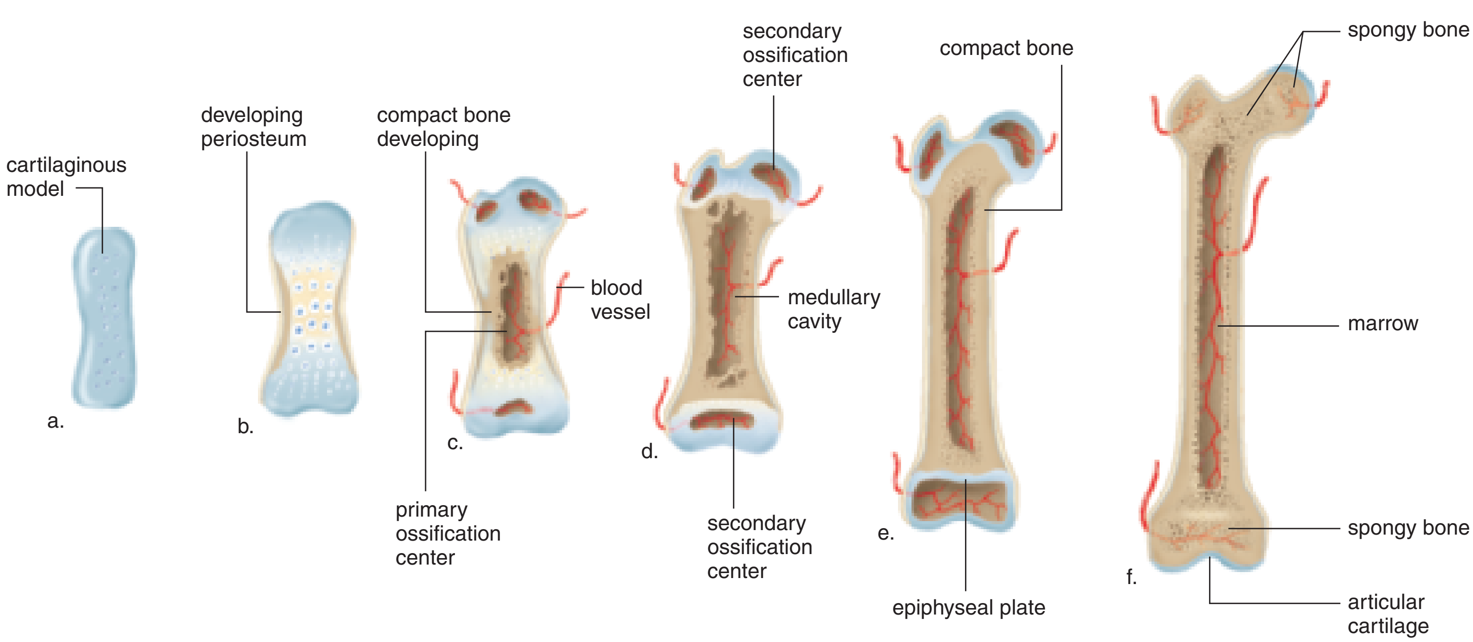
The term **ossification** refers to the formation of bone. The bones of the skeleton form during embryonic development in two distinctive ways—intramembranous ossification and endochondral ossification.

In **intramembranous ossification,** bone develops between sheets of fibrous connective tissue. Cells derived from connective tissue become osteoblasts that form a matrix resembling the trabeculae of spongy bone. Other osteoblasts associated with a periosteum lay down compact bone over the surface of the spongy bone. The osteoblasts become osteocytes when they are surrounded by a mineralized matrix. The bones of the skull develop in this manner.

Most of the bones of the human skeleton form by **endochondral ossification.** Hyaline cartilage models, which appear during fetal development, are replaced by bone as development continues. During endochondral ossification of a long bone, the cartilage begins to break down in the center of the diaphysis, which is now covered by a periosteum (Fig. 6.3). Osteoblasts invade the region and begin to lay down spongy bone in what is called a primary ossification center. Other osteoblasts lay down compact bone beneath the periosteum. As the compact bone thickens, the spongy bone of the diaphysis is broken down by osteoclasts, and the cavity created becomes the medullary cavity.

After birth, the epiphyses of a long bone continue to grow, but soon secondary ossification centers appear in these regions. Here spongy bone forms and does not break down. A band of cartilage called an **epiphyseal plate** remains between the primary ossification center and each secondary center. The limbs keep increasing in length and width as long as epiphyseal plates are still present. The rate of growth is controlled by hormones, such as growth hormones and the sex hormones. Eventually, the epiphyseal plates become ossified, and the bone stops growing.

Figure 6.3 **Endochondral ossification of a long bone. a. A cartilaginous model develops during fetal development. b. A periosteum develops. c. A primary ossification center contains spongy bone surrounded by compact bone. d. The medullary cavity forms in the diaphysis, and secondary ossification centers develop in the epiphyses. e. After birth, growth is still possible as long as cartilage remains at the epiphyseal plates. f. When the bone is fully formed, the remnants of the epiphyseal plates become a thin line.**



Remodeling of Bones

In the adult, bone is continually being broken down and built up again. Osteoclasts derived from monocytes in red bone marrow break down bone, remove worn cells, and assist in depositing calcium in the blood. After a period of about three weeks, the osteoclasts disappear, and the bone is repaired by the work of osteoblasts. As they form new bone, osteoblasts take calcium from the blood. Eventually some of these cells get caught in the mineralized matrix they secrete and are converted to osteocytes, the cells found within the lacunae of osteons.

Strange as it may seem, adults apparently require more calcium in the diet (about 1,000 to 1,500 mg daily) than do children in order to promote the work of osteoblasts. Otherwise, osteoporosis, a condition in which weak and thin bones easily fracture, may develop. Osteoporosis is discussed in the Medical Focus on page 88.

Bone Repair

Repair of a bone is required after it breaks, or **fractures.** Bone repair occurs in a series of four steps:

1. *Hematoma.* Within six to eight hours after a fracture, blood escapes from ruptured blood vessels and forms a hematoma (mass of clotted blood) in the space between the broken bones.
2. *Fibrocartilaginous callus.* Tissue repair begins, and fibrocartilage fills the space between the ends of the broken bone for about three weeks.
3. *Bony callus.* Osteoblasts produce trabeculae of spongy bone and convert the fibrocartilaginous callus to a bony callus that joins the broken bones together and lasts about three to four months.
4. *Remodeling.* Osteoblasts build new compact bone at the periphery, and osteoclasts reabsorb the spongy bone, creating a new medullary cavity.

In some ways, bone repair parallels the development of a bone except that the first step, hematoma, indicates that injury has occurred, and then fibrocartilage instead of hyaline cartilage precedes the production of compact bone.

The naming of fractures describes what kind of break occurred. A fracture is *complete* if the bone is broken clear through and *incomplete* if the bone is not separated into two parts. A fracture is *simple* if it does not pierce the skin and *compound* if it does pierce the skin. *Impacted* means that the broken ends are wedged into each other, and a *spiral fracture* occurs when the break is ragged due to twisting of a bone.

Surface Features of Bones

As we study the various bones of the skeleton, refer to Table 6.1, which lists and explains the surface features of bones.

Table 6.1 Surface Features of Bones

Term	Definition	Example
PROCESSES		
Articulating Surfaces		
Condyle (kon′dīl)	A large, rounded, articulating knob	Mandibular condyle of the mandible (Fig 6.6*b*)
Head	A prominent, rounded, articulating proximal end of a bone	Head of the femur (Fig. 6.16)
Projections for Muscle Attachment		
Crest	A narrow, ridgelike projection	Iliac crest of the coxal bone (Fig. 6.15)
Spine	A sharp, slender process	Spine of the scapula (Fig. 6.11*b*)
Trochanter (tro-kan′ter)	A massive process found only on the femur	Greater trochanter and lesser trochanter of the femur (Fig. 6.16)
Tubercle (tu′ber-kl)	A small, rounded process	Greater tubercle of the humerus (Fig. 6.12)
Tuberosity (tu″bĕ-ros′ĭ-te)	A large, roughened process	Radial tuberosity of the radius (Fig. 6.13)
DEPRESSIONS AND OPENINGS		
Foramen (fo-ra′men)	A rounded opening through a bone	Foramen magnum of the occipital bone (Fig. 6.7*a*)
Fossa (fos′uh)	A flattened or shallow surface	Mandibular fossa of the temporal bone (Fig. 6.7*a*)
Meatus (me-a′tus)	A tubelike passageway through a bone	External auditory meatus of the temporal bone (Fig. 6.6*b*)
Sinus (si′nus)	A cavity or hollow space in a bone	Frontal sinus of the frontal bone (Fig. 6.5)

Source: Data from Kent M. Van De Graaff and Stuart Ira Fox, *Concepts of Human Anatomy and Physiology*, 5th ed., 1999, p. 187.

Osteoporosis

Osteoporosis is a condition in which the bones are weakened due to a decrease in the bone mass that makes up the skeleton. Throughout life, bones are continuously remodeled. While a child is growing, the rate of bone formation is greater than the rate of bone breakdown. The skeletal mass continues to increase until ages 20 to 30. After that, the rates of formation and breakdown of bone mass are equal until ages 40 to 50. Then, reabsorption begins to exceed formation, and the total bone mass slowly decreases.

Over time, men are apt to lose 25% and women 35% of their bone mass. But we have to consider that men tend to have denser bones than women anyway, and their testosterone (male sex hormone) level generally does not begin to decline significantly until after age 65. In contrast, the estrogen (female sex hormone) level in women begins to decline at about age 45. Because sex hormones play an important role in maintaining bone strength, this difference means that women are more likely than men to suffer fractures, involving especially the hip, vertebrae, long bones, and pelvis. Although osteoporosis may at times be the result of various disease processes, it is essentially a disease of aging.

Everyone can take measures to avoid having osteoporosis when they get older. Adequate dietary calcium throughout life is an important protection against osteoporosis. The U.S. National Institutes of Health recommend a calcium intake of 1,200–1,500 mg per day during puberty. Males and females require 1,000 mg per day until age 65 and 1,500 mg per day after age 65, because the intestinal tract has fewer vitamin D receptors in the elderly.

A small daily amount of vitamin D is also necessary to absorb calcium from the digestive tract. Exposure to sunlight is required to allow skin to synthesize vitamin D. If you reside on or north of a "line" drawn from Boston to Milwaukee, to Minneapolis, to Boise, chances are, you're not getting enough vitamin D during the winter months. Therefore, you should avail yourself of the vitamin D in fortified foods such as low-fat milk and cereal.

Postmenopausal women should have an evaluation of their bone density. Presently, bone density is measured by a method called dual energy X-ray absorptiometry (DEXA). This test measures bone density based on the absorption of photons generated by an X-ray tube. Soon, a blood and urine test may be able to detect the biochemical markers of bone loss, making it possible for physicians to screen all older women and at-risk men for osteoporosis.

If the bones are thin, it is worthwhile to take measures to gain bone density because even a slight increase can significantly reduce fracture risk. Regular, moderate, weight-bearing exercise such as walking or jogging is a good way to maintain bone strength (Fig. 6A). A combination of exercise and drug treatment, as recommended by a physician, may yield the best results.

A wide variety of prescribed drugs that have different modes of action are available. Hormone therapy includes black cohosh, which is a phytoestrogen (estrogen made by a plant as opposed to an animal). Calcitonin is a naturally occurring hormone whose main site of action is the skeleton where it inhibits the action of osteoclasts, the cells that break down bone. Promising new drugs include slow-release fluoride therapy and certain growth hormones. These medications stimulate the formation of new bone.

Figure 6A **Preventing osteoporosis. a. Exercise can help prevent osteoporosis, but when playing golf, you should carry your own clubs and walk instead of using a golf cart. b. Normal bone growth compared to bone from a person with osteoporosis.**

6.2 Axial Skeleton

The skeleton is divided into the axial skeleton and the appendicular skeleton. The tissues of the axial and appendicular skeletons are bone (both compact and spongy), cartilage (hyaline, fibrocartilage, and elastic cartilage), and dense connective tissue, a type of fibrous connective tissue. (The various types of connective tissues were extensively discussed in Chapter 3.)

In Figure 6.4, the bones of the axial skeleton are colored orange, and the bones of the appendicular skeleton are colored yellow for easy distinction. Notice that the **axial skeleton** lies in the midline of the body and contains the bones of the skull, the hyoid bone, the vertebral column, and the thoracic cage. Six tiny middle ear bones (three in each ear) are also in the axial skeleton; we will study them in Chapter 9 in connection with the ear.

Figure 6.4 **Major bones of the skeleton. a. Anterior view. b. Posterior view. The bones of the axial skeleton are shown in orange, and those of the appendicular skeleton are shown in yellow.**

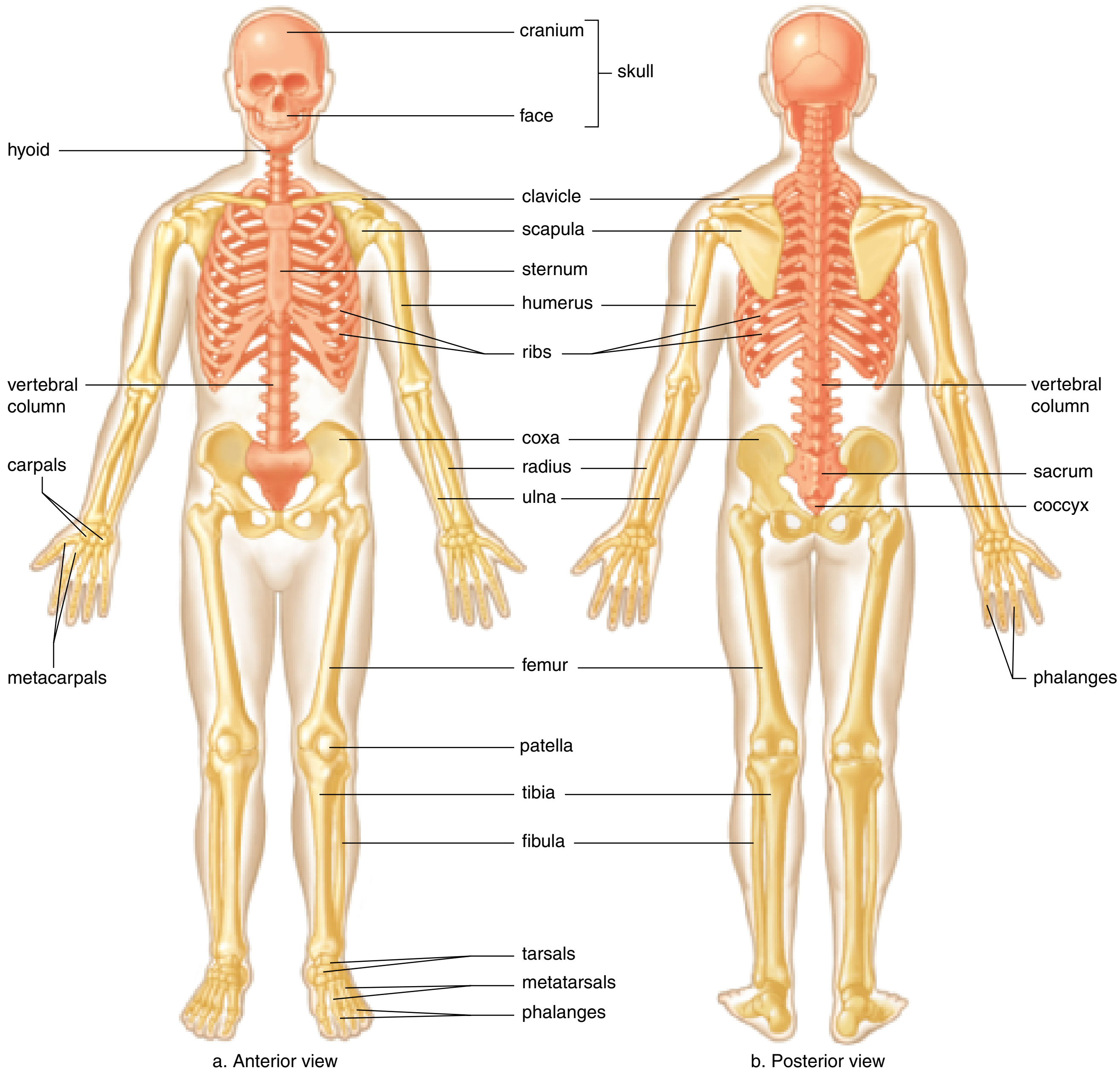
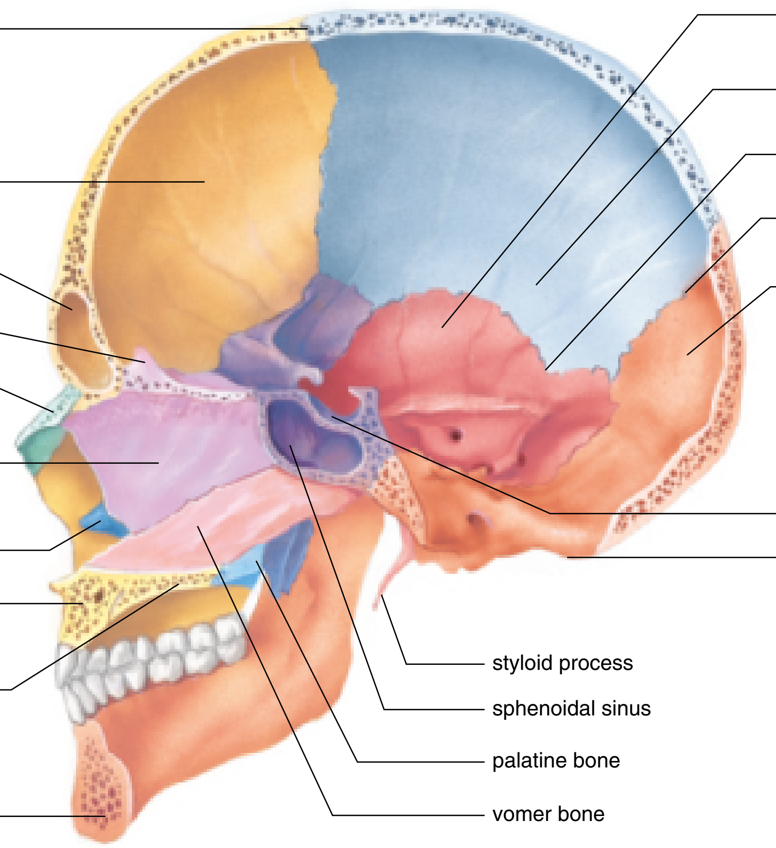


Figure 6.5 Sagittal section of the skull.



Skull

The skull is formed by the cranium and the facial bones. These bones contain **sinuses** (Fig. 6.5), air spaces lined by mucous membranes, that reduce the weight of the skull and give the voice a resonant sound. The paranasal sinuses empty into the nose and are named for their locations. They include the maxillary, frontal, sphenoidal, and ethmoidal sinuses. The two mastoid sinuses drain into the middle ear. **Mastoiditis,** a condition that can lead to deafness, is an inflammation of these sinuses.

Bones of the Cranium

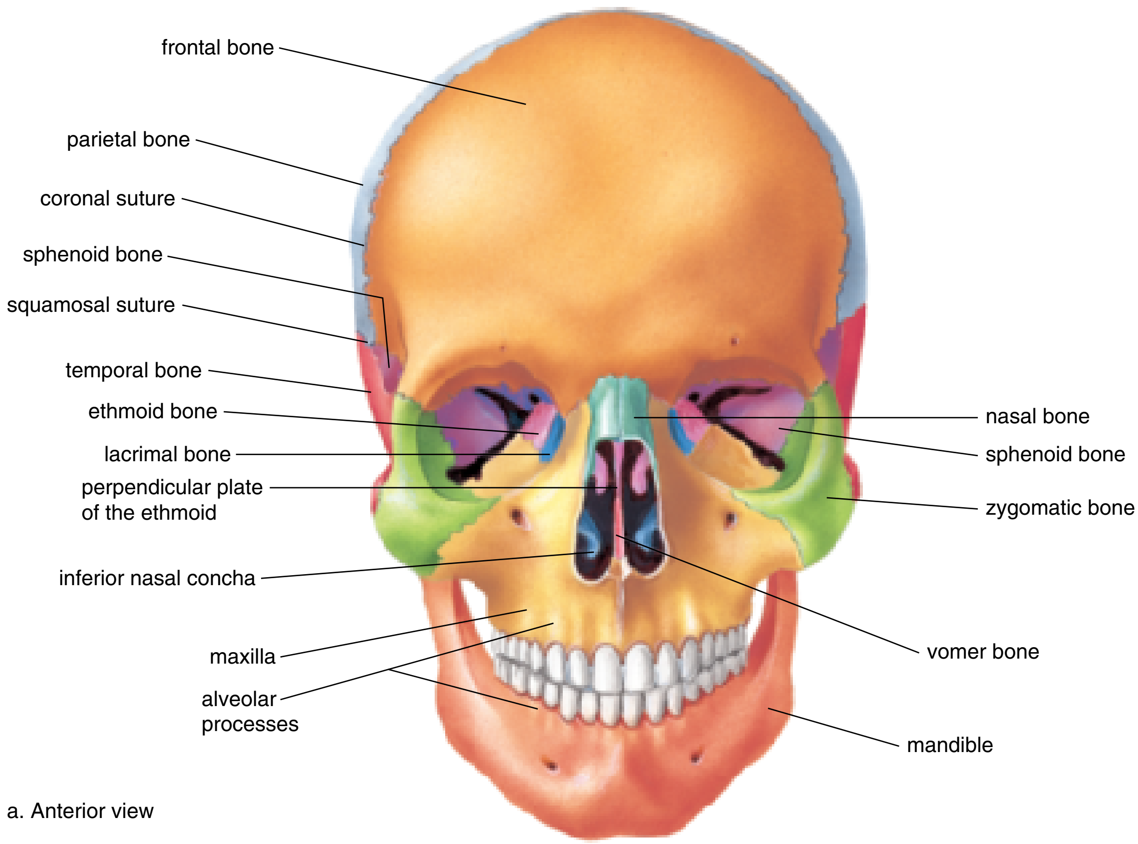
The cranium protects the brain and is composed of eight bones. These bones are separated from each other by immovable joints called **sutures.** Newborns have membranous regions called **fontanels,** where more than two bones meet. The largest of these is the anterior fontanel, which is located where the two parietal bones meet the two parts of the frontal bone. The fontanels permit the bones of the skull to shift during birth as the head passes through the birth canal. The anterior fontanel (often called the "soft spot") usually closes by the age of two years. Besides the frontal bone, the cranium is composed of two parietal bones, one occipital bone, two temporal bones, one sphenoid bone, and one ethmoid bone (Figs. 6.6 and 6.7).

Frontal Bone One frontal bone forms the forehead, a portion of the nose, and the superior portions of the orbits (bony sockets of the eyes).

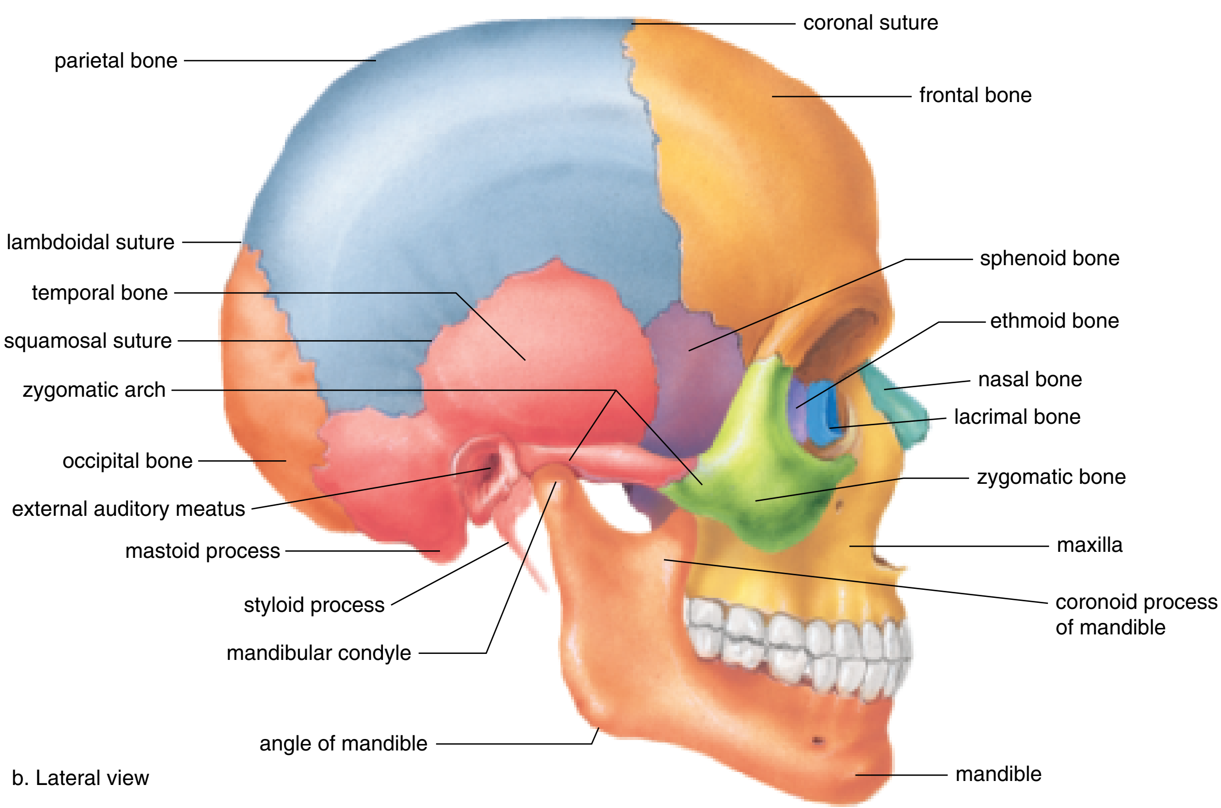
Parietal Bones Two parietal bones are just posterior to the frontal bone. They form the roof of the cranium and also help form its sides.

Occipital Bone One occipital bone forms the most posterior part of the skull and the base of the cranium. The spinal cord joins the brain by passing through a large opening in the occipital bone called the foramen magnum. The **occipital condyles** (Fig. 6.7*a*) are rounded processes on either side of the foramen magnum that articulate with the first vertebra of the spinal column.

Figure 6.6 Skull anatomy. **a.** Anterior view. **b.** Lateral view.



a. Anterior view



b. Lateral view

Temporal Bones Two temporal bones are just inferior to the parietal bones on the sides of the cranium. They also help form the base of the cranium (Figs. 6.6*b* and 6.7*a*). Each temporal bone has the following:

external auditory meatus, a canal that leads to the middle ear;
mandibular fossa, which articulates with the mandible;
mastoid process, which provides a place of attachment for certain neck muscles;
styloid process, which provides a place of attachment for muscles associated with the tongue and larynx;
zygomatic process, which projects anteriorly and helps form the cheekbone.

Sphenoid Bone The sphenoid bone helps form the sides and floor of the cranium and the rear wall of the orbits. The sphenoid bone has the shape of a bat and this shape means that it articulates with and holds together the other cranial bones (Fig. 6.7). Within the cranial cavity, the sphenoid bone has a saddle-shaped midportion called the **sella turcica** (Fig. 6.7*b*), which houses the pituitary gland in a depression.

Ethmoid Bone The ethmoid bone is anterior to the sphenoid bone and helps form the floor of the cranium. It contributes to the medial sides of the orbits and forms the roof and sides of the nasal cavity (Figs. 6.6 and 6.7*b*). The ethmoid bone contains the following:

crista galli (cock's comb), a triangular process that serves as an attachment for membranes that enclose the brain;
cribriform plate with tiny holes that serve as passageways for nerve fibers from the olfactory receptors;
perpendicular plate (Fig. 6.5), which projects downward to form the nasal septum;
superior and **middle nasal conchae,** which project toward the perpendicular plate. These projections support mucous membranes that line the nasal cavity.

Bones of the Face

Maxillae The two maxillae form the upper jaw. Aside from contributing to the floors of the orbits and to the sides of the floor of the nasal cavity, each maxilla has the following processes:

alveolar process (Fig. 6.6*a*). The alveolar processes contain the tooth sockets for teeth: incisors, canines, premolars, and molars.
palatine process (Fig. 6.7*a*)**.** The left and right palatine processes form the anterior portion of the **hard palate** (roof of the mouth).

Palatine Bones The two palatine bones contribute to the floor and lateral wall of the nasal cavity (Fig. 6.5). The horizontal plates of the palatine bones form the posterior portion of the hard palate (Fig. 6.7*a*).

Notice that the hard palate consists of (1) portions of the maxillae (i.e., the palatine processes) and (2) horizontal plates of the palatine bones. A cleft palate results when either (1) or (2) have failed to fuse.

Zygomatic Bones The two zygomatic bones form the sides of the orbits (Fig. 6.7*a*). They also contribute to the "cheekbones." Each zygomatic bone has a **temporal process.** A **zygomatic arch,** the most prominent feature of a cheekbone consists of a temporal process connected to a zygomatic process (a portion of the temporal bone).

Lacrimal Bones The two small, thin lacrimal bones are located on the medial walls of the orbits (Fig. 6.6). A small opening between the orbit and the nasal cavity serves as a pathway for a duct that carries tears from the eyes to the nose.

Nasal Bones The two nasal bones are small, rectangular bones that form the bridge of the nose (Fig. 6.5). The ventral portion of the nose is cartilage, which explains why the nose is not seen on a skull.

Vomer Bone The vomer bone joins with the perpendicular plate of the ethmoid bone to form the nasal septum (Figs. 6.5 and 6.6*a*).

Inferior Nasal Conchae The two inferior nasal conchae are thin, curved bones that form a part of the inferior lateral wall of the nasal cavity (Fig. 6.6*a*). Like the superior and middle nasal conchae, they project into the nasal cavity and support the mucous membranes that line the nasal cavity.

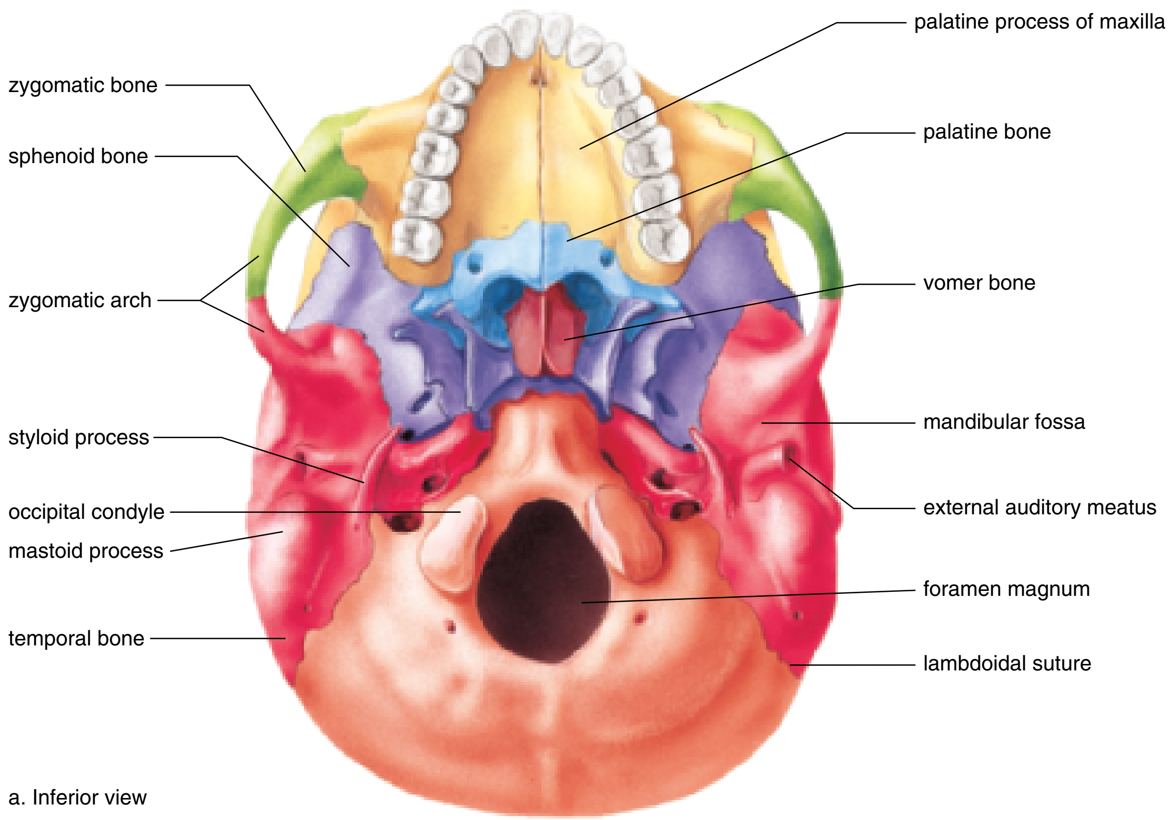
Mandible The mandible, or lower jaw, is the only movable portion of the skull. The horseshoe-shaped front and horizontal sides of the mandible, referred to as the *body*, form the chin. The body has an **alveolar process** (Fig. 6.6*a*), which contains tooth sockets for 16 teeth. Superior to the left and right angle of the mandible are upright projections called *rami*. Each ramus has the following:

mandibular condyle (Fig. 6.6*b*), which articulates with a temporal bone;
coronoid process (Fig. 6.6*b*), which serves as a place of attachment for the muscles used for chewing.

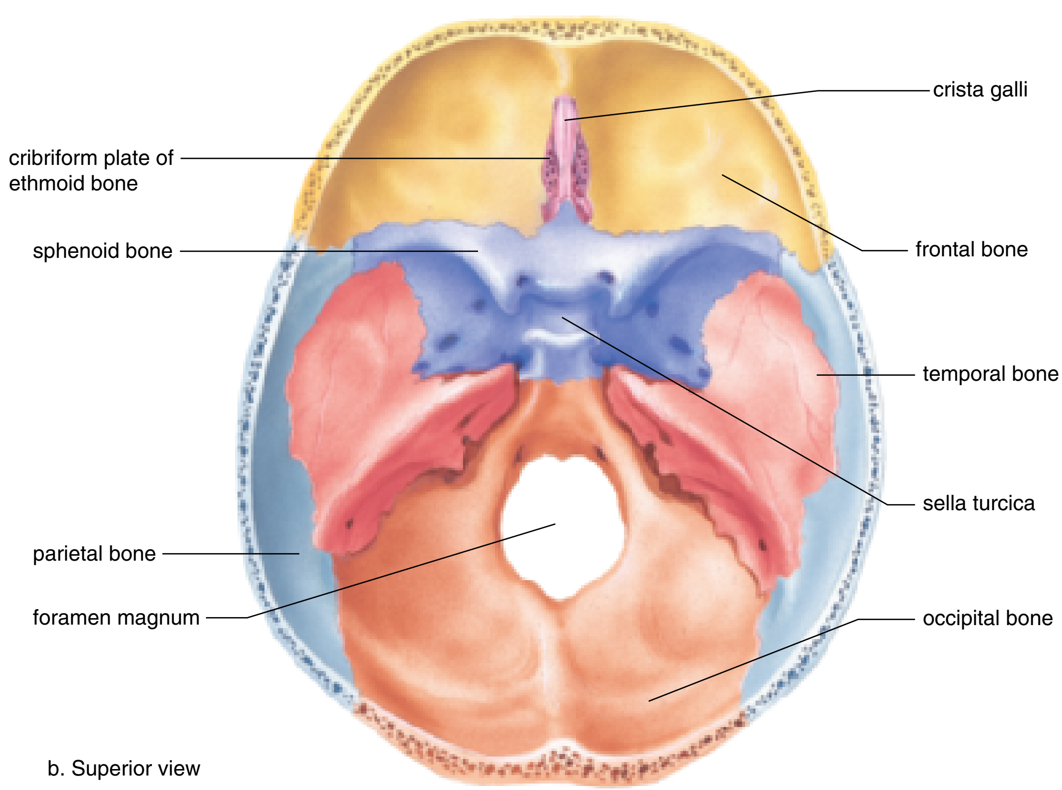
Hyoid Bone

The U-shaped hyoid bone (Fig. 6.4) is located superior to the larynx (voice box) in the neck. It is the only bone in the body that does not articulate with another bone. Instead, it is suspended from the styloid processes of the temporal bones by the stylohyoid muscles and ligaments. It anchors the tongue and serves as the site for the attachment of several muscles associated with swallowing.

Figure 6.7 Skull anatomy continued. **a.** Inferior view. **b.** Superior view.



a. Inferior view



b. Superior view

Vertebral Column (Spine)

The **vertebral column** extends from the skull to the pelvis. It consists of a series of separate bones, the **vertebrae,** separated by pads of fibrocartilage called the **intervertebral disks** (Fig. 6.8). The vertebral column is located in the middorsal region and forms the vertical axis. The skull rests on the superior end of the vertebral column, which also supports the rib cage and serves as a point of attachment for the pelvic girdle. The vertebral column also protects the spinal cord, which passes through a vertebral canal formed by the vertebrae. The vertebrae are named according to their location: seven *cervical* (neck) *vertebrae,* twelve *thoracic* (chest) *vertebrae,* five *lumbar* (lower back) *vertebrae,* five *sacral vertebrae* fused to form the sacrum, and three to five *coccygeal vertebrae* fused into one coccyx.

When viewed from the side, the vertebral column has four normal curvatures, named for their location (Fig. 6.8). The cervical and lumbar curvatures are convex anteriorly, and the thoracic and sacral curvatures are concave anteriorly. In the fetus, the vertebral column has but one curve, and it is concave anteriorly. The cervical curve develops three to four months after birth, when the child begins to hold the head up. The lumbar curvature develops when a child begins to stand and walk, around one year of age. The curvatures of the vertebral column provide more support than a straight column would, and they also provide the balance needed to walk upright.

The curvatures of the vertebral column are subject to abnormalities. An abnormally exaggerated lumbar curvature is called **lordosis,** or "swayback." People who are balancing a heavy midsection, such as pregnant women or men with "potbellies," may have swayback. An increased roundness of the thoracic curvature is **kyphosis,** or "hunchback." This abnormality sometimes develops in older people. An abnormal lateral (side-to-side) curvature is called **scoliosis.** Occurring most often in the thoracic region, scoliosis is usually first seen during late childhood.

Intervertebral Disks

The fibrocartilaginous intervertebral disks located between the vertebrae act as a cushion. They prevent the vertebrae from grinding against one another and absorb shock caused by such movements as running, jumping, and even walking. The disks also allow motion between the vertebrae so that a person can bend forward, backward, and from side to side. Unfortunately, these disks become weakened with age, and can slip or even rupture (called a **herniated disk**). A damaged disk pressing against the spinal cord or the spinal nerves causes pain. Such a disk may need to be removed surgically. If a disk is removed, the vertebrae are fused together, limiting the body's flexibility.

Figure 6.8 Curvatures of the spine. The vertebrae are named for their location in the body. Note the presence of the coccyx, also called the tailbone.

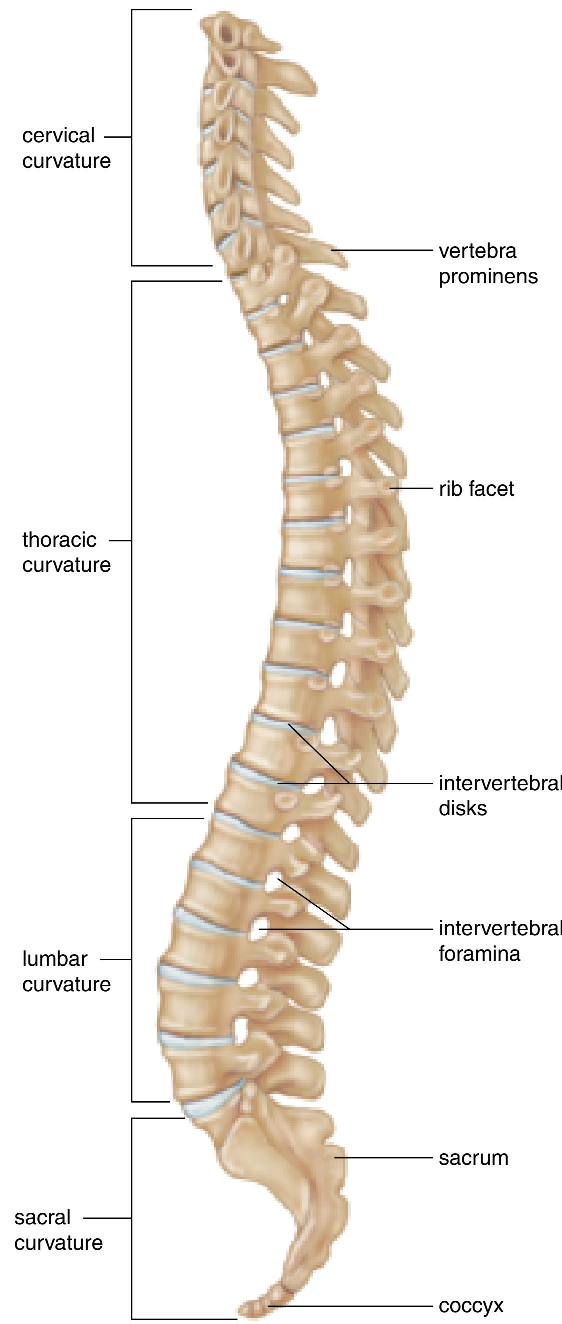
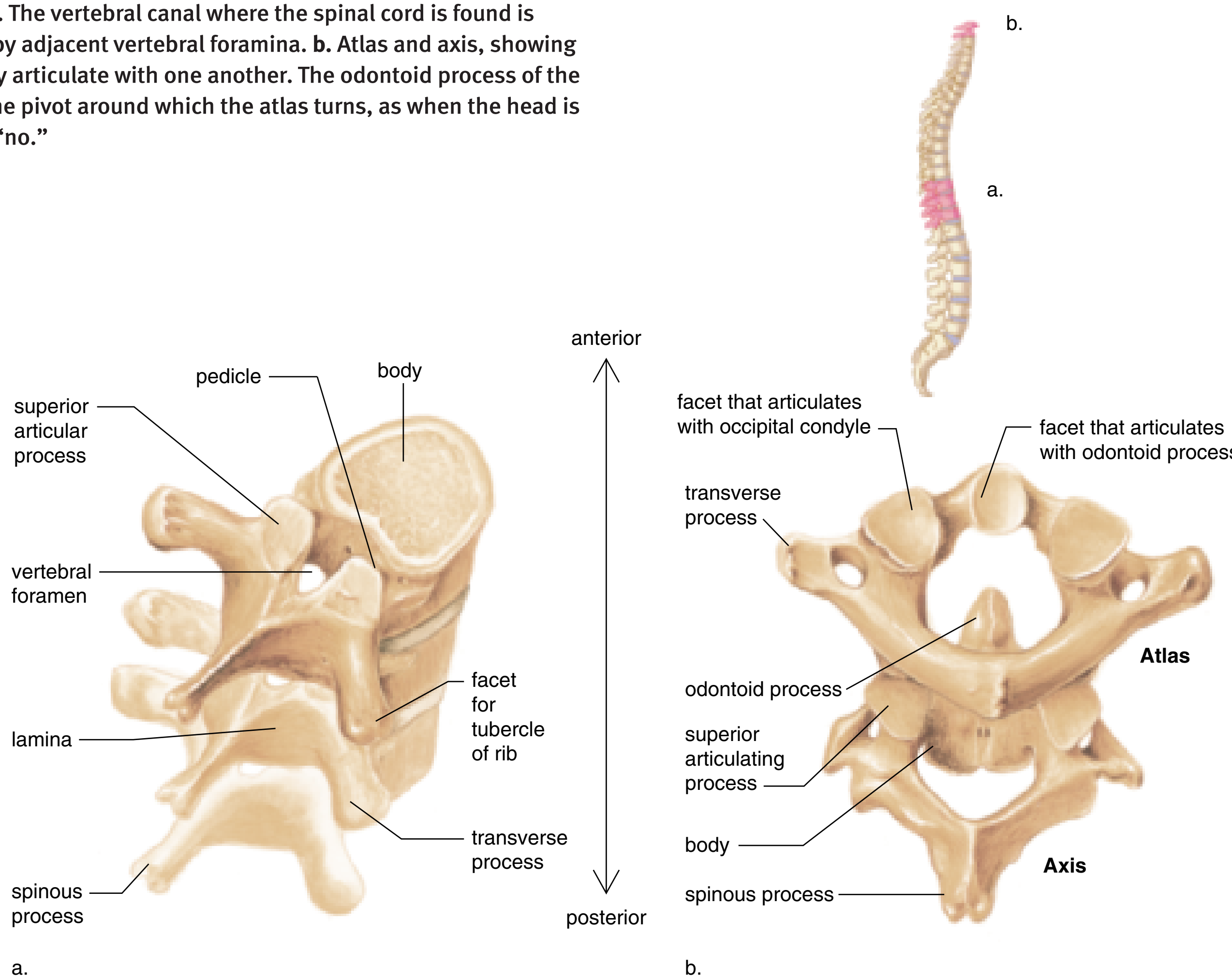


Figure 6.9 Vertebrae. **a.** A typical vertebra in articular position. The vertebral canal where the spinal cord is found is formed by adjacent vertebral foramina. **b.** Atlas and axis, showing how they articulate with one another. The odontoid process of the axis is the pivot around which the atlas turns, as when the head is shaken "no."



Vertebrae

Figure 6.9*a* shows that a typical vertebra has an anteriorly placed *body* and a posteriorly placed vertebral *arch.* The vertebral arch forms the wall of a *vertebral foramen* (pl., *foramina*). The foramina become a canal through which the spinal cord passes.

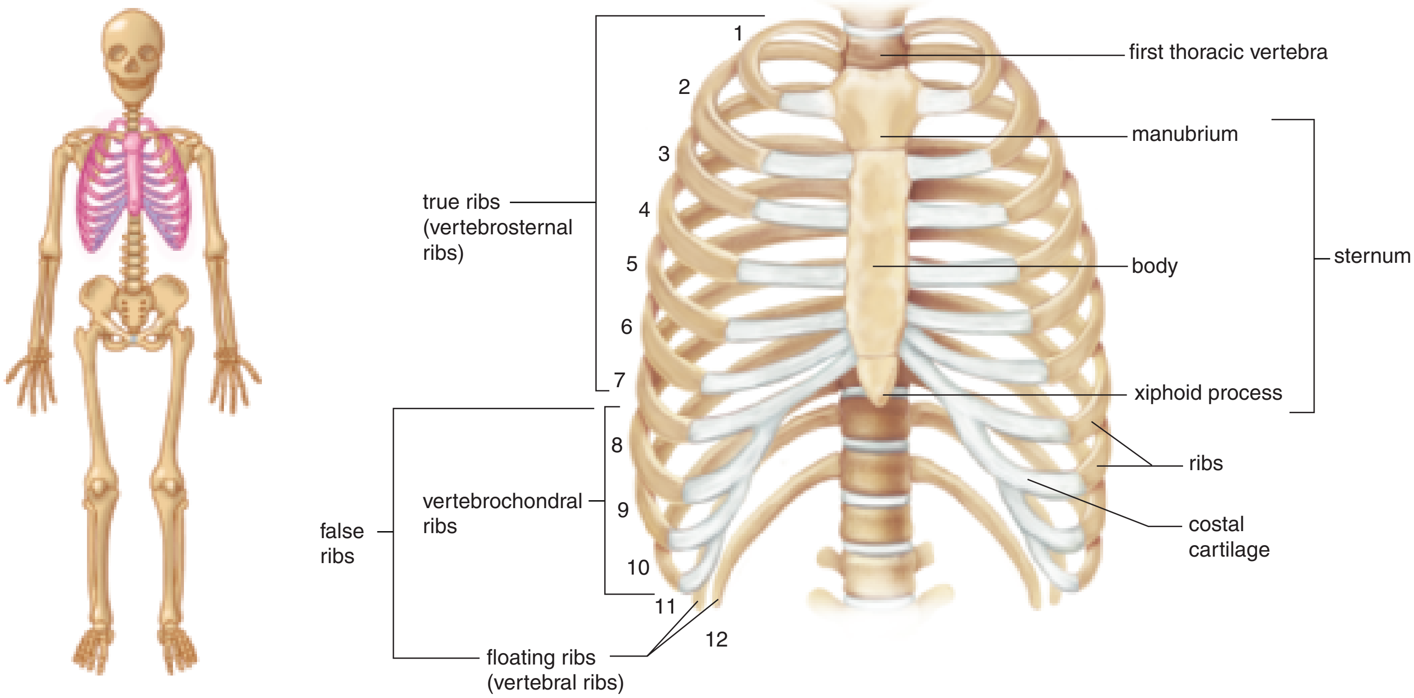
The vertebral *spinous process (spine)* occurs where two thin plates of bone called *laminae* meet. A transverse process is located where a pedicle joins a lamina. These processes serve for the attachment of muscles and ligaments. Articular processes (superior and inferior) serve for the joining of vertebrae.

The vertebrae have regional differences. For example, as the vertebral column descends, the bodies get bigger and are better able to carry more weight. In the cervical region, the spines are short and tend to have a split, or bifurcation. The thoracic spines are long and slender and project downward. The lumbar spines are massive and square and project posteriorly. The transverse processes of thoracic vertebrae have articular facets for connecting to ribs.

Atlas and Axis The first two cervical vertebrae are not typical (Fig. 6.9*b*). The **atlas** supports and balances the head. It has two depressions that articulate with the occipital condyles, allowing movement of the head forward and back. The **axis** has an *odontoid process* (also called the dens) that projects into the ring of the atlas. When the head moves from side to side, the atlas pivots around the odontoid process.

Sacrum and Coccyx The five sacral vertebrae are fused to form the **sacrum.** The sacrum articulates with the pelvic girdle and forms the posterior wall of the pelvic cavity (see Fig. 6.15). The **coccyx,** or tailbone, is the last part of the vertebral column. It is formed from a fusion of three to five vertebrae.

Figure 6.10 The rib cage. This structure includes the thoracic vertebrae, the ribs, and the sternum. The three bones that make up the sternum are the manubrium, body, and xiphoid process. The ribs numbered 1–7 are true ribs; those numbered 8–12 are false ribs.



The Rib Cage

The **rib cage** (Fig. 6.10), sometimes called the thoracic cage, is composed of the thoracic vertebrae, ribs and associated cartilages, and sternum.

The rib cage demonstrates how the skeleton is protective but also flexible. The rib cage protects the heart and lungs; yet it swings outward and upward upon inspiration and then downward and inward upon expiration. The rib cage also provides support for the bones of the pectoral girdle (see page 97).

The Ribs

There are twelve pairs of ribs. All twelve pairs connect directly to the thoracic vertebrae in the back. After connecting with thoracic vertebrae, each rib first curves outward and then forward and downward. A rib articulates with the body of one vertebra and the transverse processes of two adjoining thoracic vertebra (called facet for tubercle of rib) (see Fig. 6.9).

The upper seven pairs of ribs connect directly to the sternum by means of costal cartilages. These are called the "true ribs," or the vertebrosternal ribs. The next three pairs of ribs are called the "false ribs," or vertebrochondral ribs, because they attach to the sternum by means of a common cartilage. The last two pairs are called "floating ribs," or vertebral ribs, because they do not attach to the sternum at all.

The Sternum

The **sternum,** or breastbone, is a flat bone that has the shape of a blade. The sternum, along with the ribs, helps protect the heart and lungs. During surgery the sternum may be split to allow access to the organs of the thoracic cavity.

The sternum is composed of three bones that fuse during fetal development. These bones are the manubrium, the body, and the xiphoid process. The *manubrium* is the superior portion of the sternum. The *body* is the middle and largest part of the sternum, and the *xiphoid process* is the inferior and smallest portion of the sternum. The manubrium joins with the body of the sternum at an angle. This joint is an important anatomical landmark because it occurs at the level of the second rib, and therefore allows the ribs to be counted. Counting the ribs is sometimes done to determine where the apex of the heart is located—usually between the fifth and sixth ribs.

The manubrium articulates with the costal cartilages of the first and second ribs; the body articulates costal cartilages of the second through tenth ribs; and the xiphoid process doesn't articulate with any ribs.

The xiphoid process is the third part of the sternum. Composed of hyaline cartilage in the child, it becomes ossified in the adult. The variably shaped xiphoid process serves as an attachment site for the diaphragm, which separates the thoracic cavity from the abdominal cavity.

6.3 Appendicular Skeleton

The **appendicular skeleton** contains the bones of the pectoral girdle, upper limbs, pelvic girdle, and lower limbs.

Pectoral Girdle

The **pectoral girdle** (shoulder girdle) contains four bones: two clavicles and two scapulae (Fig. 6.11). It supports the arms and serves as a place of attachment for muscles that move the arms. The bones of this girdle are not held tightly together; rather, they are weakly attached and held in place by ligaments and muscles. This arrangement allows great flexibility but means that the pectoral girdle is prone to dislocation.

Clavicles

The **clavicles** (collarbones) are slender and S-shaped. Each clavicle articulates medially with the manubrium of the sternum. This is the only place where the pectoral girdle is attached to the axial skeleton.

Each clavicle also articulates with a scapula. The clavicle serves as a brace for the scapula and helps stabilize the shoulder. It is structurally weak, however, and if undue force is applied to the shoulder, the clavicle will fracture.

Scapulae

The **scapulae** (sing., scapula), also called the shoulder blades, are broad bones that somewhat resemble triangles (Fig. 6.11*b*). One reason for the pectoral girdle's flexibility is that the scapulae are not joined to each other (see Fig. 6.4).

Each scapula has a spine, as well as the following features:

acromion process, which articulates with a clavicle and provides a place of attachment for arm and chest muscles;
coracoid process, which serves as a place of attachment for arm and chest muscles;
glenoid cavity, which articulates with the head of the arm bone (humerus). The pectoral girdle's flexibility is also a result of the glenoid cavity being smaller than the head of the humerus.

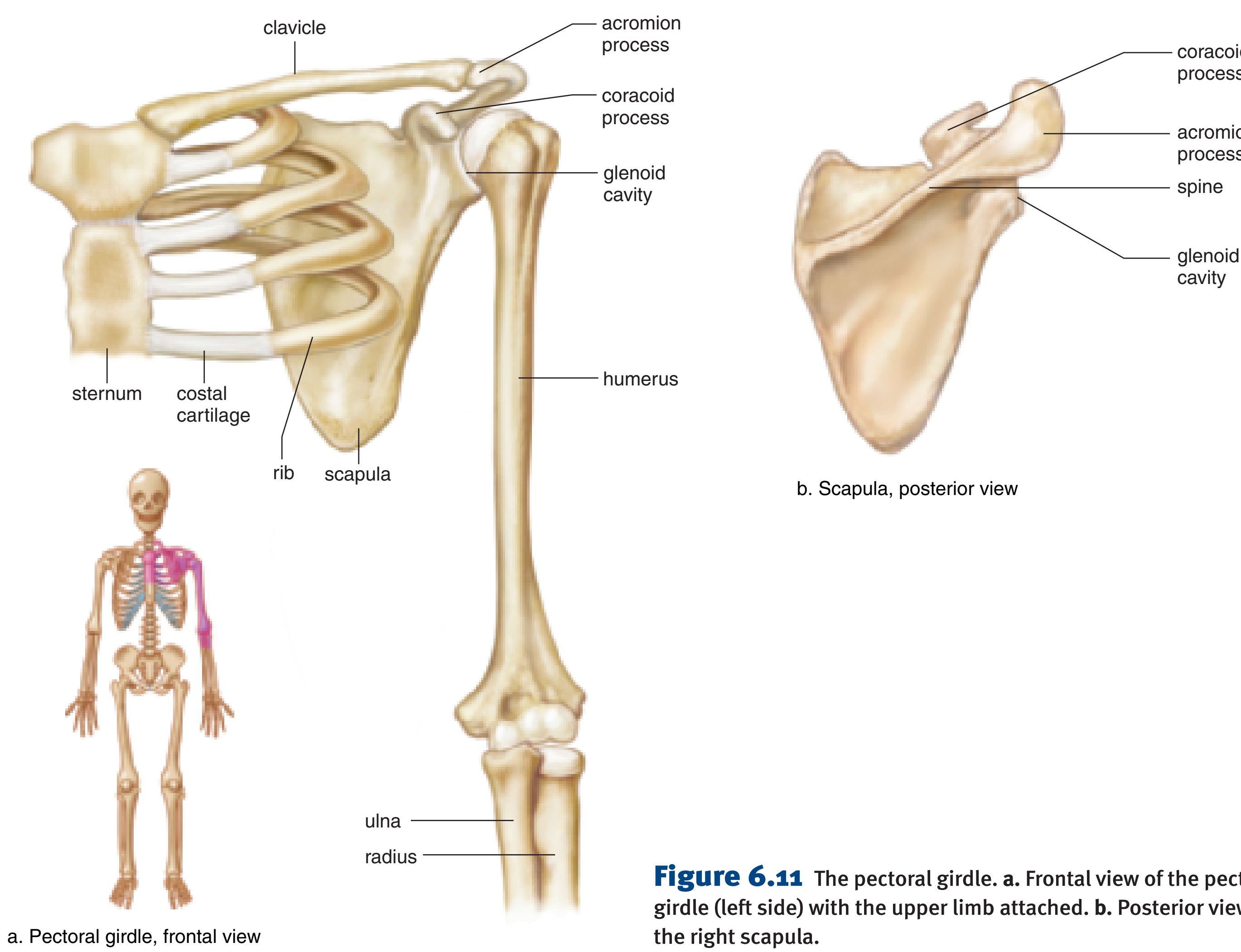
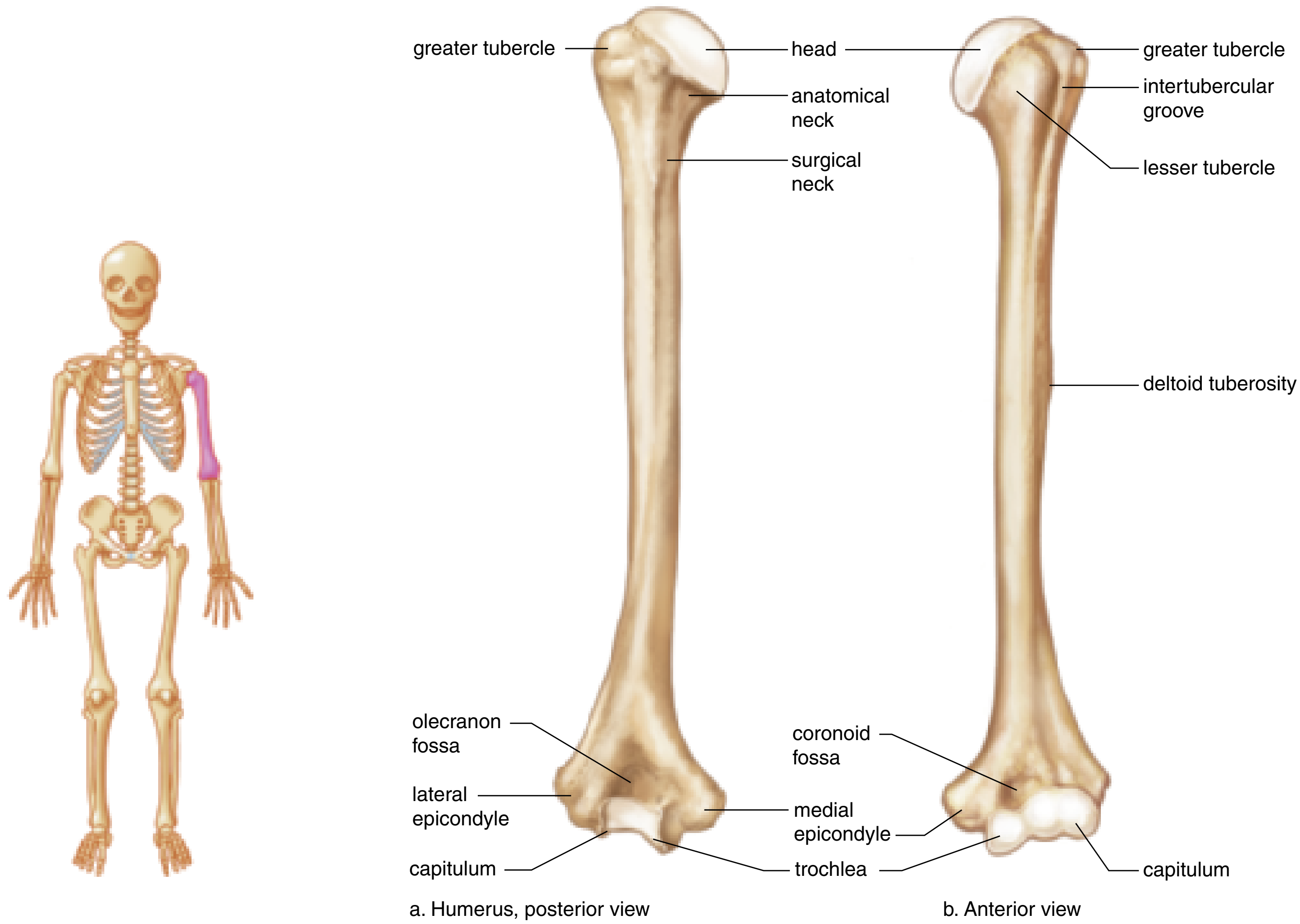


Figure 6.11 **The pectoral girdle. a. Frontal view of the pectoral girdle (left side) with the upper limb attached. b. Posterior view of the right scapula.**

Figure 6.12 Left humerus. **a.** Posterior surface view. **b.** Anterior surface view.



Upper Limb

The upper limb includes the bones of the arm (humerus), the forearm (radius and ulna), and the hand (carpals, metacarpals, and phalanges).[1]

Humerus

The **humerus** (Fig. 6.12) is the bone of the arm. It is a long bone with the following features at the proximal end:

head, which articulates with the glenoid cavity of the scapula;

greater and **lesser tubercles,** which provide attachments for muscles that move the arm and shoulder;

intertubercular groove, which holds a tendon from the biceps brachii, a muscle of the arm;

deltoid tuberosity, which provides an attachment for the deltoid, a muscle that covers the shoulder joint.

The humerus has the following features at the distal end:

capitulum, a lateral condyle that articulates with the head of the radius;

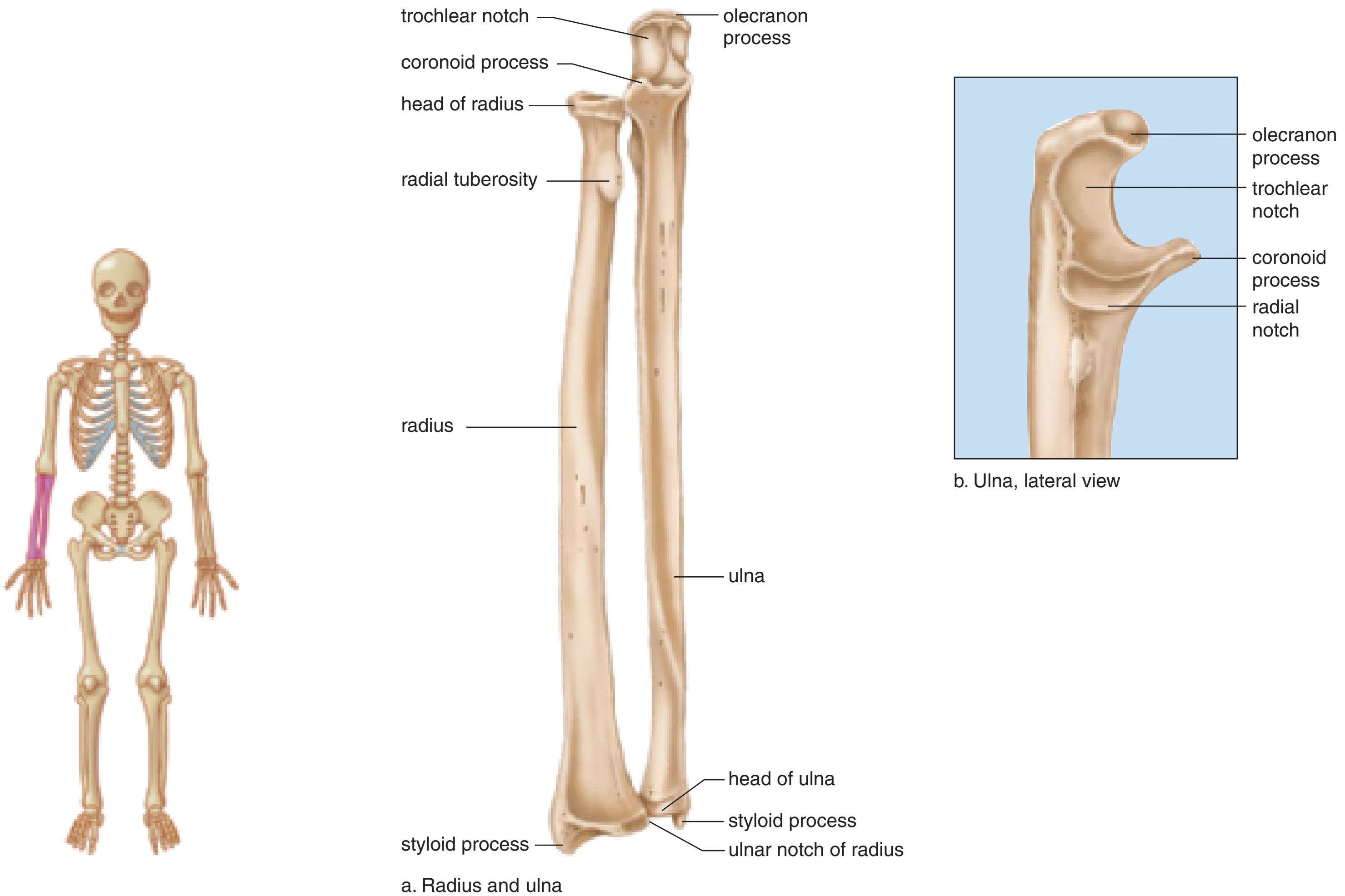
trochlea, a spool-shaped condyle that articulates with the ulna;

coronoid fossa, a depression for a process of the ulna when the elbow is flexed;

olecranon fossa, a depression for a process of the ulna when the elbow is extended.

[1]The term *upper extremity* is used to include a clavicle and scapula (of the pectoral girdle), an arm, forearm, wrist, and hand.

Figure 6.13 Right radius and ulna. **a.** The head of the radius articulates with the radial notch of the ulna. The head of the ulna articulates with the ulnar notch of the radius. **b.** Lateral view of the proximal end of the ulna.



Radius

The **radius** and **ulna** (see Figs. 6.11*a* and 6.13) are the bones of the forearm. The radius is on the lateral side of the forearm (the thumb side). When you turn your hand from the "palms up" position to the "palms down" position, the radius crosses over the ulna, so the two bones are criss-crossed. Proximally, the radius has the following features:

head, which articulates with the capitulum of the humerus and fits into the radial notch of the ulna;
radial tuberosity, which serves as a place of attachment for a tendon from the biceps brachii;

Distally, the radius has the following features:

ulnar notch, which articulates with the head of the ulna;
styloid process, which serves as a place of attachment for ligaments that run to the wrist.

Ulna

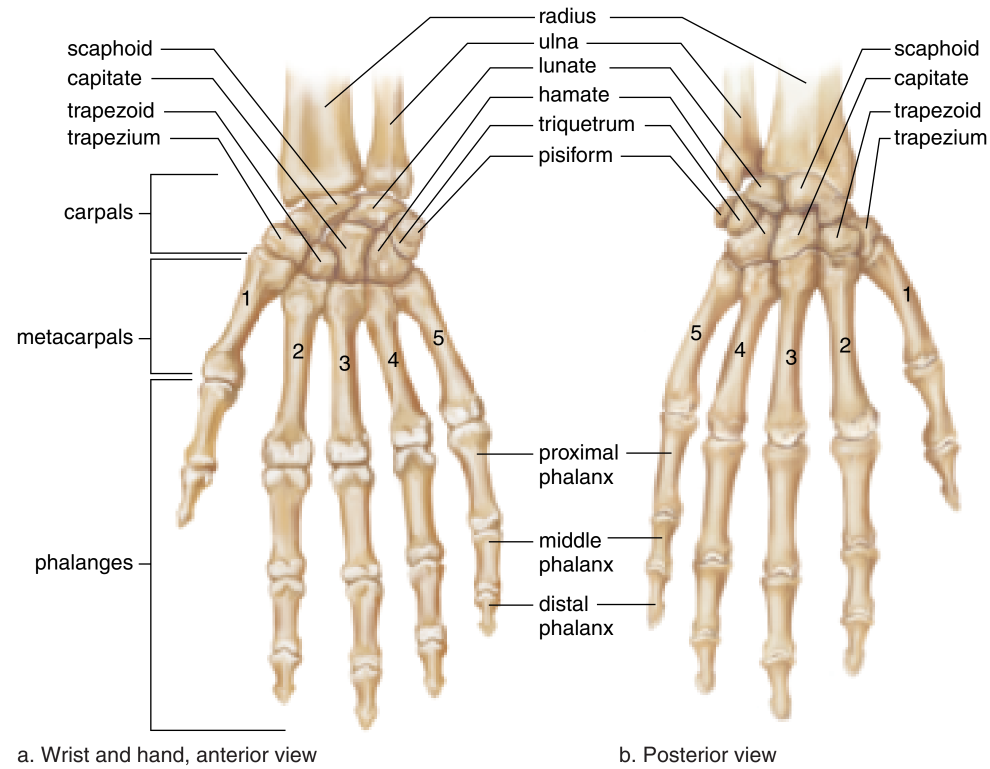
The ulna is the longer bone of the forearm. Proximally, the ulna has the following features:

coronoid process, which articulates with the coronoid fossa of the humerus when the elbow is flexed;
olecranon process, the point of the elbow, articulates with the olecranon fossa of the humerus when the elbow is extended;
trochlear notch, which articulates with the trochlea of the humerus at the elbow joint;
radial notch, which articulates with head of the radius.

Distally, the ulna has the following features:

head, which articulates with the ulnar notch of the radius;
styloid process, which serves as a place of attachment for ligaments that run to the wrist.

Figure 6.14 Right wrist and hand. **a.** Anterior view. **b.** Posterior view.



Hand

Each hand (Fig. 6.14) has a wrist, a palm, and five fingers, or digits.

The wrist, or carpus, contains eight small carpal bones, tightly bound by ligaments in two rows of four each. Where we wear a "wrist watch" is the distal forearm—the true wrist is the proximal part of what we generally call the hand. Only two of the carpals (the scaphoid and lunate) articulate with the radius. Anteriorly, the concave region of the wrist is covered by a ligament, forming the so-called carpal tunnel. Inflammation of the tendons running though this area causes them to compress a nerve and the result is a numbness known as carpal tunnel syndrome.

Five metacarpal bones, numbered 1 to 5 from the thumb side of the hand toward the little finger, fan out to form the palm. When the fist is clenched, the heads of the metacarpals, which articulate with the phalanges, become obvious. The first metacarpal is more anterior than the others, and this allows the thumb to touch each of the other fingers.

The fingers, including the thumb, contain bones called the *phalanges*. The thumb has only two phalanges (proximal and distal), but the other fingers have three each (proximal, middle, and distal).

Pelvic Girdle

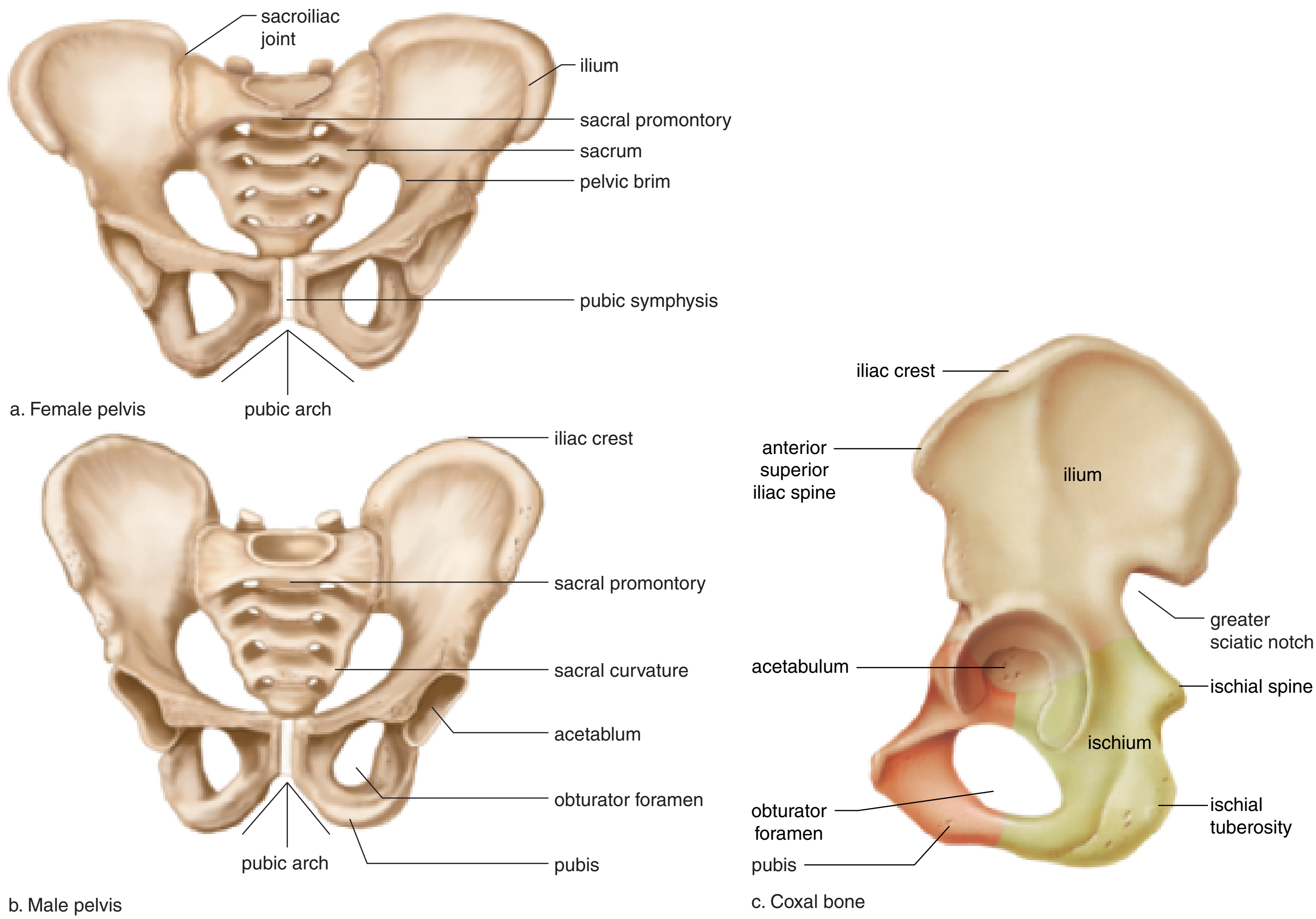
The **pelvic girdle** contains two coxal bones (hipbones), as well as the sacrum and coccyx (Fig. 6.15*a,b*; see Fig. 6.8). The strong bones of the pelvic girdle are firmly attached to one another and bear the weight of the body. The pelvis also serves as the place of attachment for the lower limbs and protects the urinary bladder, the internal reproductive organs, and a portion of the large intestine.

Coxal Bones

Each **coxal bone** has the following three parts:

1. **ilium** (Fig. 6.15). The ilium, the largest part of a coxal bone, flares outward to give the hip prominence. The margin of the ilium is called the iliac crest. Each ilium connects posteriorly with the sacrum at a **sacroiliac joint.**
2. **ischium** (Fig. 6.15*c*). The ischium is the most inferior part of a coxal bone. Its posterior region, the *ischial tuberosity,* allows a person to sit. Near the junction of the ilium and ischium is the **ischial spine,** which projects into the pelvic cavity. The distance between the ischial spines tells the size of the pelvic cavity. The **greater sciatic notch** is the site where blood vessels and the large sciatic nerve pass posteriorly into the lower leg.

Figure 6.15 **The female pelvis is usually wider in all diameters and roomier than that of the male. a. Female pelvis. b. Male pelvis. c. Left coxal bone, lateral view.**



3. **pubis** (Fig. 6.15). The pubis is the anterior part of a coxal bone. The two pubic bones join together at the *pubic symphysis.* Posterior to where the pubis and the ischium join together is a large opening, the *obturator foramen,* through which blood vessels and nerves pass anteriorly into the leg.

Where the three parts of each coxal bone meet is a depression called the **acetabulum,** which receives the rounded head of the femur.

False and True Pelvises

The false pelvis is the portion of the trunk bounded laterally by the flared parts of the ilium. This space is much larger than that of the true pelvis. The true pelvis, which is inferior to the false pelvis, is the portion of the trunk bounded by the sacrum, lower ilium, ischium, and pubic bones. The true pelvis is said to have an upper inlet and a lower outlet. The dimensions of these outlets are important for females because the outlets must be large enough to allow a baby to pass through during the birth process.

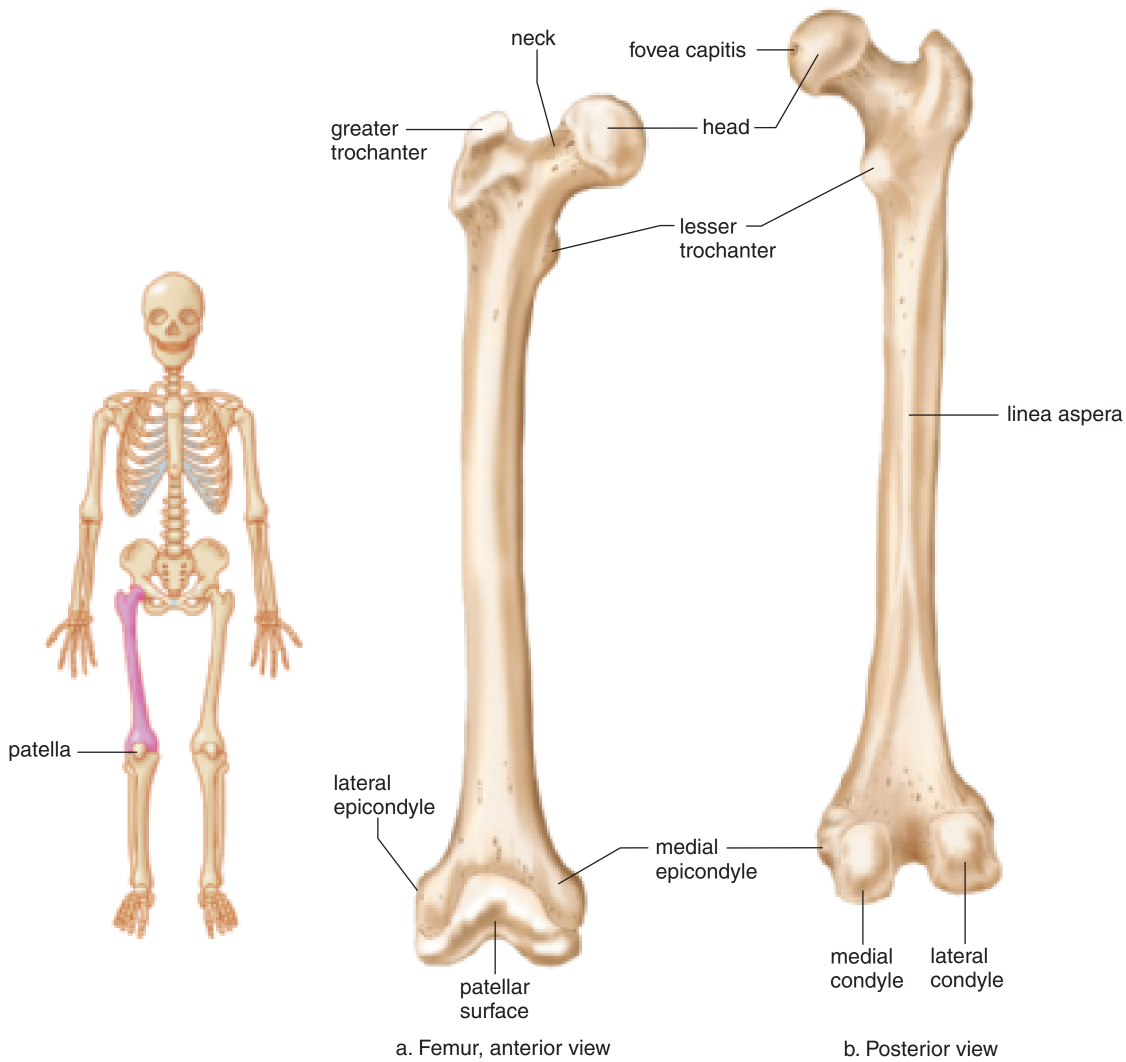
Sex Differences

Female and male pelvises (Fig. 6.15) usually differ in several ways, including the following:

1. Female iliac bones are more flared than those of the male; therefore, the female has broader hips.
2. The female pelvis is wider between the ischial spines and the ischial tuberosities.
3. The female inlet and outlet of the true pelvis are wider.
4. The female pelvic cavity is more shallow, while the male pelvic cavity is more funnel shaped.
5. Female bones are lighter and thinner.
6. The female pubic arch (angle at the pubic symphysis) is wider.

In addition to these differences in pelvic structure, male pelvic bones are larger and heavier, the articular ends are thicker, and the points of muscle attachment may be larger.

Figure 6.16 Right femur. **a.** Anterior view. **b.** Posterior view.



Lower Limb

The lower limb includes the bones of the thigh (femur), the kneecap (patella), the leg (tibia and fibula), and the foot (tarsals, metatarsals, and phalanges).[2]

Femur

The **femur** (Fig. 6.16), or thighbone, is the longest and strongest bone in the body. Proximally, the femur has the following features:

head, which fits into the acetabulum of the coxal bone;
greater and **lesser trochanters,** which provide a place of attachment for the muscles of the thighs and buttocks;
linea aspera, a crest that serves as a place of attachment for several muscles.

Distally, the femur has the following features:

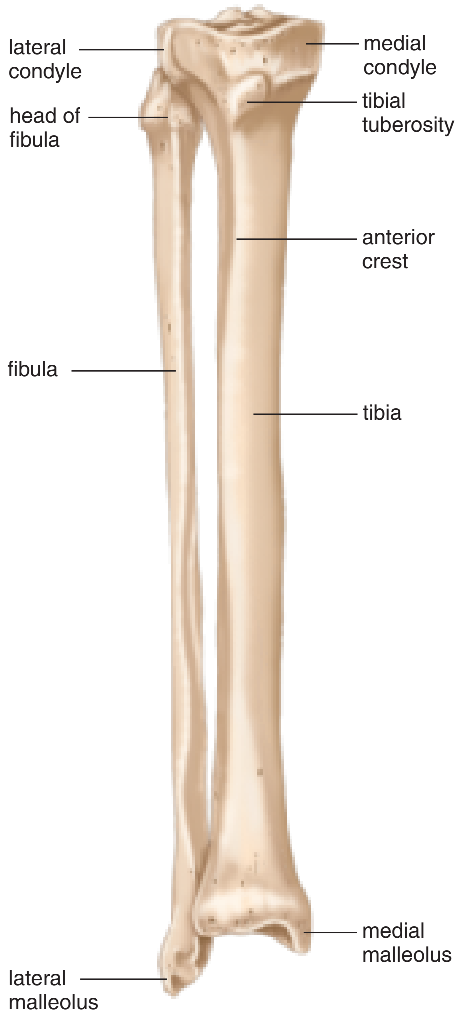
medial and **lateral epicondyles** that serve as sites of attachment for muscles and ligaments;
lateral and **medial condyles** that articulate with the tibia;
patellar surface, which is located between the condyles on the anterior surface, articulates with the **patella,** a small triangular bone that protects the knee joint.

Tibia

The **tibia** and **fibula** (Fig. 6.17) are the bones of the leg. The tibia, or shinbone, is medial to the fibula. It is thicker than the fibula and bears the weight from the femur, with which it articulates. It has the following features:

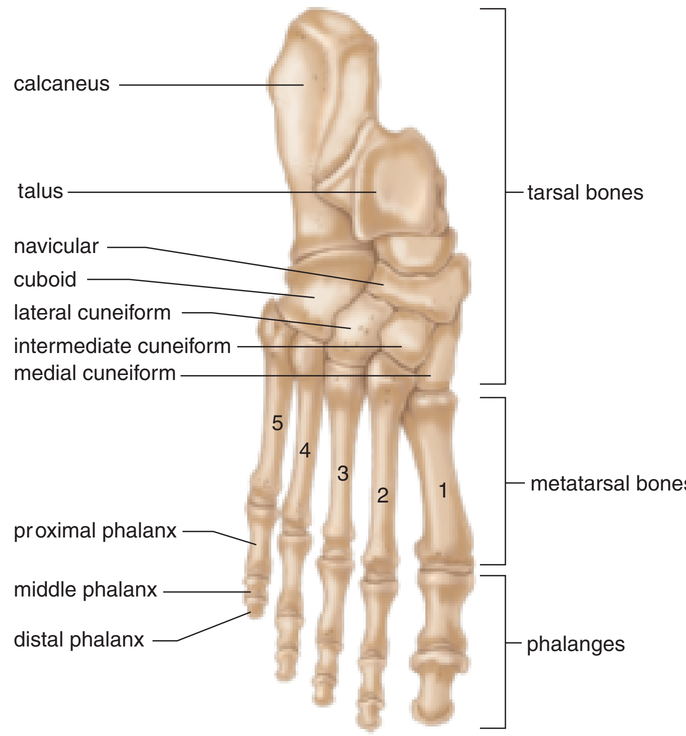
[2] The term *lower extremity* is used to include a coxal bone (of the pelvic girdle), the thigh, kneecap, leg, ankle, and foot.

Figure 6.17 Bones of the right leg, viewed anteriorly.



Leg bones, anterior view

Figure 6.18 The right foot, viewed superiorly.



Right foot, superior view

medial and **lateral condyles,** which articulate with the femur;

tibial tuberosity, where the patellar (kneecap) ligaments attach;

anterior crest, commonly called the shin;

medial malleolus, the bulge of the inner ankle, articulates with the talus in the foot.

Fibula

The fibula is lateral to the tibia and is more slender. It has a head that articulates with the tibia just below the lateral condyle. Distally, the **lateral malleolus** articulates with the talus and forms the outer bulge of the ankle. Its role is to stabilize the ankle.

Foot

Each foot (Fig. 6.18) has an ankle, an instep, and five toes (also called digits).

The ankle has seven **tarsal bones;** together, they are called the tarsus. Only one of the seven bones, the **talus,** can move freely where it joins the tibia and fibula. The largest of the ankle bones is the **calcaneus,** or heel bone. Along with the talus, it supports the weight of the body.

The instep has five elongated **metatarsal bones.** The distal ends of the metatarsals form the ball of the foot. Along with the tarsals, these bones form the arches of the foot (longitudinal and transverse), which give spring to a person's step. If the ligaments and tendons holding these bones together weaken, fallen arches, or "flat feet," can result.

The toes contain the **phalanges.** The big toe has only two phalanges, but the other toes have three each.

6.4 Joints (Articulations)

Bones articulate at the **joints,** which are often classified according to the amount of movement they allow:

Fibrous joints are immovable. Fibrous connective tissue joins bone to bone.
Cartilaginous joints are slightly movable. Fibrocartilage is located between two bones.
Synovial joints are freely movable. In these joints, the bones do not come in contact with each other.

Fibrous Joints

Some bones, such as those that make up the cranium, are sutured together by a thin layer of fibrous connective tissue and are *immovable.* Review Figures 6.6 and 6.7, and note the following immovable sutures:

coronal suture, between the parietal bones and the frontal bone;
lambdoidal suture, between the parietal bones and the occipital bone;
squamosal suture, between each parietal bone and each temporal bone;
sagittal suture, between the parietal bones (not shown).

Cartilaginous Joints

Slightly movable joints are those in which the bones are joined by fibrocartilage. The ribs are joined to the sternum by costal cartilages (see Fig. 6.10). The *bodies* of adjacent vertebrae are separated by intervertebral disks (see Fig. 6.8) that increase vertebral flexibility. The **pubic symphysis,** which occurs between the pubic bones (see Fig. 6.15), consists largely of fibrocartilage. Due to hormonal changes, this joint becomes more flexible during late pregnancy, which allows the pelvis to expand during childbirth.

Synovial Joints

All synovial joints are freely movable because, unlike the joints discussed so far, the two bones are separated by a *joint cavity* (Figs. 6.19 and 6.20). The cavity is lined by a **synovial membrane,** which produces **synovial fluid,** a lubricant for the joint. The absence of tissue between the articulating bones allows them to be freely movable but means that the joint has to be stabilized in some way.

The joint is stabilized by the joint capsule, a sleevelike extension of the periosteum of each articulating bone. **Ligaments,** which are composed of dense regular connective tissue, bind the two bones to one another and add even more stability. Tendons, which are cords of dense fibrous connective tissue that connect muscle to bone, also help stabilize a synovial joint.

The articulating surfaces of the bones are protected in several ways. The bones are covered by a layer of articular (hyaline) cartilage. In addition, the joint, such as the knee, contains **menisci** (sing., *meniscus*), crescent-shaped pieces of cartilage and fluid-filled sacs called **bursae,** which ease friction between all parts of the joint. Inflammation of the bursae is called **bursitis.** Tennis elbow is a form of bursitis.

Figure 6.19 **Generalized anatomy of a synovial joint.**

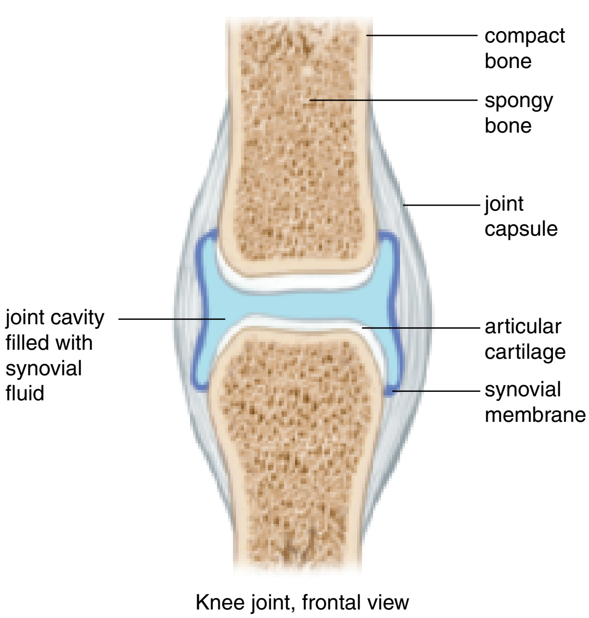


Figure 6.20 **The knee joint. Notice the menisci and bursae associated with the knee joint.**

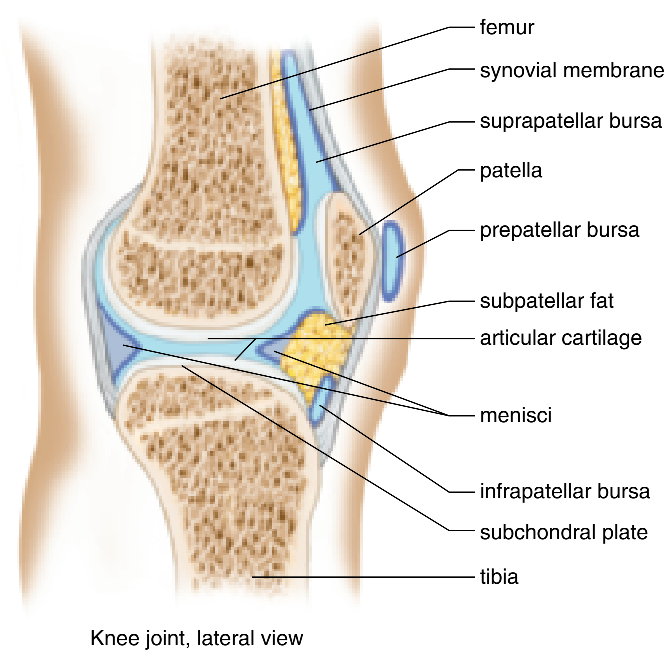
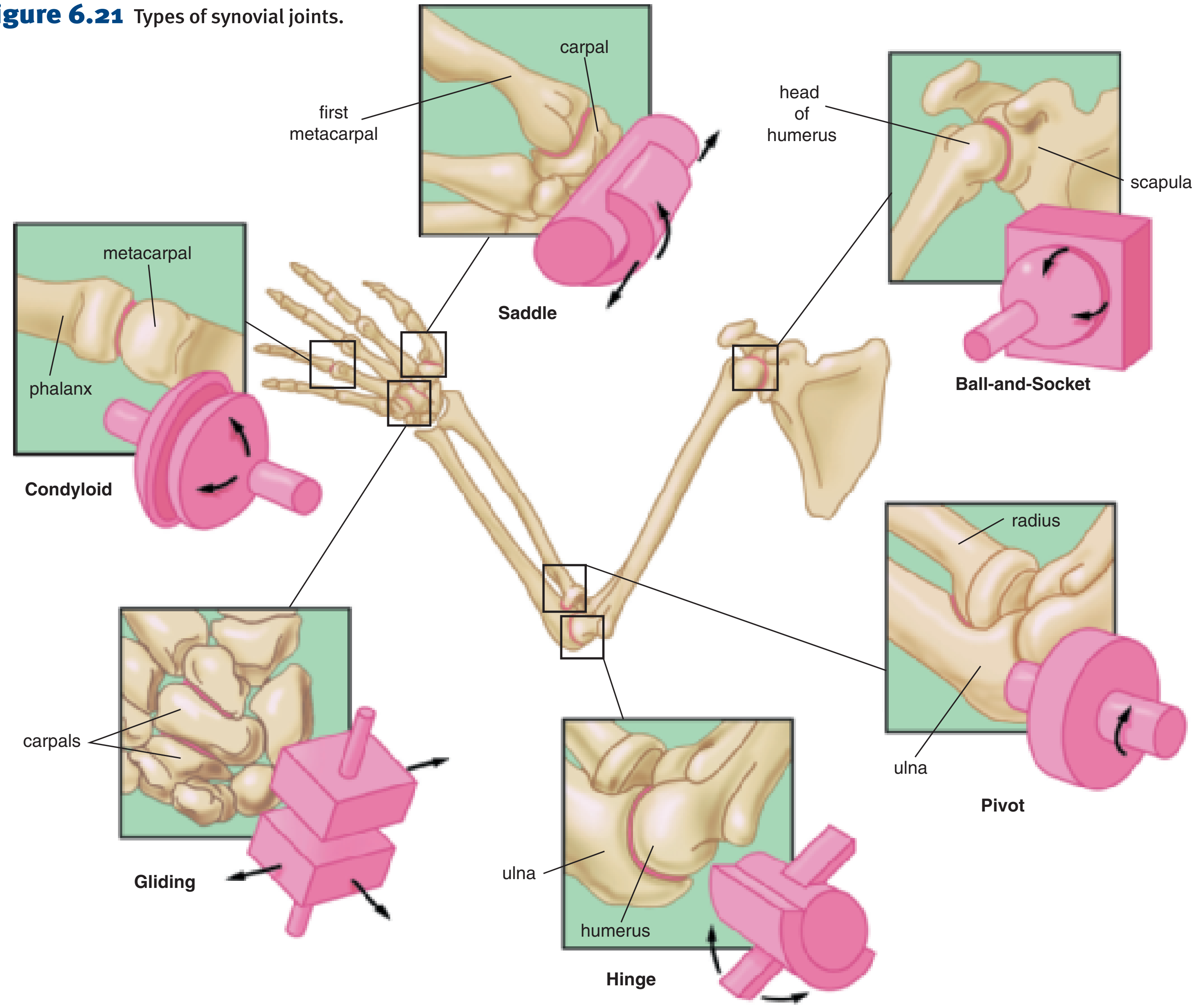


Figure 6.21 Types of synovial joints.



Types of Synovial Joints

Different types of freely movable joints are listed here and depicted in Figure 6.21.

Saddle joint. Each bone is saddle-shaped and fits into the complementary regions of the other. A variety of movements are possible. *Example*: the joint between the carpal and metacarpal bones of the thumb.

Ball-and-socket joint. The ball-shaped head of one bone fits into the cup-shaped socket of another. Movement in all planes, as well as rotation, are possible. *Examples*: the shoulder and hip joints.

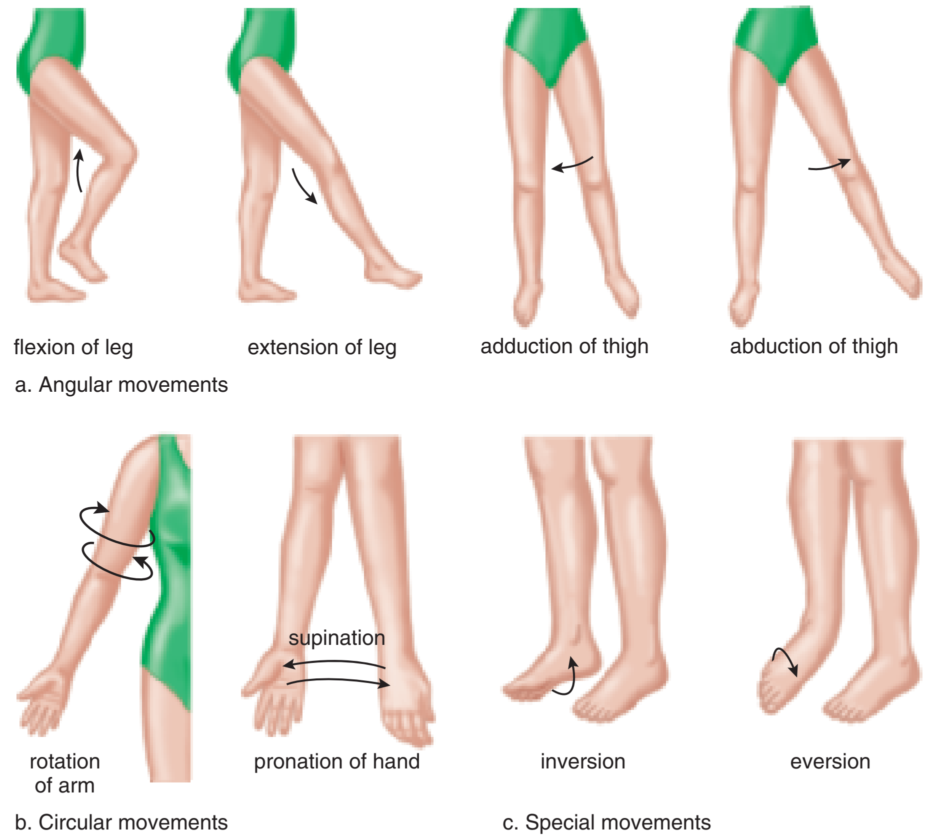
Pivot joint. A small, cylindrical projection of one bone pivots within the ring formed of bone and ligament of another bone. Only rotation is possible. *Examples*: the joint between the proximal ends of the radius and ulna, and the joint between the atlas and axis.

Hinge joint. The convex surface of one bone articulates with the concave surface of another. Up-and-down motion in one plane is possible. *Examples*: the elbow and knee joints.

Gliding joint. Flat or slightly curved surfaces of bones articulate. Sliding or twisting in various planes is possible. *Examples*: the joints between the bones of the wrist and between the bones of the ankle.

Condyloid joint. The oval-shaped condyle of one bone fits into the elliptical cavity of another. Movement in different planes is possible, but rotation is not. *Examples*: the joints between the metacarpals and phalanges.

Figure 6.22 Joint movements. **a.** Angular movements increase or decrease the angle between the bones of a joint. **b.** Circular movements describe a circle or part of a circle. **c.** Special movements are unique to certain joints.



Movements Permitted by Synovial Joints

Skeletal muscles are attached to bones by tendons that cross joints. When a muscle contracts, one bone moves in relation to another bone. The more common types of movements are described here.

Angular Movements (Fig. 6.22*a*):

Flexion decreases the joint angle. Flexion of the elbow moves the forearm toward the arm; flexion of the knee moves the leg toward the thigh. *Dorsiflexion* is flexion of the foot upward, as when you stand on your heels; *plantar flexion* is flexion of the foot downward, as when you stand on your toes.

Extension increases the joint angle. Extension of the flexed elbow straightens the upper limb. Hyperextension occurs when a portion of the body part is extended beyond 180°. It is possible to hyperextend the head and the trunk of the body, and also the shoulder and wrist (arm and hand).

Adduction is the movement of a body part toward the midline. For example, adduction of the arms or legs moves them back to the sides, toward the body.

Abduction is the movement of a body part laterally, away from the midline. Abduction of the arms or legs moves them laterally, away from the body.

Circular Movements (Fig. 6.22*b*):

Circumduction is the movement of a body part in a wide circle, as when a person makes arm circles. Careful observation of the motion reveals that, because the proximal end of the arm is stationary, the shape outlined by the arm is actually a cone.

Rotation is the movement of a body part around its own axis, as when the head is turned to answer "no" or when the arm is twisted toward the trunk (medial rotation) and away from the trunk (lateral rotation).

Supination is the rotation of the forearm so that the palm is upward; **pronation** is the opposite—the movement of the forearm so that the palm is downward.

Special movements (Fig. 6.22*c*):

Inversion and **eversion** apply only to the feet. Inversion is turning the foot so that the sole faces inward, and eversion is turning the foot so that the sole faces outward.

Elevation and **depression** refer to the lifting up and down, respectively, of a body part, as when you shrug your shoulders or move your jaw up and down.

Coaxing the Chondrocytes for Knee Repair

To the young, otherwise healthy, 30-something athlete on the physician's exam table, the diagnosis must seem completely unfair. Perhaps he's a former football player, or she's a trained dancer. Whatever the sport or activity, the patient is slender and fit, but knee pain and swelling are this athlete's constant companions. Examination of the knee shows the result of decades of use and abuse while performing a sport: The hyaline cartilage, also called articular cartilage, of the knee joint has degenerated. Hyaline cartilage (see page 84) is the "Teflon coating" for the bones of freely movable joints such as the knee. Hyaline cartilage allows easy, frictionless movement between the bones of the joint. Once repeated use has worn it away, hyaline cartilage does not grow back naturally. Exposed bone ends can grind against one another, resulting in pain, swelling, and restricted movements that can cripple the athlete. In severe cases, total knee replacement with a prosthetic joint is the athlete's only option (Fig. 6B).

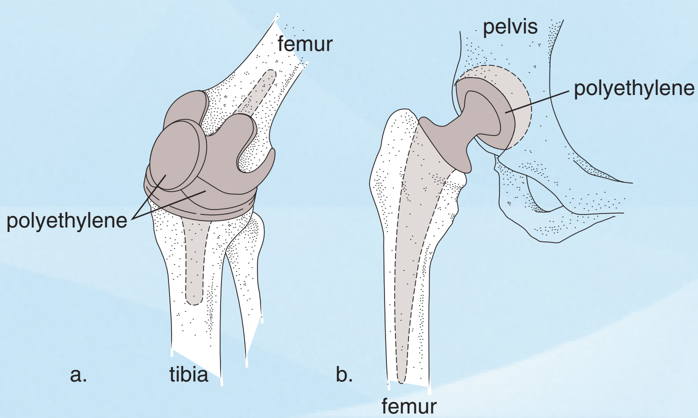


Figure 6B **Artificial joints in which polyethylene replaces articular cartilage. a. Knee. b. Hip.**

Now the technique of tissue culture (growing cells outside of the patient's body in a special medium) can help young athletes with cartilage injuries regenerate their own hyaline cartilage. In an autologous chondrocyte implantation (ACI) surgery, a piece of healthy hyaline cartilage from the patient's knee is first removed surgically. This piece of cartilage, about the size of a pencil eraser, is typically taken from an undamaged area at the top edge of the knee. The chondrocytes, living cells of hyaline cartilage, are grown outside the body in tissue culture medium. Millions of the patient's own cells can be grown to create a "patch" of living cartilage. Growing these cells takes two to three weeks. Once the chondrocytes have grown, a pocket is created over the damaged area using the patient's own periosteum, the connective tissue that surrounds the bone (see page 84). The periosteum pocket will hold the hyaline cartilage cells in place. The cells are injected into the pocket and left to grow.

As with all injuries to the knee, once the cartilage cells are firmly established, the patient still faces a lengthy rehabilitation. The patient must use crutches or a cane for three to four months to protect the joint. Physical therapy will stimulate cartilage growth without overstressing the area being repaired. In six months, the athlete can return to light-impact training and jogging. Full workouts can be resumed in about one year after surgery. However, most patients regain full mobility and a pain-free life after ACI surgery and do not have to undergo total knee replacement.

ACI surgery can't be used for the elderly or for overweight patients with osteoarthritis. Muscle or bone defects in the knee joint must be corrected before the surgery can be attempted. As with all surgeries, there is a risk for postoperative complications, such as bleeding or infection. However, ACI may offer young athletes the chance to restore essential hyaline cartilage and regain a healthy, functional knee joint.

6.5 Effects of Aging

Both cartilage and bone tend to deteriorate as a person ages. The chemical nature of cartilage changes, and the bluish color typical of young cartilage changes to an opaque, yellowish color. The chondrocytes die, and reabsorption occurs as the cartilage undergoes calcification, becoming hard and brittle. Calcification interferes with the ready diffusion of nutrients and waste products through the matrix. The articular cartilage may no longer function properly, and the symptoms of arthritis can appear. There are three common types of arthritis: (1) **Osteoarthritis** is accompanied by deterioration of the articular cartilage. (2) In **rheumatoid arthritis,** the synovial membrane becomes inflamed and grows thicker cartilage, possibly due to an autoimmune reaction. (3) Gout, or gouty arthritis, is caused by an excessive buildup of uric acid (a metabolic waste) in the blood. Rather than being excreted in the urine, the acid is deposited as crystals in the joints, where it causes inflammation and pain.

Osteoporosis, discussed in the Medical Focus on page 88, is present when weak and thin bones cause aches and pains. Such bones tend to fracture easily.

6.6 Homeostasis

The illustration in Human Systems Work Together on page 109 tells how the skeletal system assists other systems (buff color) and how other systems assist the skeletal system (aqua color). Let's review again the functions of the skeletal system, but this time as they relate to the other systems of the body.

Functions of the Skeletal System

The bones protect the internal organs. The rib cage protects the heart and lungs; the skull protects the brain; and the vertebrae protect the spinal cord. The endocrine organs, such as the pituitary gland, pineal gland, thymus, and thyroid gland, are also protected by bone. The nervous system and the endocrine system work together to control the other organs and, ultimately, homeostasis.

The bones assist all phases of respiration (Fig. 6.23). The rib cage assists the breathing process, enabling oxygen to enter the blood, where it is transported by red blood cells to the tissues. Red bone marrow produces the blood cells, including the red blood cells that transport oxygen. Without a supply of oxygen, the cells of the body could not efficiently produce ATP. ATP is needed for muscle contraction and for nerve conduction as well as for the many synthesis reactions that occur in cells.

The bones store and release calcium. The storage of calcium in the bones is under hormonal control. A dynamic equilibrium is maintained between the concentrations of calcium in the bones and in the blood. Calcium ions play a major role in muscle contraction and nerve conduction. Calcium ions also help regulate cellular metabolism. Protein hormones, which cannot enter cells, are called the first messenger, and a second messenger such as calcium ions jump-starts cellular metabolism, directing it to proceed in a particular way.

The bones assist the lymphatic system and immunity. Red bone marrow produces not only the red blood cells but also the white blood cells. The white cells, which congregate in the lymphatic organs, are involved in defending the body against pathogens and cancerous cells. Without the ability to withstand foreign invasion, the body may quickly succumb to disease and die.

The bones assist digestion. The jaws contain sockets for the teeth, which chew food, and a place of attachment for the muscles that move the jaws. Chewing breaks food into pieces small enough to be swallowed and chemically digested. Without digestion, nutrients would not enter the body to serve as building blocks for repair and a source of energy for the production of ATP.

The skeleton is necessary to locomotion. Locomotion is efficient in human beings because they have a jointed skeleton for the attachment of muscles that move the bones. Our jointed skeleton allows us to seek out and move to a more suitable external environment in order to maintain the internal environment within reasonable limits.

Functions of Other Systems

How do the other systems of the body help the skeletal system carry out its functions?

The integumentary system and the muscles help the skeletal system protect internal organs. For example, anteriorally, the abdominal organs are only protected by muscle and skin.

The digestive system absorbs the calcium from food so that it enters the body. The plasma portion of blood transports calcium from the digestive system to the bones and any other organs that need it. The endocrine system regulates the storage of calcium in the bones.

The thyroid gland, a lymphatic organ, is instrumental in the maturity of certain white blood cells produced by the red bone marrow. The cardiovascular system transports the red blood cells as they deliver oxygen to the tissues and as they return to the lungs where they pick up oxygen.

Movement of the bones would be impossible without contraction of the muscles. In these and other ways, the systems of the body help the skeletal systems carry out its functions.

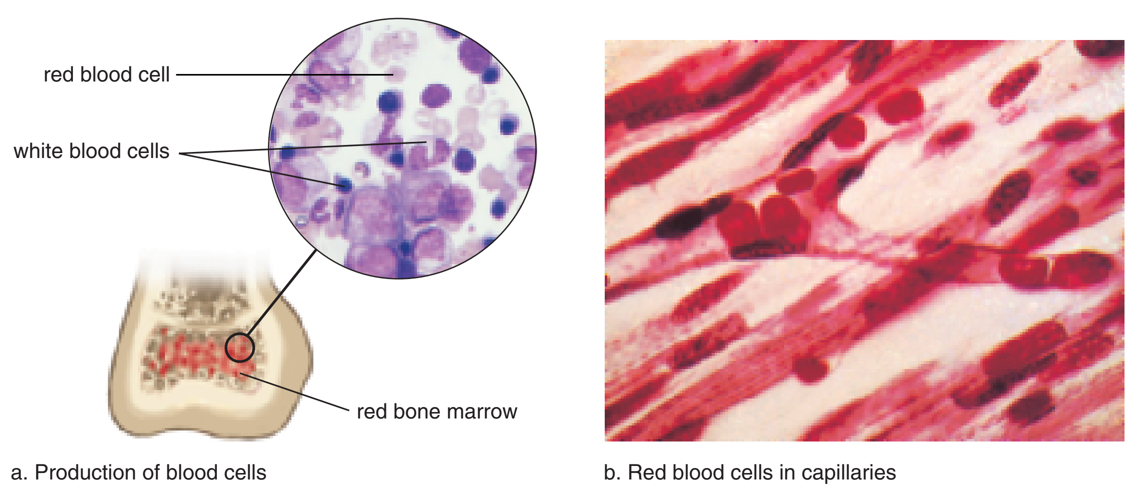
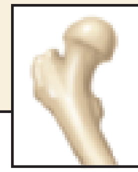


Figure 6.23 **The skeletal system and cardiovascular system work together. a. Red bone marrow produces the blood cells, including the red and white blood cells. b. As the red blood cells pass through the capillaries, they deliver oxygen to the body's cells. Some white blood cells exit blood and enter the tissues at capillaries, where they phagocytize pathogens. Others stay in the blood (and lymph), where they produce antibodies against invaders.**

Human Systems Work Together

How the Skeletal System works with other body systems



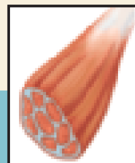
Integumentary System

Bones provide support for skin.

Skin protects bones; helps provide vitamin D for Ca^{2+} absorption.

Muscular System

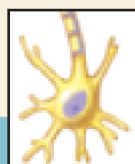
Bones provide attachment sites for muscles; store Ca^{2+} for muscle function.



Muscular contraction causes bones to move joints; muscles help protect bones.

Nervous System

Bones protect sense organs, brain, and spinal cord; store Ca^{2+} for nerve function.



Receptors send sensory input from bones to joints.

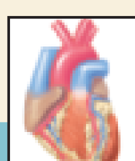
Endocrine System

Bones provide protection for glands; store Ca^{2+} used as second messenger.

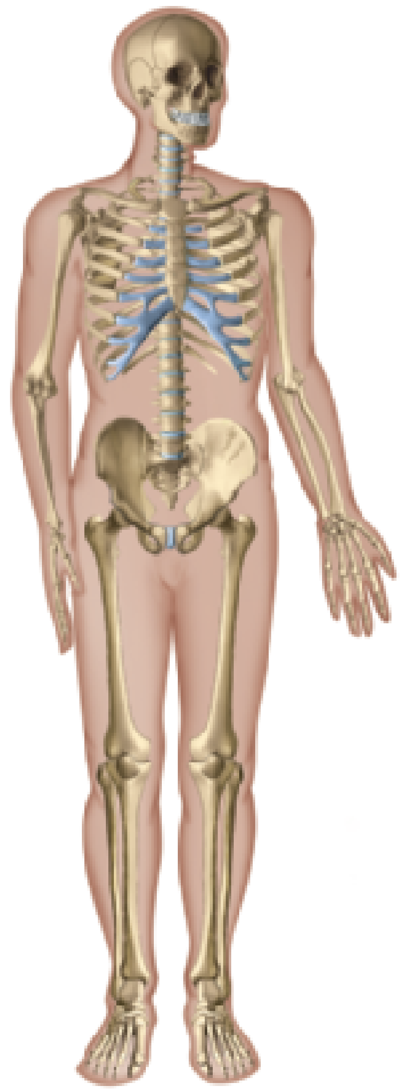
Growth hormone regulates bone development; parathyroid hormone and calcitonin regulate Ca^{2+} content.

Cardiovascular System

Rib cage protects heart; red bone marrow produces blood cells; bones store Ca^{2+} for blood clotting.



Blood vessels deliver nutrients and oxygen to bones, carry away wastes.



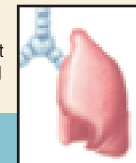
Lymphatic System/Immunity

Red bone marrow produces white blood cells involved in immunity.

Lymphatic vessels pick up excess tissue fluid; immune system protects against infections.

Respiratory System

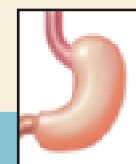
Rib cage protects lungs and assists breathing; bones provide attachment sites for muscles involved in breathing.



Gas exchange in lungs provides oxygen and rids body of carbon dioxide.

Digestive System

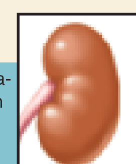
Jaws contain teeth that chew food; hyoid bone assists swallowing.



Digestive tract provides Ca^{2+} and other nutrients for bone growth and repair.

Urinary System

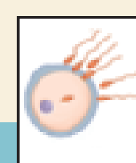
Bones provide support and protection.



Kidneys provide active vitamin D for Ca^{2+} absorption and help maintain blood level of Ca^{2+}, needed for bone growth and repair.

Reproductive System

Bones provide support and protection of reproductive organs.



Sex hormones influence bone growth and density in males and females.

Selected New Terms

Basic Key Terms

abduction (ab-duk′shun), p. 106
adduction (uh-duk′shun), p. 106
appendicular skeleton (ap″en-dik′yū-ler skel′ĕ-ton), p. 97
articular cartilage (ar-tik′yū-ler kar′tĭ-lij), p. 84
articulation (ar-tik″yū-la′shun), p. 84
axial skeleton (ak′se-al skel′ĕ-ton), p. 89
bursa (bur′suh), p. 104
circumduction (ser″kum-duk′shun), p. 106
compact bone (kom′pakt bōn), p. 84
diaphysis (di-af′ĭ-sis), p. 84
epiphyseal plate (ep″ĭ-fiz′e-al plāt), p. 86
epiphysis (ĕ-pif′ĭ-sis), p. 84
eversion (e-ver′zhun), p. 106
extension (ek-sten′shun), p. 106
flexion (flek′shun), p. 106
fontanel (fon″tuh-nel′), p. 90
hematopoiesis (hem″ah-to-poi-e′sis), p. 84
intervertebral disk (in″ter-ver′tĕ-bral disk), p. 94
inversion (in-ver′zhun), p. 106
ligament (lig′uh-ment), p. 104
medullary cavity (med′u-lār″e kav′ĭ-te), p. 84
meniscus (mĕ-nis′kus), p. 104
ossification (os′-ĭ-fĭ-ka′shun), p. 86
osteoblast (os′te-o-blast″), p. 86
osteoclast (os′te-o-klast″), p. 86
osteocyte (os′te-o-sīt), p. 86
pectoral girdle (pek′tor-al ger′dl), p. 97
pelvic girdle (pel′vik ger′dl), p. 100
periosteum (per″e-os′te-um), p. 84
pronation (pro-na′shun), p. 106
red bone marrow (red bōn mār′o), p. 84
rotation (ro-ta′shun), p. 106
sinus (si′nus), p. 90
spongy bone (spunj′e bōn), p. 84
supination (su″pĭ-na′shun), p. 106
suture (su′cher), p. 90
synovial fluid (si-no′ve-al flu′id), p. 104
synovial joint (si-no′ve-al joint), p. 104
synovial membrane (si-no′ve-al mem′brān), p. 104
vertebral column (ver′tĕ-bral kah′lum), p. 94

Clinical Key Terms

bursitis (ber-si′tis), p. 104
fracture (frak′cher), p. 87
herniated disk (her′ne-a-ted disk), p. 94
kyphosis (ki-fo′sis), p. 94
lordosis (lor-do′sis), p. 94
mastoiditis (mas″toi-di′tis), p. 90
osteoarthritis (os″te-o-ar-thri′tis), p. 107
osteoporosis (os″te-o-po-ro′sis), p. 107
rheumatoid arthritis (ru′muh-toid ar-thri′tis), p. 107
scoliosis (sko″le-o′sis), p. 94

Summary

6.1 Skeleton: Overview

A. The skeleton supports and protects the body; produces red blood cells; serves as a storehouse for inorganic calcium and phosphate ions and fat; and permits flexible movement.

B. A long bone has a shaft (diaphysis) and two ends (epiphyses), which are covered by articular cartilage. The diaphysis contains a medullary cavity with yellow marrow and is bounded by compact bone. The epiphyses contain spongy bone with red bone marrow that produces red blood cells.

C. Bone is a living tissue. It develops, grows, remodels, and repairs itself. In all these processes, osteoclasts break down bone, and osteoblasts build bone.

D. Fractures are of various types, but repair requires four steps: (1) hematoma, (2) fibrocartilaginous callus, (3) bony callus, and (4) remodeling.

6.2 Axial Skeleton

The axial skeleton lies in the midline of the body and consists of the skull, the hyoid bone, the vertebral column, and the thoracic cage.

A. The skull is formed by the cranium and the facial bones. The cranium includes the frontal bone, two parietal bones, one occipital bone, two temporal bones, one sphenoid bone, and one ethmoid bone. The facial bones include two maxillae, two palatine bones, two zygomatic bones, two lacrimal bones, two nasal bones, the vomer bone, two inferior nasal conchae, and the mandible.

B. The U-shaped hyoid bone is located in the neck. It anchors the tongue and does not articulate with any other bone.

C. The typical vertebra has a body, a vertebral arch surrounding the vertebral foramen, and a spinous process. The first two vertebrae are the atlas and axis. The vertebral column has four curvatures and contains the cervical, thoracic, lumbar, sacral, and coccygeal vertebrae, which are separated by intervertebral disks.

D. The rib cage contains the thoracic vertebrae, ribs and associated cartilages, and the sternum.

6.3 Appendicular Skeleton
The appendicular skeleton consists of the bones of the pectoral girdle, upper limbs, pelvic girdle, and lower limbs.

A. The pectoral (shoulder) girdle contains two clavicles and two scapulae.
B. The upper limb contains the humerus, the radius, the ulna, and the bones of the hand (the carpals, metacarpals, and phalanges).
C. The pelvic girdle contains two coxal bones, as well as the sacrum and coccyx. The female pelvis is generally wider and more shallow than the male pelvis.
D. The lower limb contains the femur, the patella, the tibia, the fibula, and the bones of the foot (the tarsals, metatarsals, and phalanges).

6.4 Joints (Articulations)

A. Joints are regions of articulation between bones. They are classified according to their degree of movement. Some joints are immovable, some are slightly movable, and some are freely movable (synovial). The different kinds of synovial joints are ball-and-socket, hinge, condyloid, pivot, gliding, and saddle.
B. Movements at joints are broadly classified as angular (flexion, extension, adduction, abduction); circular (circumduction, rotation, supination, and pronation); and special (inversion, eversion, elevation, and depression).

6.5 Effects of Aging
Two fairly common effects of aging on the skeletal system are arthritis and osteoporosis.

6.6 Homeostasis

A. The bones protect the internal organs: The rib cage protects the heart and lungs; the skull protects the brain; and the vertebrae protect the spinal cord.
B. The bones assist all phases of respiration. The rib cage assists the breathing process, and red bone marrow produces the red blood cells that transport oxygen.
C. The bones store and release calcium. Calcium ions play a major role in muscle contraction and nerve conduction. Calcium ions also help regulate cellular metabolism.
D. The bones assist the lymphatic system and immunity. Red bone marrow produces not only the red blood cells but also the white blood cells.
E. The bones assist digestion. The jaws contain sockets for the teeth, which chew food, and a place of attachment for the muscles that move the jaws.
F. The skeleton is necessary for locomotion. Locomotion is efficient in human beings because they have a jointed skeleton for the attachment of muscles that move the bones.

Study Questions

1. What are five functions of the skeleton? (p. 84)
2. What are five major categories of bones based on their shapes? (p. 84)
3. What are the parts of a long bone? What are some differences between compact bone and spongy bone? (pp. 84–85)
4. How does bone grow in children, and how is it remodeled in all age groups? (pp. 86–87)
5. What are the various types of fractures? What four steps are required for fracture repair? (p. 87)
6. List the bones of the axial and appendicular skeletons. (Fig. 6.4, p. 89)
7. What are the bones of the cranium and the face? What are the special features of the temporal bones, sphenoid bone, and ethmoid bone? (pp. 90–93)
8. What are the parts of the vertebral column, and what are its curvatures? Distinguish between the atlas, axis, sacrum, and coccyx. (pp. 94–95)
9. What are the bones of the rib cage, and what are several of its functions? (p. 96)
10. What are the bones of the pectoral girdle? Give examples to demonstrate the flexibility of the pectoral girdle. What are the special features of a scapula? (p. 97)
11. What are the bones of the upper limb? What are the special features of these bones? (pp. 98–100)
12. What are the bones of the pelvic girdle, and what are their functions? (pp. 100–101)
13. What are the false and true pelvises, and what are several differences between the male and female pelvises? (p. 101)
14. What are the bones of the lower limb? Describe the special features of these bones. (pp. 102–3)
15. How are joints classified? Give examples of each type of joint. (p. 104)
16. How can joint movements permitted by synovial joints be categorized? Give an example of each category. (p. 106)
17. How does aging affect the skeletal system? (p. 107)
18. What functions of the skeletal system are particularly helpful in maintaining homeostasis? (pp. 108–9)

Objective Questions

I. Match the items in the key to the bones listed in questions 1–6.

Key:

a. forehead
b. chin
c. cheekbone
d. elbow
e. shoulder blade
f. hip
g. ankle

1. temporal and zygomatic bones
2. tibia and fibula
3. frontal bone
4. ulna
5. coxal bone
6. scapula

II. Match the items in the key to the bones listed in questions 7–13.

Key:

a. external auditory meatus
b. cribriform plate
c. xiphoid process
d. glenoid cavity
e. olecranon process
f. acetabulum
g. greater and lesser trochanters

7. scapula
8. sternum
9. femur
10. temporal bone
11. coxal bone
12. ethmoid bone
13. ulna

III. Fill in the blanks.

14. Long bones are ________________ than they are wide.
15. The epiphysis of a long bone contains ________________ bone, where red blood cells are produced.
16. The ________________ are the air-filled spaces in the cranium.
17. The sacrum is a part of the ________________ , and the sternum is a part of the ________________ .
18. The pectoral girdle is specialized for ________________ , while the pelvic girdle is specialized for ________________ .
19. The term *phalanges* is used for the bones of both the ________________ and the ________________ .
20. The knee is a freely movable (synovial) joint of the ________________ type.

Medical Terminology Reinforcement Exercise

Consult Appendix B for help in pronouncing and analyzing the meaning of the terms that follow.

1. chondromalacia (kon″dro-muh-la′ she-uh)
2. osteomyelitis (os″te-o-mi″e-li′tis)
3. craniosynostosis (kra″ne-o-sin″ os-to′sis)
4. myelography (mi″ĕ-log′ruh-fe)
5. acrocyanosis (ak″ro-si″uh-no′sis)
6. syndactylism (sin-dak′tĭ-lizm)
7. orthopedist (or″tho-pe′dist)
8. prognathism (prog′nah-thizm)
9. micropodia (mi″kro-po′de-uh)
10. arthroscopic (ar″thro-skop′ik)
11. bursectomy (ber-sek′to-me)
12. synovitis (sin-o-vi′tis)
13. acephaly (a-sef′uh-le)
14. sphenoidostomy (sfe-noy-dos′to-me)
15. acetabuloplasty (as-ĕ-tab′yū-lo-plas-te)

Website Link

Visit the Student Edition of the Online Learning Center at http://www.mhhe.com/maderap5 for additional quizzes, interactive learning exercises, and other study tools.

chapter 6

The Skeletal System

Anterior view of the bones in the right hand and wrist of an adult as shown by X ray.

chapter outline & learning objectives

After you have studied this chapter, you should be able to:

6.1 Skeleton: Overview (p. 84)

- Name at least five functions of the skeleton.
- Explain a classification of bones based on their shapes.
- Describe the anatomy of a long bone.
- Describe the growth and development of bones.
- Name and describe six types of fractures, and state the four steps in fracture repair.

6.2 Axial Skeleton (p. 89)

- Distinguish between the axial and appendicular skeletons.
- Name the bones of the skull, and state the important features of each bone.
- Describe the structure and function of the hyoid bone.
- Name the bones of the vertebral column and the thoracic cage. Be able to label diagrams of them.
- Describe a typical vertebra, the atlas and axis, and the sacrum and coccyx.
- Name the three types of ribs and the three parts of the sternum.

6.3 Appendicular Skeleton (p. 97)

- Name the bones of the pectoral girdle and the pelvic girdle. Be able to label diagrams of them.
- Name the bones of the upper limb (arm and forearm) and the lower limb (thigh and leg). Be able to label diagrams that include surface features.
- Cite at least five differences between the female and male pelvises.

6.4 Joints (Articulations) (p. 104)

- Explain how joints are classified, and give examples of each type of joint.
- List the types of movements that occur at synovial joints.

6.5 Effects of Aging (p. 107)

- Describe the anatomical and physiological changes that occur in the skeletal system as we age.

6.6 Homeostasis (p. 108)

- List and discuss six ways the skeletal system contributes to homeostasis. Discuss ways the other systems assist the skeletal system.

Medical Focus

Osteoporosis (p. 88)

What's New

Coaxing the Chondrocytes for Knee Repair (p. 107)

6.1 Skeleton: Overview

The skeletal system consists of the bones (206 in adults) and joints, along with the cartilage and ligaments that occur at the joints.

Functions of the Skeleton

The skeleton has the following functions:

The skeleton supports the body. The bones of the lower limbs support the entire body when we are standing, and the pelvic girdle supports the abdominal cavity.

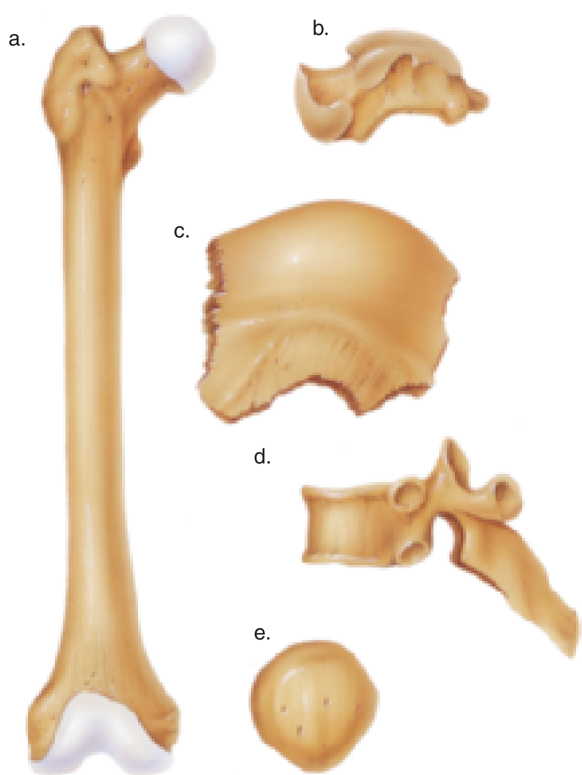
The skeleton protects soft body parts. The bones of the skull protect the brain; the rib cage protects the heart and lungs.

The skeleton produces blood cells. All bones in the fetus have red bone marrow that produces blood cells. In the adult, only certain bones produce blood cells.

The skeleton stores minerals and fat. All bones have a matrix that contains calcium phosphate, a source of calcium ions and phosphate ions in the blood. Fat is stored in yellow bone marrow.

The skeleton, along with the muscles, permits flexible body movement. While articulations (joints) occur between all the bones, we associate body movement in particular with the bones of the limbs.

Figure 6.1 **Classification of bones. a. Long bones are longer than they are wide. b. Short bones are cube shaped; their lengths and widths are about equal. c. Flat bones are platelike and have broad surfaces. d. Irregular bones have varied shapes with many places for connections with other bones. e. Round bones are circular.**



Anatomy of a Long Bone

Bones are classified according to their shape. Long bones are longer than they are wide. Short bones are cube shaped—that is, their lengths and widths are about equal. Flat bones, such as those of the skull, are platelike with broad surfaces. Irregular bones have varied shapes that permit connections with other bones. Round bones are circular in shape (Fig. 6.1).

A long bone, such as the one in Figure 6.2, can be used to illustrate certain principles of bone anatomy. The bone is enclosed in a tough, fibrous, connective tissue covering called the **periosteum,** which is continuous with the ligaments and tendons that anchor bones. The periosteum contains blood vessels that enter the bone and service its cells. At both ends of a long bone is an expanded portion called an **epiphysis;** the portion between the epiphyses is called the **diaphysis.**

As shown in the section of an adult bone in Figure 6.2, the diaphysis is not solid but has a **medullary cavity** containing yellow marrow. Yellow marrow contains large amounts of fat. The medullary cavity is bounded at the sides by compact bone. The epiphyses contain spongy bone. Beyond the spongy bone is a thin shell of compact bone and, finally, a layer of hyaline cartilage called the **articular cartilage.** Articular cartilage is so named because it occurs where bones articulate (join). **Articulation** is the joining together of bones at a joint. The medullary cavity and the spaces of spongy bone are lined with *endosteum,* a thin, fibrous membrane.

Compact Bone

Compact bone, or dense bone, contains many cylinder-shaped units called osteons. The osteocytes (bone cells) are in tiny chambers called *lacunae* that occur between concentric layers of matrix called *lamellae.* The matrix contains collagenous protein fibers and mineral deposits, primarily of calcium and phosphorus salts.

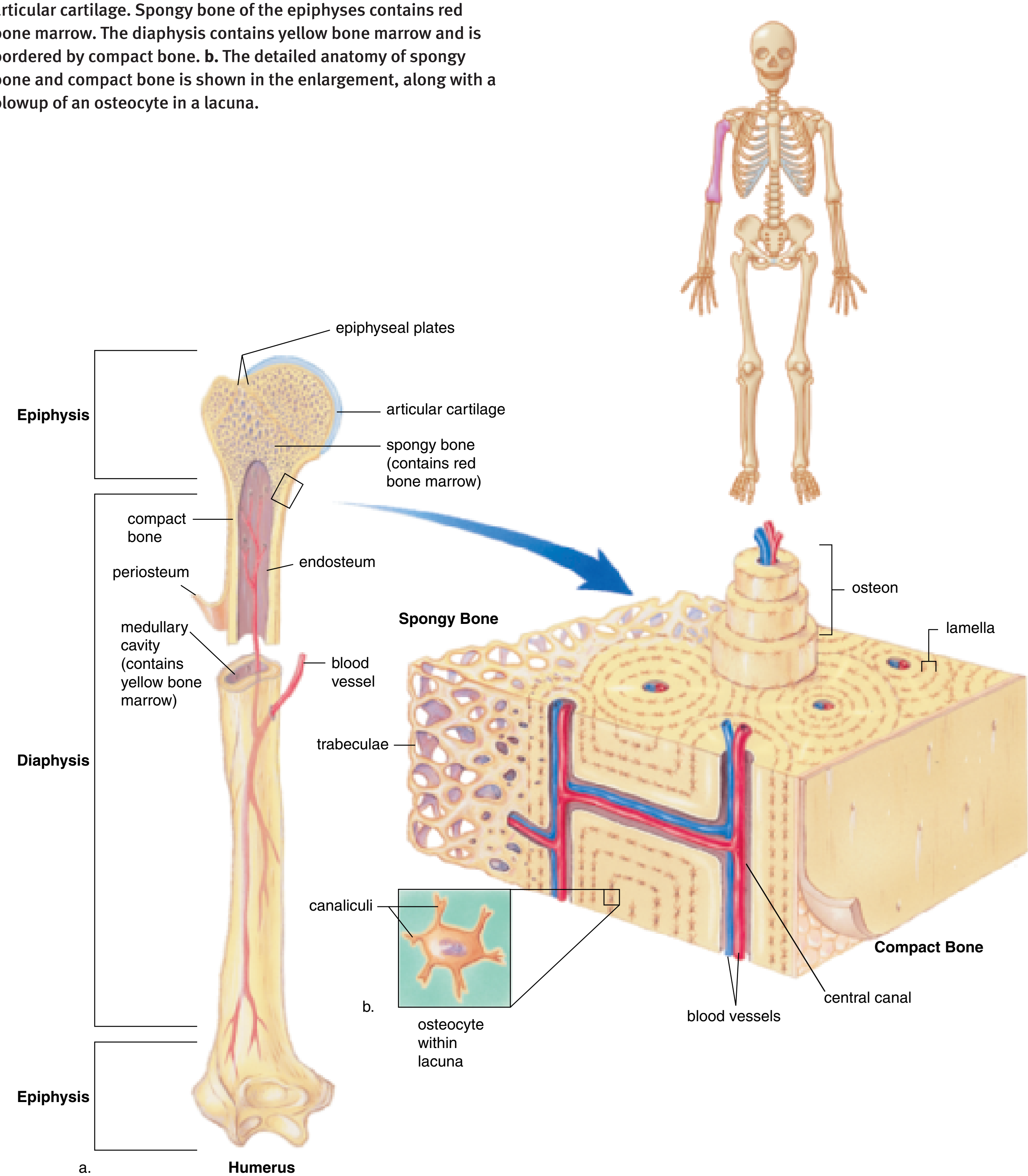
In each osteon, the lamellae and lacunae surround a single central canal. Blood vessels and nerves from the periosteum enter the central canal. The osteocytes have extensions that extend into passageways called *canaliculi,* and thereby the osteocytes are connected to each other and to the central canal.

Spongy Bone

Spongy bone, or cancellous bone, contains numerous bony bars and plates, called *trabeculae.* Although lighter than compact bone, spongy bone is still designed for strength. Like braces used for support in buildings, the trabeculae of spongy bone follow lines of stress.

In infants, **red bone marrow,** a specialized tissue that produces blood cells, is found in the cavities of most bones. In adults, red blood cell formation, called **hematopoiesis,** occurs in the spongy bone of the skull, ribs, sternum (breastbone), and vertebrae, and in the ends of the long bones.

Figure 6.2 Anatomy of a long bone. **a.** A long bone is encased by the periosteum except at the epiphyses, which are covered by articular cartilage. Spongy bone of the epiphyses contains red bone marrow. The diaphysis contains yellow bone marrow and is bordered by compact bone. **b.** The detailed anatomy of spongy bone and compact bone is shown in the enlargement, along with a blowup of an osteocyte in a lacuna.



Bone Growth and Repair

Bones are composed of living tissues, as exemplified by their ability to grow and undergo repair. Several different types of cells are involved in bone growth and repair:

Osteoprogenitor cells are unspecialized cells present in the inner portion of the periosteum, in the endosteum, and in the central canal of compact bone.

Osteoblasts are bone-forming cells derived from osteoprogenitor cells. They are responsible for secreting the matrix characteristic of bone.

Osteocytes are mature bone cells derived from osteoblasts. Once the osteoblasts are surrounded by matrix, they become the osteocytes in bone.

Osteoclasts are thought to be derived from monocytes, a type of white blood cell present in red bone marrow. Osteoclasts perform bone resorption; that is, they break down bone and assist in depositing calcium and phosphate in the blood. The work of osteoclasts is important to the growth and repair of bone.

Bone Development and Growth

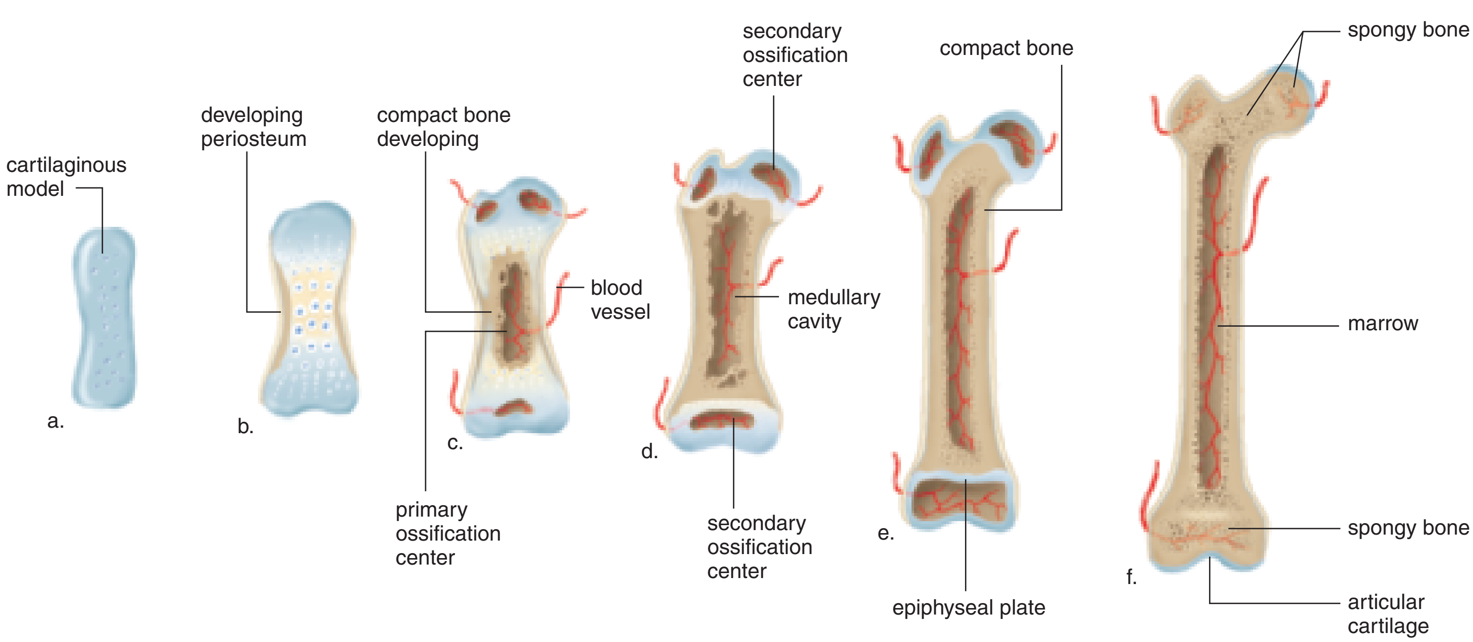
The term **ossification** refers to the formation of bone. The bones of the skeleton form during embryonic development in two distinctive ways—intramembranous ossification and endochondral ossification.

In **intramembranous ossification,** bone develops between sheets of fibrous connective tissue. Cells derived from connective tissue become osteoblasts that form a matrix resembling the trabeculae of spongy bone. Other osteoblasts associated with a periosteum lay down compact bone over the surface of the spongy bone. The osteoblasts become osteocytes when they are surrounded by a mineralized matrix. The bones of the skull develop in this manner.

Most of the bones of the human skeleton form by **endochondral ossification.** Hyaline cartilage models, which appear during fetal development, are replaced by bone as development continues. During endochondral ossification of a long bone, the cartilage begins to break down in the center of the diaphysis, which is now covered by a periosteum (Fig. 6.3). Osteoblasts invade the region and begin to lay down spongy bone in what is called a primary ossification center. Other osteoblasts lay down compact bone beneath the periosteum. As the compact bone thickens, the spongy bone of the diaphysis is broken down by osteoclasts, and the cavity created becomes the medullary cavity.

After birth, the epiphyses of a long bone continue to grow, but soon secondary ossification centers appear in these regions. Here spongy bone forms and does not break down. A band of cartilage called an **epiphyseal plate** remains between the primary ossification center and each secondary center. The limbs keep increasing in length and width as long as epiphyseal plates are still present. The rate of growth is controlled by hormones, such as growth hormones and the sex hormones. Eventually, the epiphyseal plates become ossified, and the bone stops growing.

Figure 6.3 **Endochondral ossification of a long bone. a. A cartilaginous model develops during fetal development. b. A periosteum develops. c. A primary ossification center contains spongy bone surrounded by compact bone. d. The medullary cavity forms in the diaphysis, and secondary ossification centers develop in the epiphyses. e. After birth, growth is still possible as long as cartilage remains at the epiphyseal plates. f. When the bone is fully formed, the remnants of the epiphyseal plates become a thin line.**



Remodeling of Bones

In the adult, bone is continually being broken down and built up again. Osteoclasts derived from monocytes in red bone marrow break down bone, remove worn cells, and assist in depositing calcium in the blood. After a period of about three weeks, the osteoclasts disappear, and the bone is repaired by the work of osteoblasts. As they form new bone, osteoblasts take calcium from the blood. Eventually some of these cells get caught in the mineralized matrix they secrete and are converted to osteocytes, the cells found within the lacunae of osteons.

Strange as it may seem, adults apparently require more calcium in the diet (about 1,000 to 1,500 mg daily) than do children in order to promote the work of osteoblasts. Otherwise, osteoporosis, a condition in which weak and thin bones easily fracture, may develop. Osteoporosis is discussed in the Medical Focus on page 88.

Bone Repair

Repair of a bone is required after it breaks, or **fractures.** Bone repair occurs in a series of four steps:

1. *Hematoma.* Within six to eight hours after a fracture, blood escapes from ruptured blood vessels and forms a hematoma (mass of clotted blood) in the space between the broken bones.
2. *Fibrocartilaginous callus.* Tissue repair begins, and fibrocartilage fills the space between the ends of the broken bone for about three weeks.
3. *Bony callus.* Osteoblasts produce trabeculae of spongy bone and convert the fibrocartilaginous callus to a bony callus that joins the broken bones together and lasts about three to four months.
4. *Remodeling.* Osteoblasts build new compact bone at the periphery, and osteoclasts reabsorb the spongy bone, creating a new medullary cavity.

In some ways, bone repair parallels the development of a bone except that the first step, hematoma, indicates that injury has occurred, and then fibrocartilage instead of hyaline cartilage precedes the production of compact bone.

The naming of fractures describes what kind of break occurred. A fracture is *complete* if the bone is broken clear through and *incomplete* if the bone is not separated into two parts. A fracture is *simple* if it does not pierce the skin and *compound* if it does pierce the skin. *Impacted* means that the broken ends are wedged into each other, and a *spiral fracture* occurs when the break is ragged due to twisting of a bone.

Surface Features of Bones

As we study the various bones of the skeleton, refer to Table 6.1, which lists and explains the surface features of bones.

Table 6.1 Surface Features of Bones

Term	Definition	Example
PROCESSES		
Articulating Surfaces		
Condyle (kon′dīl)	A large, rounded, articulating knob	Mandibular condyle of the mandible (Fig 6.6*b*)
Head	A prominent, rounded, articulating proximal end of a bone	Head of the femur (Fig. 6.16)
Projections for Muscle Attachment		
Crest	A narrow, ridgelike projection	Iliac crest of the coxal bone (Fig. 6.15)
Spine	A sharp, slender process	Spine of the scapula (Fig. 6.11*b*)
Trochanter (tro-kan′ter)	A massive process found only on the femur	Greater trochanter and lesser trochanter of the femur (Fig. 6.16)
Tubercle (tu′ber-kl)	A small, rounded process	Greater tubercle of the humerus (Fig. 6.12)
Tuberosity (tu″bĕ-ros′ĭ-te)	A large, roughened process	Radial tuberosity of the radius (Fig. 6.13)
DEPRESSIONS AND OPENINGS		
Foramen (fo-ra′men)	A rounded opening through a bone	Foramen magnum of the occipital bone (Fig. 6.7*a*)
Fossa (fos′uh)	A flattened or shallow surface	Mandibular fossa of the temporal bone (Fig. 6.7*a*)
Meatus (me-a′tus)	A tubelike passageway through a bone	External auditory meatus of the temporal bone (Fig. 6.6*b*)
Sinus (si′nus)	A cavity or hollow space in a bone	Frontal sinus of the frontal bone (Fig. 6.5)

Source: Data from Kent M. Van De Graaff and Stuart Ira Fox, *Concepts of Human Anatomy and Physiology*, 5th ed., 1999, p. 187.

Medical Focus

Osteoporosis

Osteoporosis is a condition in which the bones are weakened due to a decrease in the bone mass that makes up the skeleton. Throughout life, bones are continuously remodeled. While a child is growing, the rate of bone formation is greater than the rate of bone breakdown. The skeletal mass continues to increase until ages 20 to 30. After that, the rates of formation and breakdown of bone mass are equal until ages 40 to 50. Then, reabsorption begins to exceed formation, and the total bone mass slowly decreases.

Over time, men are apt to lose 25% and women 35% of their bone mass. But we have to consider that men tend to have denser bones than women anyway, and their testosterone (male sex hormone) level generally does not begin to decline significantly until after age 65. In contrast, the estrogen (female sex hormone) level in women begins to decline at about age 45. Because sex hormones play an important role in maintaining bone strength, this difference means that women are more likely than men to suffer fractures, involving especially the hip, vertebrae, long bones, and pelvis. Although osteoporosis may at times be the result of various disease processes, it is essentially a disease of aging.

Everyone can take measures to avoid having osteoporosis when they get older. Adequate dietary calcium throughout life is an important protection against osteoporosis. The U.S. National Institutes of Health recommend a calcium intake of 1,200–1,500 mg per day during puberty. Males and females require 1,000 mg per day until age 65 and 1,500 mg per day after age 65, because the intestinal tract has fewer vitamin D receptors in the elderly.

A small daily amount of vitamin D is also necessary to absorb calcium from the digestive tract. Exposure to sunlight is required to allow skin to synthesize vitamin D. If you reside on or north of a "line" drawn from Boston to Milwaukee, to Minneapolis, to Boise, chances are, you're not getting enough vitamin D during the winter months. Therefore, you should avail yourself of the vitamin D in fortified foods such as low-fat milk and cereal.

Postmenopausal women should have an evaluation of their bone density. Presently, bone density is measured by a method called dual energy X-ray absorptiometry (DEXA). This test measures bone density based on the absorption of photons generated by an X-ray tube. Soon, a blood and urine test may be able to detect the biochemical markers of bone loss, making it possible for physicians to screen all older women and at-risk men for osteoporosis.

If the bones are thin, it is worthwhile to take measures to gain bone density because even a slight increase can significantly reduce fracture risk. Regular, moderate, weight-bearing exercise such as walking or jogging is a good way to maintain bone strength (Fig. 6A). A combination of exercise and drug treatment, as recommended by a physician, may yield the best results.

A wide variety of prescribed drugs that have different modes of action are available. Hormone therapy includes black cohosh, which is a phytoestrogen (estrogen made by a plant as opposed to an animal). Calcitonin is a naturally occurring hormone whose main site of action is the skeleton where it inhibits the action of osteoclasts, the cells that break down bone. Promising new drugs include slow-release fluoride therapy and certain growth hormones. These medications stimulate the formation of new bone.

Figure 6A Preventing osteoporosis. **a.** Exercise can help prevent osteoporosis, but when playing golf, you should carry your own clubs and walk instead of using a golf cart. **b.** Normal bone growth compared to bone from a person with osteoporosis.

6.2 Axial Skeleton

The skeleton is divided into the axial skeleton and the appendicular skeleton. The tissues of the axial and appendicular skeletons are bone (both compact and spongy), cartilage (hyaline, fibrocartilage, and elastic cartilage), and dense connective tissue, a type of fibrous connective tissue. (The various types of connective tissues were extensively discussed in Chapter 3.)

In Figure 6.4, the bones of the axial skeleton are colored orange, and the bones of the appendicular skeleton are colored yellow for easy distinction. Notice that the **axial skeleton** lies in the midline of the body and contains the bones of the skull, the hyoid bone, the vertebral column, and the thoracic cage. Six tiny middle ear bones (three in each ear) are also in the axial skeleton; we will study them in Chapter 9 in connection with the ear.

Figure 6.4 **Major bones of the skeleton. a. Anterior view. b. Posterior view. The bones of the axial skeleton are shown in orange, and those of the appendicular skeleton are shown in yellow.**

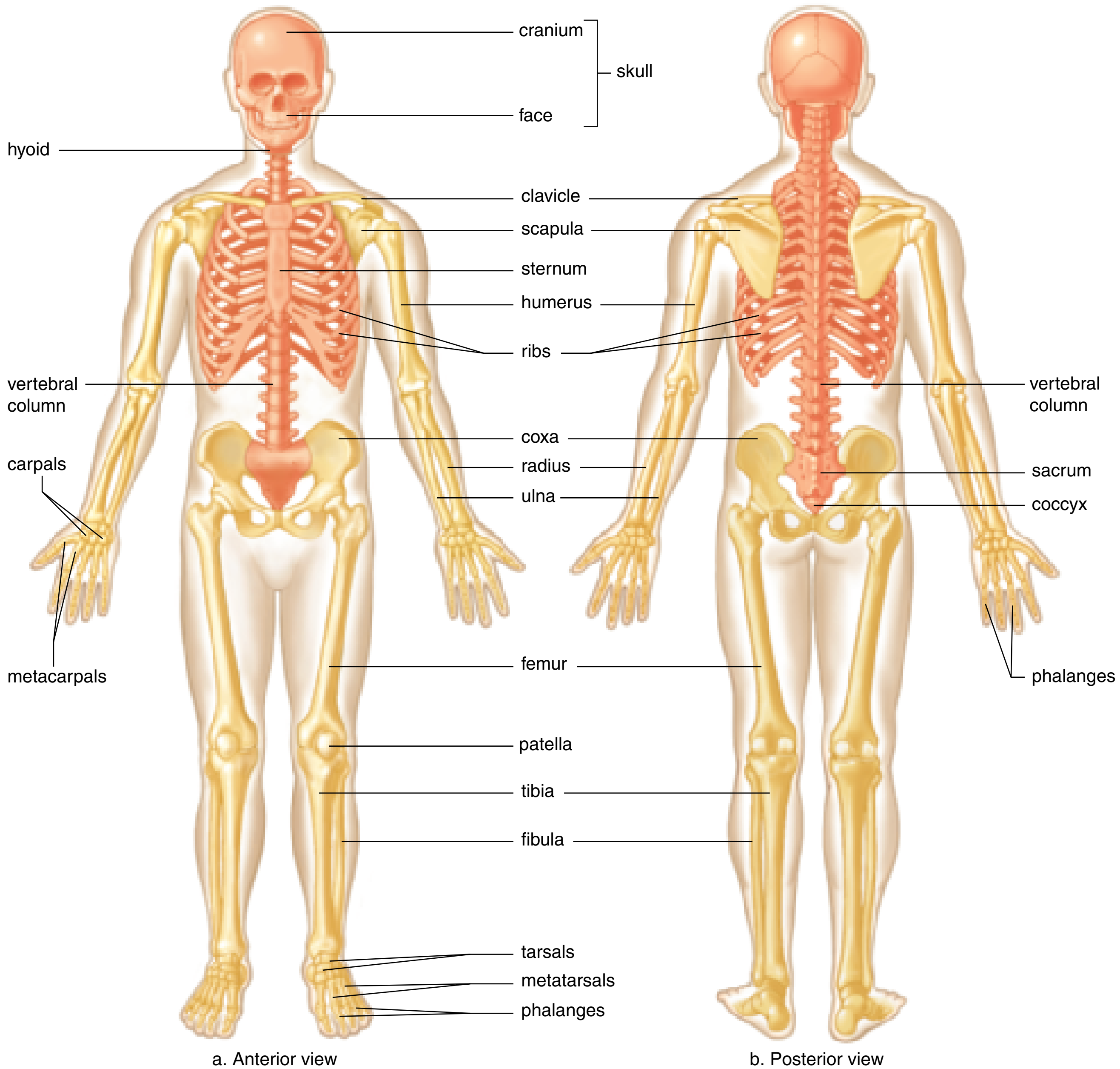
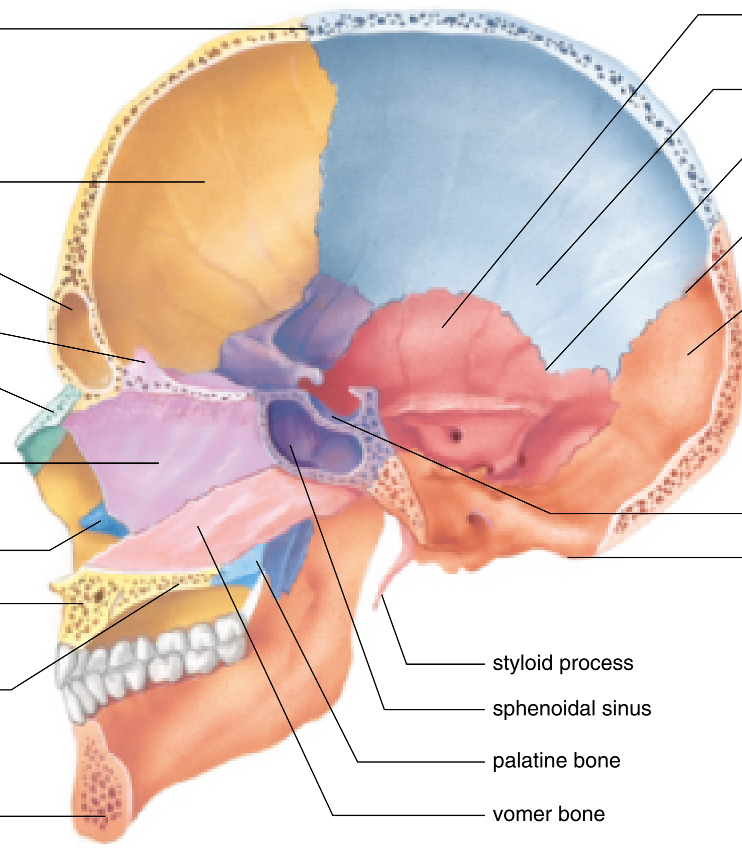


Figure 6.5 Sagittal section of the skull.



Skull

The skull is formed by the cranium and the facial bones. These bones contain **sinuses** (Fig. 6.5), air spaces lined by mucous membranes, that reduce the weight of the skull and give the voice a resonant sound. The paranasal sinuses empty into the nose and are named for their locations. They include the maxillary, frontal, sphenoidal, and ethmoidal sinuses. The two mastoid sinuses drain into the middle ear. **Mastoiditis,** a condition that can lead to deafness, is an inflammation of these sinuses.

Bones of the Cranium

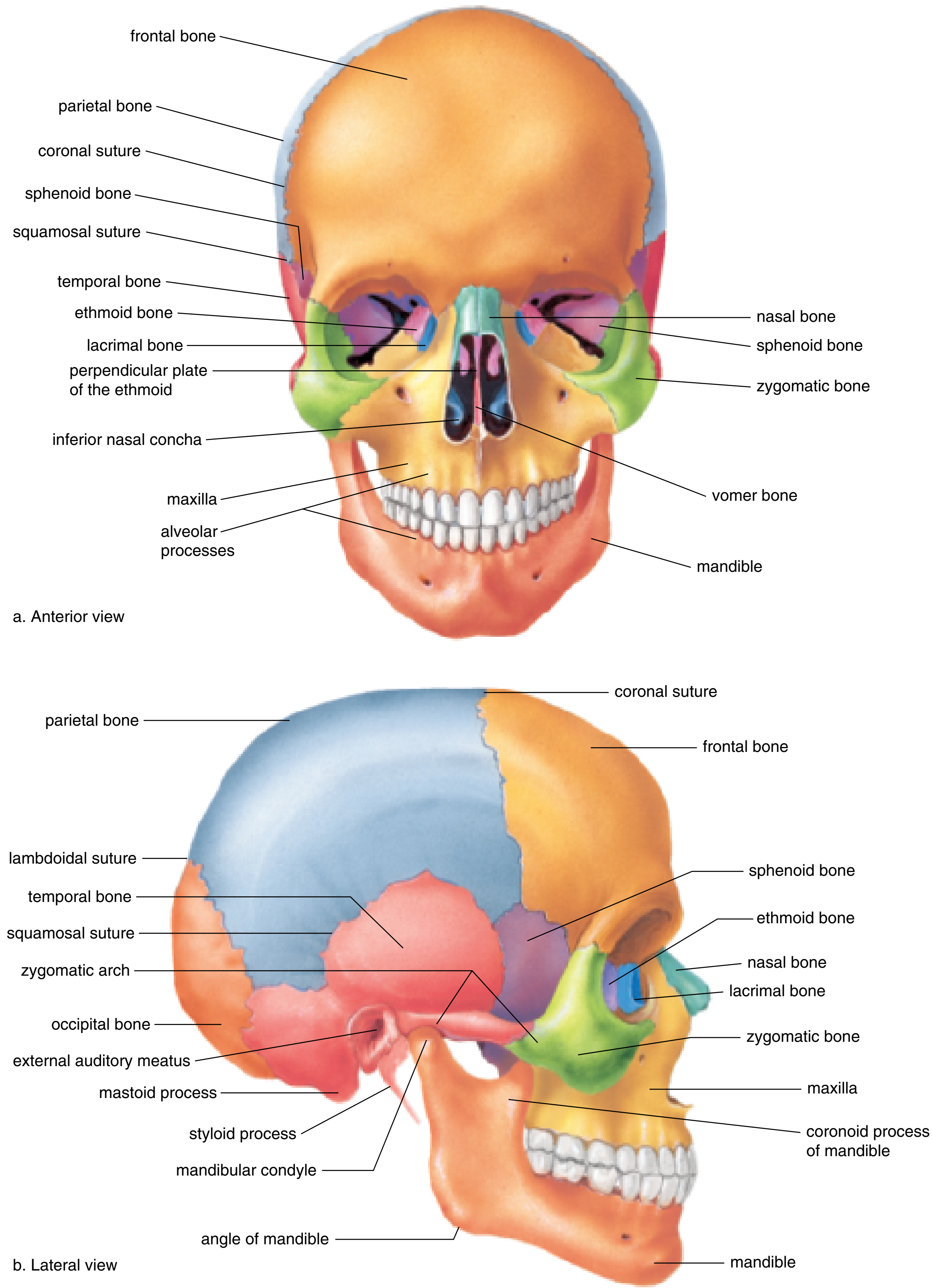
The cranium protects the brain and is composed of eight bones. These bones are separated from each other by immovable joints called **sutures.** Newborns have membranous regions called **fontanels,** where more than two bones meet. The largest of these is the anterior fontanel, which is located where the two parietal bones meet the two parts of the frontal bone. The fontanels permit the bones of the skull to shift during birth as the head passes through the birth canal. The anterior fontanel (often called the "soft spot") usually closes by the age of two years. Besides the frontal bone, the cranium is composed of two parietal bones, one occipital bone, two temporal bones, one sphenoid bone, and one ethmoid bone (Figs. 6.6 and 6.7).

Frontal Bone One frontal bone forms the forehead, a portion of the nose, and the superior portions of the orbits (bony sockets of the eyes).

Parietal Bones Two parietal bones are just posterior to the frontal bone. They form the roof of the cranium and also help form its sides.

Occipital Bone One occipital bone forms the most posterior part of the skull and the base of the cranium. The spinal cord joins the brain by passing through a large opening in the occipital bone called the foramen magnum. The **occipital condyles** (Fig. 6.7*a*) are rounded processes on either side of the foramen magnum that articulate with the first vertebra of the spinal column.

Figure 6.6 Skull anatomy. **a.** Anterior view. **b.** Lateral view.



Temporal Bones Two temporal bones are just inferior to the parietal bones on the sides of the cranium. They also help form the base of the cranium (Figs. 6.6*b* and 6.7*a*). Each temporal bone has the following:

external auditory meatus, a canal that leads to the middle ear;
mandibular fossa, which articulates with the mandible;
mastoid process, which provides a place of attachment for certain neck muscles;
styloid process, which provides a place of attachment for muscles associated with the tongue and larynx;
zygomatic process, which projects anteriorly and helps form the cheekbone.

Sphenoid Bone The sphenoid bone helps form the sides and floor of the cranium and the rear wall of the orbits. The sphenoid bone has the shape of a bat and this shape means that it articulates with and holds together the other cranial bones (Fig. 6.7). Within the cranial cavity, the sphenoid bone has a saddle-shaped midportion called the **sella turcica** (Fig. 6.7*b*), which houses the pituitary gland in a depression.

Ethmoid Bone The ethmoid bone is anterior to the sphenoid bone and helps form the floor of the cranium. It contributes to the medial sides of the orbits and forms the roof and sides of the nasal cavity (Figs. 6.6 and 6.7*b*). The ethmoid bone contains the following:

crista galli (cock's comb), a triangular process that serves as an attachment for membranes that enclose the brain;
cribriform plate with tiny holes that serve as passageways for nerve fibers from the olfactory receptors;
perpendicular plate (Fig. 6.5), which projects downward to form the nasal septum;
superior and **middle nasal conchae,** which project toward the perpendicular plate. These projections support mucous membranes that line the nasal cavity.

Bones of the Face

Maxillae The two maxillae form the upper jaw. Aside from contributing to the floors of the orbits and to the sides of the floor of the nasal cavity, each maxilla has the following processes:

alveolar process (Fig. 6.6*a*). The alveolar processes contain the tooth sockets for teeth: incisors, canines, premolars, and molars.
palatine process (Fig. 6.7*a*)**.** The left and right palatine processes form the anterior portion of the **hard palate** (roof of the mouth).

Palatine Bones The two palatine bones contribute to the floor and lateral wall of the nasal cavity (Fig. 6.5). The horizontal plates of the palatine bones form the posterior portion of the hard palate (Fig. 6.7*a*).

Notice that the hard palate consists of (1) portions of the maxillae (i.e., the palatine processes) and (2) horizontal plates of the palatine bones. A cleft palate results when either (1) or (2) have failed to fuse.

Zygomatic Bones The two zygomatic bones form the sides of the orbits (Fig. 6.7*a*). They also contribute to the "cheekbones." Each zygomatic bone has a **temporal process.** A **zygomatic arch,** the most prominent feature of a cheekbone consists of a temporal process connected to a zygomatic process (a portion of the temporal bone).

Lacrimal Bones The two small, thin lacrimal bones are located on the medial walls of the orbits (Fig. 6.6). A small opening between the orbit and the nasal cavity serves as a pathway for a duct that carries tears from the eyes to the nose.

Nasal Bones The two nasal bones are small, rectangular bones that form the bridge of the nose (Fig. 6.5). The ventral portion of the nose is cartilage, which explains why the nose is not seen on a skull.

Vomer Bone The vomer bone joins with the perpendicular plate of the ethmoid bone to form the nasal septum (Figs. 6.5 and 6.6*a*).

Inferior Nasal Conchae The two inferior nasal conchae are thin, curved bones that form a part of the inferior lateral wall of the nasal cavity (Fig. 6.6*a*). Like the superior and middle nasal conchae, they project into the nasal cavity and support the mucous membranes that line the nasal cavity.

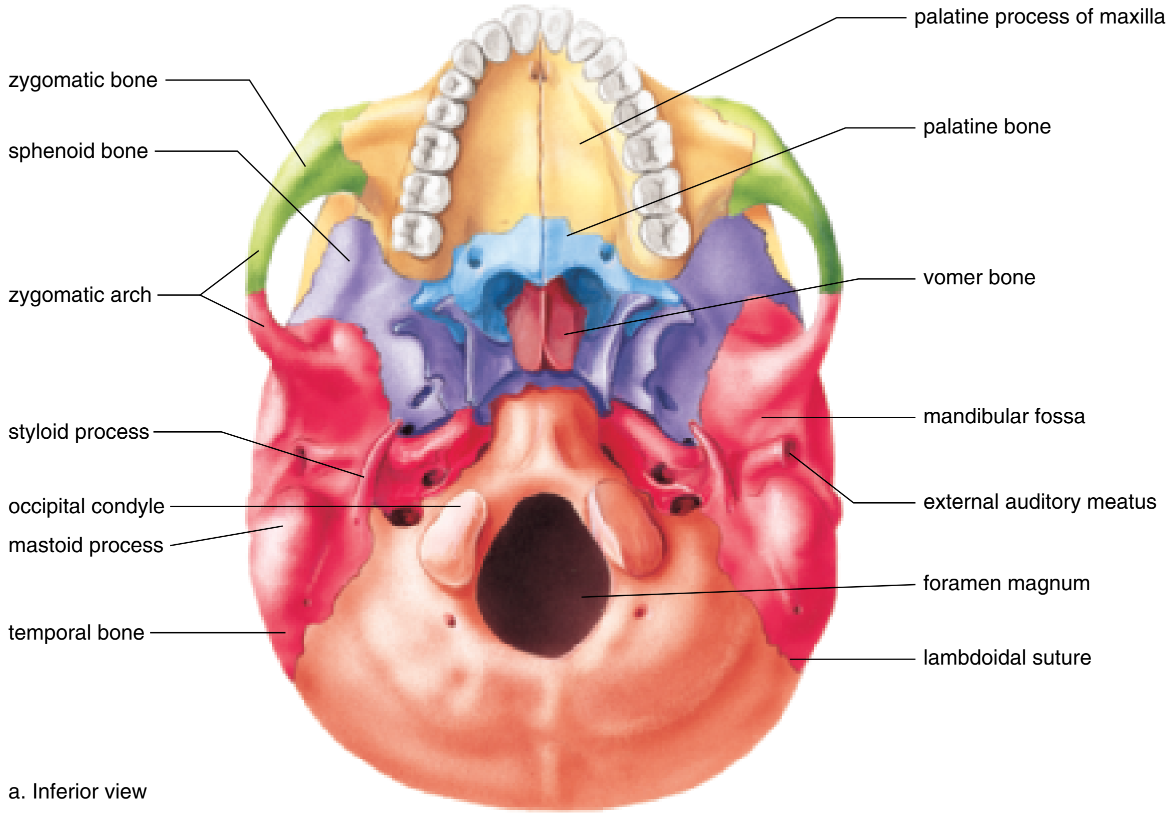
Mandible The mandible, or lower jaw, is the only movable portion of the skull. The horseshoe-shaped front and horizontal sides of the mandible, referred to as the *body*, form the chin. The body has an **alveolar process** (Fig. 6.6*a*), which contains tooth sockets for 16 teeth. Superior to the left and right angle of the mandible are upright projections called *rami*. Each ramus has the following:

mandibular condyle (Fig. 6.6*b*), which articulates with a temporal bone;
coronoid process (Fig. 6.6*b*), which serves as a place of attachment for the muscles used for chewing.

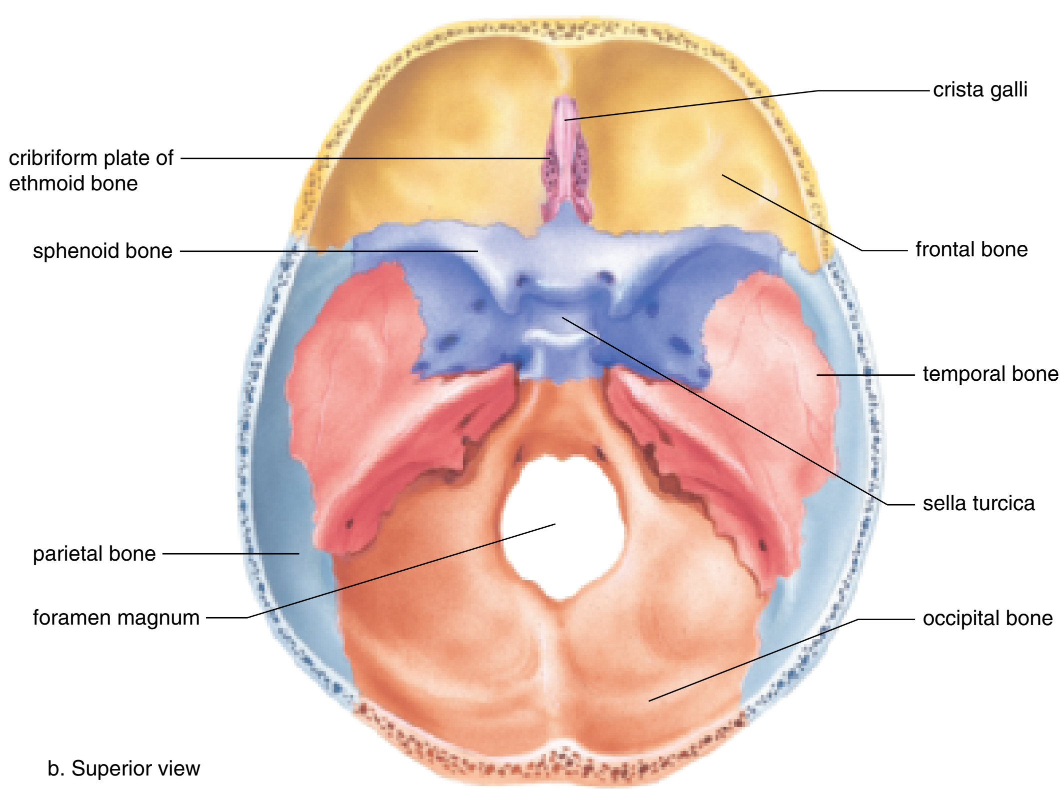
Hyoid Bone

The U-shaped hyoid bone (Fig. 6.4) is located superior to the larynx (voice box) in the neck. It is the only bone in the body that does not articulate with another bone. Instead, it is suspended from the styloid processes of the temporal bones by the stylohyoid muscles and ligaments. It anchors the tongue and serves as the site for the attachment of several muscles associated with swallowing.

Figure 6.7 Skull anatomy continued. **a.** Inferior view. **b.** Superior view.



a. Inferior view



b. Superior view

Vertebral Column (Spine)

The **vertebral column** extends from the skull to the pelvis. It consists of a series of separate bones, the **vertebrae,** separated by pads of fibrocartilage called the **intervertebral disks** (Fig. 6.8). The vertebral column is located in the middorsal region and forms the vertical axis. The skull rests on the superior end of the vertebral column, which also supports the rib cage and serves as a point of attachment for the pelvic girdle. The vertebral column also protects the spinal cord, which passes through a vertebral canal formed by the vertebrae. The vertebrae are named according to their location: seven *cervical* (neck) *vertebrae,* twelve *thoracic* (chest) *vertebrae,* five *lumbar* (lower back) *vertebrae,* five *sacral vertebrae* fused to form the sacrum, and three to five *coccygeal vertebrae* fused into one coccyx.

When viewed from the side, the vertebral column has four normal curvatures, named for their location (Fig. 6.8). The cervical and lumbar curvatures are convex anteriorly, and the thoracic and sacral curvatures are concave anteriorly. In the fetus, the vertebral column has but one curve, and it is concave anteriorly. The cervical curve develops three to four months after birth, when the child begins to hold the head up. The lumbar curvature develops when a child begins to stand and walk, around one year of age. The curvatures of the vertebral column provide more support than a straight column would, and they also provide the balance needed to walk upright.

The curvatures of the vertebral column are subject to abnormalities. An abnormally exaggerated lumbar curvature is called **lordosis,** or "swayback." People who are balancing a heavy midsection, such as pregnant women or men with "potbellies," may have swayback. An increased roundness of the thoracic curvature is **kyphosis,** or "hunchback." This abnormality sometimes develops in older people. An abnormal lateral (side-to-side) curvature is called **scoliosis.** Occurring most often in the thoracic region, scoliosis is usually first seen during late childhood.

Intervertebral Disks

The fibrocartilaginous intervertebral disks located between the vertebrae act as a cushion. They prevent the vertebrae from grinding against one another and absorb shock caused by such movements as running, jumping, and even walking. The disks also allow motion between the vertebrae so that a person can bend forward, backward, and from side to side. Unfortunately, these disks become weakened with age, and can slip or even rupture (called a **herniated disk**). A damaged disk pressing against the spinal cord or the spinal nerves causes pain. Such a disk may need to be removed surgically. If a disk is removed, the vertebrae are fused together, limiting the body's flexibility.

Figure 6.8 Curvatures of the spine. The vertebrae are named for their location in the body. Note the presence of the coccyx, also called the tailbone.

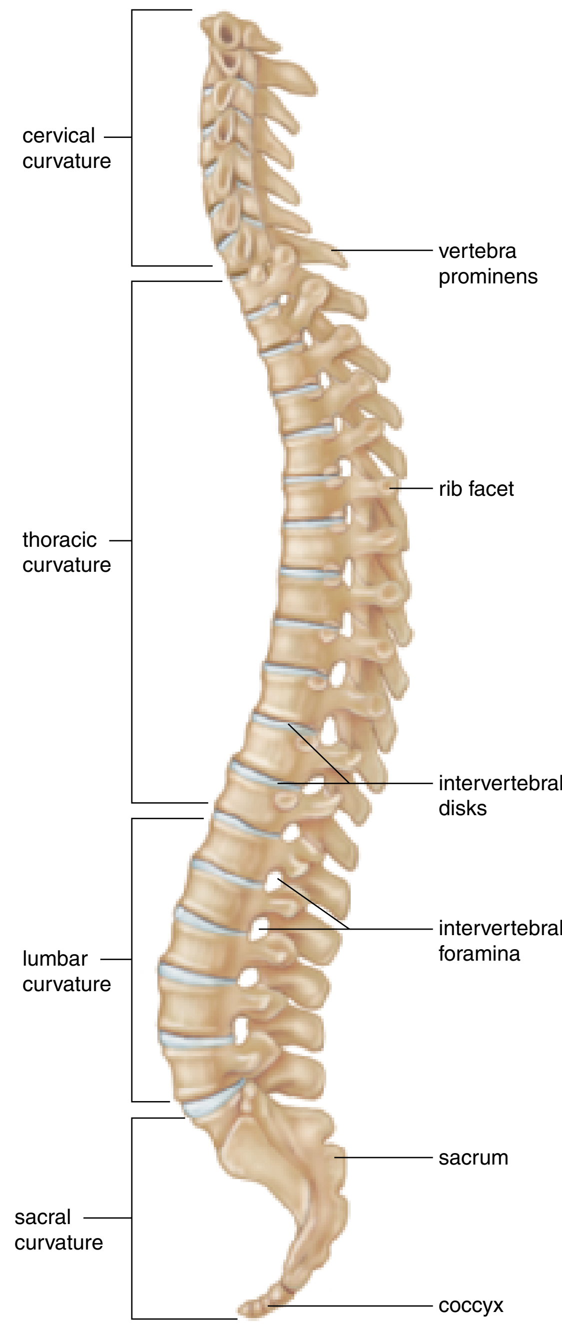
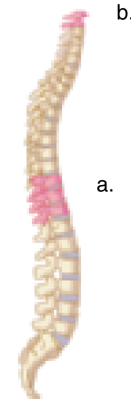
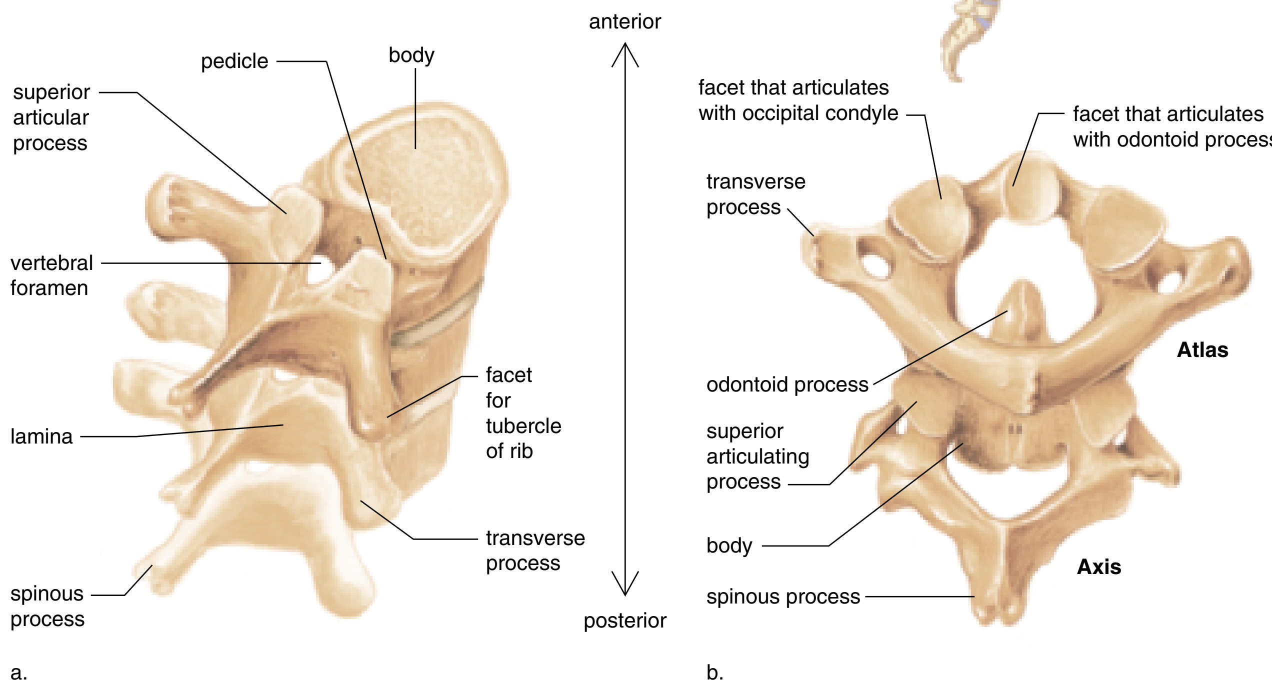


Figure 6.9 Vertebrae. **a.** A typical vertebra in articular position. The vertebral canal where the spinal cord is found is formed by adjacent vertebral foramina. **b.** Atlas and axis, showing how they articulate with one another. The odontoid process of the axis is the pivot around which the atlas turns, as when the head is shaken "no."





Vertebrae

Figure 6.9*a* shows that a typical vertebra has an anteriorly placed *body* and a posteriorly placed vertebral *arch.* The vertebral arch forms the wall of a *vertebral foramen* (pl., *foramina*). The foramina become a canal through which the spinal cord passes.

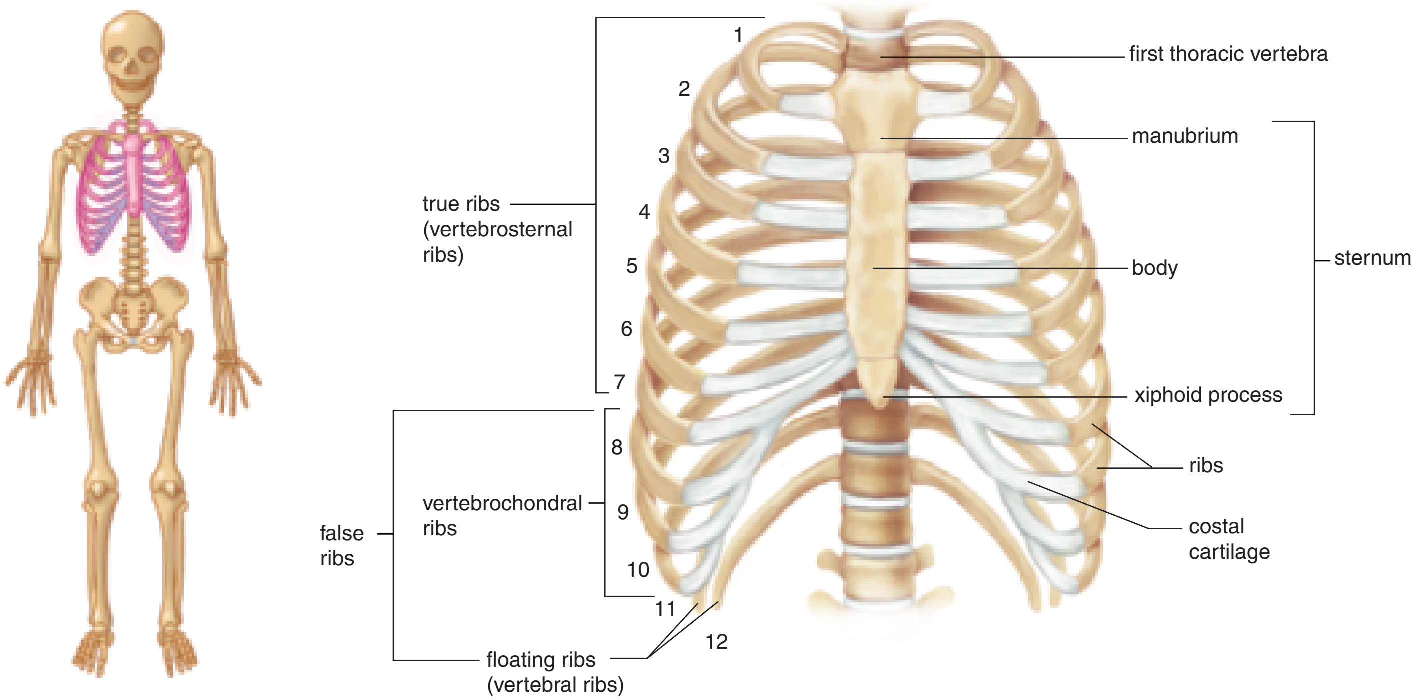
The vertebral *spinous process (spine)* occurs where two thin plates of bone called *laminae* meet. A transverse process is located where a pedicle joins a lamina. These processes serve for the attachment of muscles and ligaments. Articular processes (superior and inferior) serve for the joining of vertebrae.

The vertebrae have regional differences. For example, as the vertebral column descends, the bodies get bigger and are better able to carry more weight. In the cervical region, the spines are short and tend to have a split, or bifurcation. The thoracic spines are long and slender and project downward. The lumbar spines are massive and square and project posteriorly. The transverse processes of thoracic vertebrae have articular facets for connecting to ribs.

Atlas and Axis The first two cervical vertebrae are not typical (Fig. 6.9*b*). The **atlas** supports and balances the head. It has two depressions that articulate with the occipital condyles, allowing movement of the head forward and back. The **axis** has an *odontoid process* (also called the dens) that projects into the ring of the atlas. When the head moves from side to side, the atlas pivots around the odontoid process.

Sacrum and Coccyx The five sacral vertebrae are fused to form the **sacrum.** The sacrum articulates with the pelvic girdle and forms the posterior wall of the pelvic cavity (see Fig. 6.15). The **coccyx,** or tailbone, is the last part of the vertebral column. It is formed from a fusion of three to five vertebrae.

Figure 6.10 **The rib cage. This structure includes the thoracic vertebrae, the ribs, and the sternum. The three bones that make up the sternum are the manubrium, body, and xiphoid process. The ribs numbered 1–7 are true ribs; those numbered 8–12 are false ribs.**



The Rib Cage

The **rib cage** (Fig. 6.10), sometimes called the thoracic cage, is composed of the thoracic vertebrae, ribs and associated cartilages, and sternum.

The rib cage demonstrates how the skeleton is protective but also flexible. The rib cage protects the heart and lungs; yet it swings outward and upward upon inspiration and then downward and inward upon expiration. The rib cage also provides support for the bones of the pectoral girdle (see page 97).

The Ribs

There are twelve pairs of ribs. All twelve pairs connect directly to the thoracic vertebrae in the back. After connecting with thoracic vertebrae, each rib first curves outward and then forward and downward. A rib articulates with the body of one vertebra and the transverse processes of two adjoining thoracic vertebra (called facet for tubercle of rib) (see Fig. 6.9).

The upper seven pairs of ribs connect directly to the sternum by means of costal cartilages. These are called the "true ribs," or the vertebrosternal ribs. The next three pairs of ribs are called the "false ribs," or vertebrochondral ribs, because they attach to the sternum by means of a common cartilage. The last two pairs are called "floating ribs," or vertebral ribs, because they do not attach to the sternum at all.

The Sternum

The **sternum,** or breastbone, is a flat bone that has the shape of a blade. The sternum, along with the ribs, helps protect the heart and lungs. During surgery the sternum may be split to allow access to the organs of the thoracic cavity.

The sternum is composed of three bones that fuse during fetal development. These bones are the manubrium, the body, and the xiphoid process. The *manubrium* is the superior portion of the sternum. The *body* is the middle and largest part of the sternum, and the *xiphoid process* is the inferior and smallest portion of the sternum. The manubrium joins with the body of the sternum at an angle. This joint is an important anatomical landmark because it occurs at the level of the second rib, and therefore allows the ribs to be counted. Counting the ribs is sometimes done to determine where the apex of the heart is located—usually between the fifth and sixth ribs.

The manubrium articulates with the costal cartilages of the first and second ribs; the body articulates costal cartilages of the second through tenth ribs; and the xiphoid process doesn't articulate with any ribs.

The xiphoid process is the third part of the sternum. Composed of hyaline cartilage in the child, it becomes ossified in the adult. The variably shaped xiphoid process serves as an attachment site for the diaphragm, which separates the thoracic cavity from the abdominal cavity.

6.3 Appendicular Skeleton

The **appendicular skeleton** contains the bones of the pectoral girdle, upper limbs, pelvic girdle, and lower limbs.

Pectoral Girdle

The **pectoral girdle** (shoulder girdle) contains four bones: two clavicles and two scapulae (Fig. 6.11). It supports the arms and serves as a place of attachment for muscles that move the arms. The bones of this girdle are not held tightly together; rather, they are weakly attached and held in place by ligaments and muscles. This arrangement allows great flexibility but means that the pectoral girdle is prone to dislocation.

Clavicles

The **clavicles** (collarbones) are slender and S-shaped. Each clavicle articulates medially with the manubrium of the sternum. This is the only place where the pectoral girdle is attached to the axial skeleton.

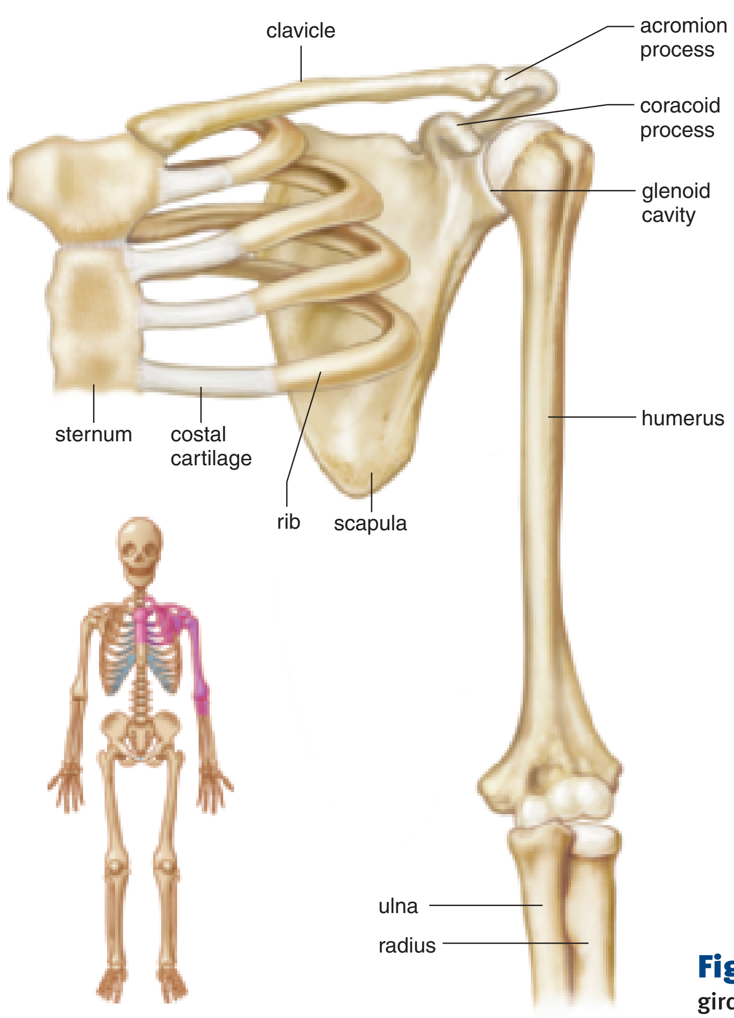
Each clavicle also articulates with a scapula. The clavicle serves as a brace for the scapula and helps stabilize the shoulder. It is structurally weak, however, and if undue force is applied to the shoulder, the clavicle will fracture.

Scapulae

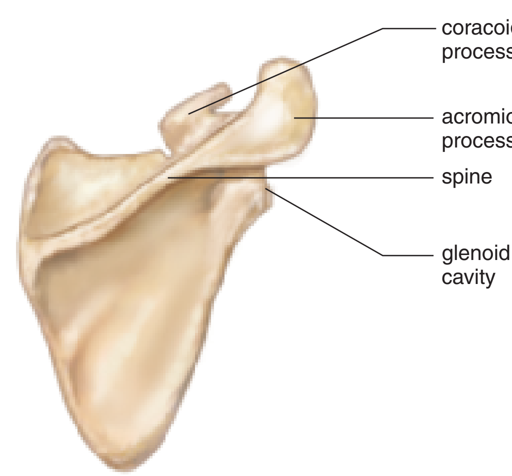
The **scapulae** (sing., scapula), also called the shoulder blades, are broad bones that somewhat resemble triangles (Fig. 6.11*b*). One reason for the pectoral girdle's flexibility is that the scapulae are not joined to each other (see Fig. 6.4).

Each scapula has a spine, as well as the following features:

acromion process, which articulates with a clavicle and provides a place of attachment for arm and chest muscles;
coracoid process, which serves as a place of attachment for arm and chest muscles;
glenoid cavity, which articulates with the head of the arm bone (humerus). The pectoral girdle's flexibility is also a result of the glenoid cavity being smaller than the head of the humerus.



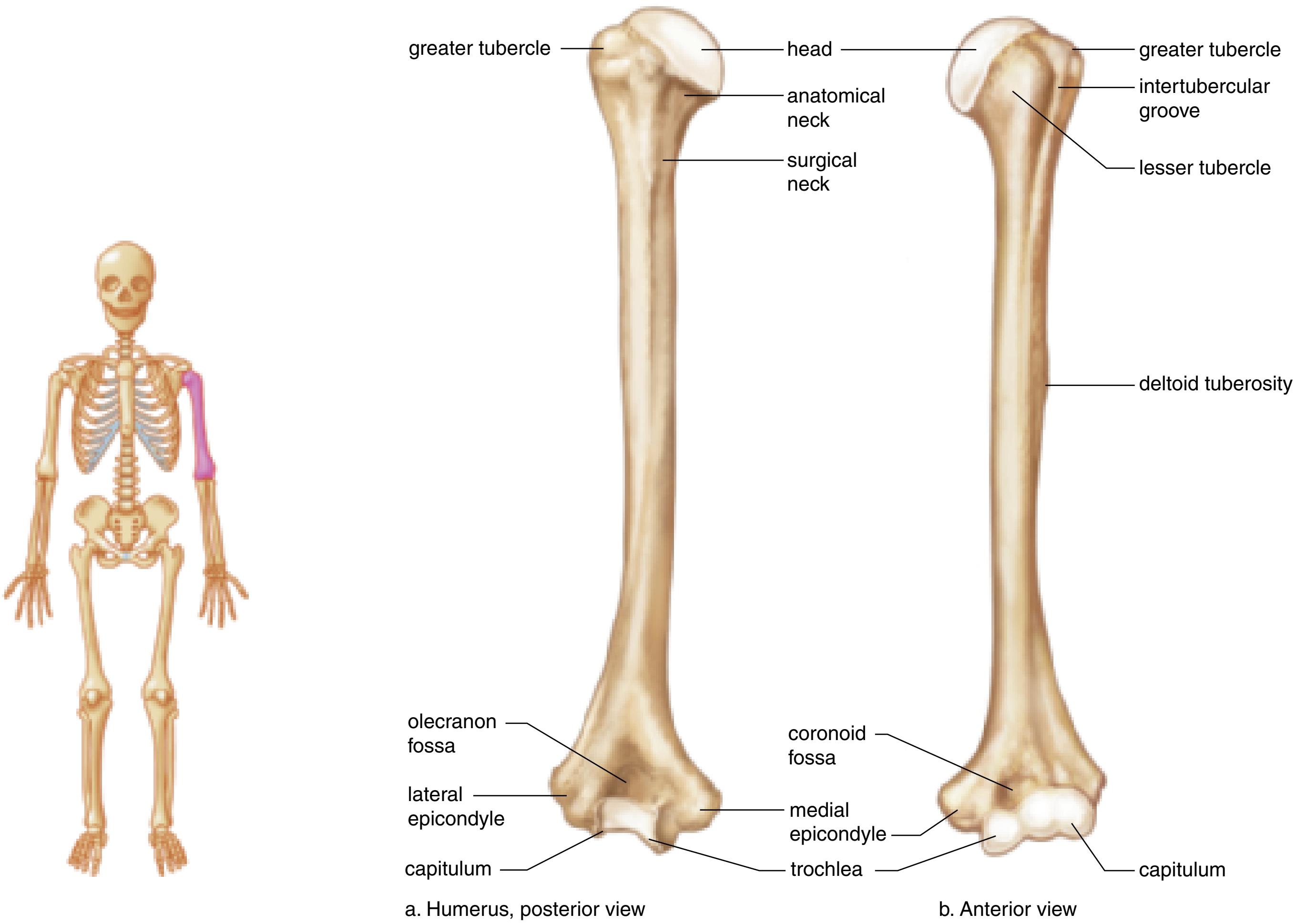
a. Pectoral girdle, frontal view



b. Scapula, posterior view

Figure 6.11 **The pectoral girdle. a. Frontal view of the pectoral girdle (left side) with the upper limb attached. b. Posterior view of the right scapula.**

Figure 6.12 Left humerus. **a.** Posterior surface view. **b.** Anterior surface view.



Upper Limb

The upper limb includes the bones of the arm (humerus), the forearm (radius and ulna), and the hand (carpals, metacarpals, and phalanges).[1]

Humerus

The **humerus** (Fig. 6.12) is the bone of the arm. It is a long bone with the following features at the proximal end:

head, which articulates with the glenoid cavity of the scapula;

greater and **lesser tubercles,** which provide attachments for muscles that move the arm and shoulder;

intertubercular groove, which holds a tendon from the biceps brachii, a muscle of the arm;

deltoid tuberosity, which provides an attachment for the deltoid, a muscle that covers the shoulder joint.

The humerus has the following features at the distal end:

capitulum, a lateral condyle that articulates with the head of the radius;

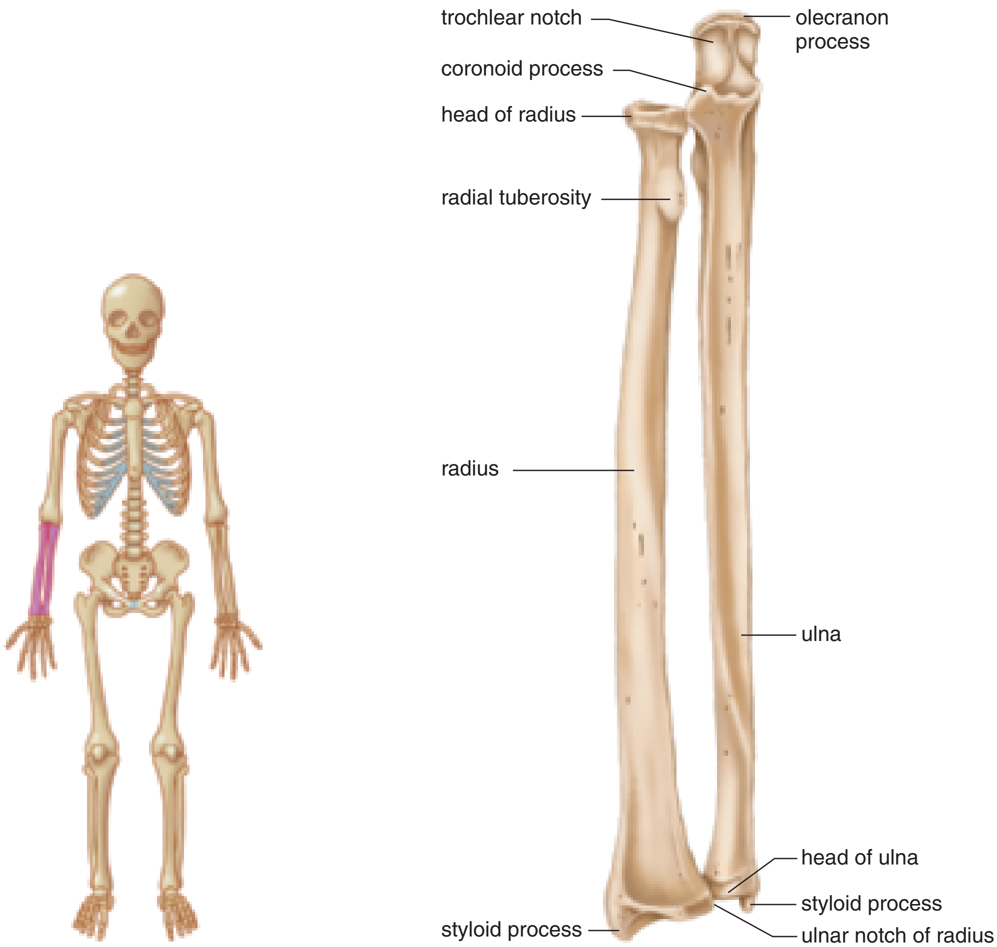
trochlea, a spool-shaped condyle that articulates with the ulna;

coronoid fossa, a depression for a process of the ulna when the elbow is flexed;

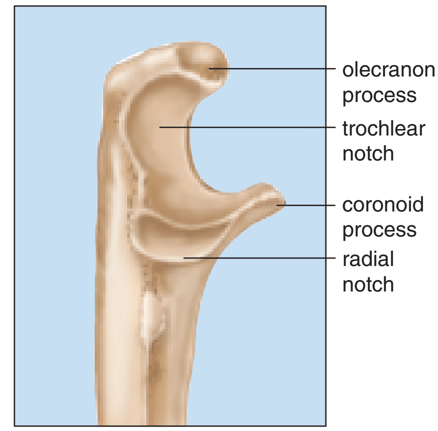
olecranon fossa, a depression for a process of the ulna when the elbow is extended.

[1]The term *upper extremity* is used to include a clavicle and scapula (of the pectoral girdle), an arm, forearm, wrist, and hand.

Figure 6.13 **Right radius and ulna. a. The head of the radius articulates with the radial notch of the ulna. The head of the ulna articulates with the ulnar notch of the radius. b. Lateral view of the proximal end of the ulna.**



a. Radius and ulna



b. Ulna, lateral view

Radius

The **radius** and **ulna** (see Figs. 6.11*a* and 6.13) are the bones of the forearm. The radius is on the lateral side of the forearm (the thumb side). When you turn your hand from the "palms up" position to the "palms down" position, the radius crosses over the ulna, so the two bones are criss-crossed. Proximally, the radius has the following features:

head, which articulates with the capitulum of the humerus and fits into the radial notch of the ulna;
radial tuberosity, which serves as a place of attachment for a tendon from the biceps brachii;

Distally, the radius has the following features:

ulnar notch, which articulates with the head of the ulna;
styloid process, which serves as a place of attachment for ligaments that run to the wrist.

Ulna

The ulna is the longer bone of the forearm. Proximally, the ulna has the following features:

coronoid process, which articulates with the coronoid fossa of the humerus when the elbow is flexed;
olecranon process, the point of the elbow, articulates with the olecranon fossa of the humerus when the elbow is extended;
trochlear notch, which articulates with the trochlea of the humerus at the elbow joint;
radial notch, which articulates with head of the radius.

Distally, the ulna has the following features:

head, which articulates with the ulnar notch of the radius;
styloid process, which serves as a place of attachment for ligaments that run to the wrist.