5

The Skeletal System

After completing this chapter, you will have a working knowledge of the functions of the skeletal system and will have mastered the objectives listed below.

The skeletal system provides an internal framework for the body, protects organs by enclosure, and anchors skeletal muscles so that muscle contraction can cause movement.

Bones: An Overview (pp. 134–144)

- Identify the subdivisions of the skeleton as axial or appendicular.
- List at least three functions of the skeletal system.
- Name the four main classifications of bones.
- Identify the major anatomical areas of a long bone.
- Explain the role of bone salts and the organic matrix in making bone both hard and flexible.
- Describe briefly the process of bone formation in the fetus, and summarize the events of bone remodeling throughout life.
- Name and describe the various types of fractures.

Axial Skeleton (pp. 144–158)

- On a skull or diagram, identify and name the bones of the skull.
- Describe how the skull of a newborn infant (or fetus) differs from that of an adult, and explain the function of fontanels.
- Name the parts of a typical vertebra, and explain in general how the cervical, thoracic, and lumbar vertebrae differ from one another.
- Discuss the importance of the intervertebral discs and spinal curvatures.
- Explain how the abnormal spinal curvatures (scoliosis, lordosis, and kyphosis) differ from one another.

Appendicular Skeleton (pp. 158–166)

- Identify on a skeleton or diagram the bones of the shoulder and pelvic girdles and their attached limbs.
- Describe important differences between a male and female pelvis.

Joints (pp. 166–174)

- Name the three major categories of joints, and compare the amount of movement allowed by each.

Developmental Aspects of the Skeleton (pp. 174–176)

- Identify some of the causes of bone and joint problems throughout life.

Although the word *skeleton* comes from the Greek word meaning "dried-up body," our internal framework is so beautifully designed and engineered that it puts any modern skyscraper to shame. Strong, yet light, it is perfectly adapted for its functions of body protection and motion. Indeed, our skeleton is a tower of bones arranged so that we can stand upright and balance ourselves. No other animal has such relatively long legs (compared to the arms or forelimbs) or such a strange foot, and few have such remarkable grasping hands. Even though the infant's backbone is like an arch, it soon changes to the swayback, or S-shaped, structure that is required for the upright posture.

The skeleton is subdivided into two divisions: the **axial skeleton,** the bones that form the longitudinal axis of the body, and the **appendicular skeleton,** the bones of the limbs and girdles. In addition to bones, the **skeletal system** includes *joints, cartilages,* and *ligaments* (fibrous cords that bind the bones together at joints). The joints give the body flexibility and allow movement to occur.

Bones: An Overview

At one time or another, all of us have heard the expressions "bone tired," "dry as a bone," or "bag of bones"—pretty unflattering and inaccurate images of some of our most phenomenal organs. Our brains, not our bones, convey feelings of fatigue, and bones are far from dry. As for "bag of bones," they are indeed more obvious in some of us, but without them to form our internal skeleton, we would creep along the ground like slugs. Let's examine how our bones contribute to overall body homeostasis.

Functions of the Bones

Besides contributing to body shape and form, our bones perform several important body functions:

1. **Support.** Bones, the "steel girders" and "reinforced concrete" of the body, form the internal framework that supports the body and cradles its soft organs. The bones of the legs act as pillars to support the body trunk when we stand, and the rib cage supports the thoracic wall.

2. **Protection.** Bones protect soft body organs. For example, the fused bones of the skull provide a snug enclosure for the brain, allowing one to head a soccer ball without worrying about injuring the brain. The vertebrae surround the spinal cord, and the rib cage helps protect the vital organs of the thorax.
3. **Movement.** Skeletal muscles, attached to bones by tendons, use the bones as levers to move the body and its parts. As a result, we can walk, swim, throw a ball, and breathe. Before continuing, take a moment to imagine that your bones have turned to putty. What if you were running when this change took place? Now imagine your bones forming a rigid metal framework inside your body, somewhat like a system of plumbing pipes. What problems could you envision with this arrangement? These images should help you understand how well our skeletal system provides support and protection while allowing movement.
4. **Storage.** Fat is stored in the internal cavities of bones. Bone itself serves as a storehouse for minerals, the most important of which are calcium and phosphorus. A small amount of calcium in its ion form (Ca^{2+}) must be present in the blood at all times for the nervous system to transmit messages, for muscles to contract, and for blood to clot. Because most of the body's calcium is deposited in the bones as calcium salts, the bones are a convenient place to get more calcium ions for the blood as they are used up. Problems occur not only when there is too little calcium in the blood, but also when there is too much. Hormones control the movement of calcium to and from the bones and blood according to the needs of the body. Indeed, "deposits" and "withdrawals" of calcium (and other minerals) to and from bones go on almost all the time.
5. **Blood cell formation.** Blood cell formation, or hematopoiesis (hem″ah-to-poi-e′sis), occurs within the marrow cavities of certain bones.

Classification of Bones

The adult skeleton is composed of 206 bones. There are two basic types of osseous, or bone, tissue: **Compact bone** is dense and looks smooth and homogeneous. **Spongy bone** is composed of small needlelike pieces of bone and lots of open space.

Bones come in many sizes and shapes (Figure 5.1). For example, the tiny pisiform bone of the wrist is the size and shape of a pea, whereas the femur, or thigh bone, is nearly 2 feet long and has a large, ball-shaped head. The unique shape of each bone fulfills a particular need. Bones are classified according to shape into four groups: long, short, flat, and irregular (see Figure 5.1).

As their name suggests, **long bones** are typically longer than they are wide. As a rule they have a shaft with heads at both ends. Long bones are mostly compact bone. All the bones of the limbs, except the patella (kneecap) and the wrist and ankle bones, are long bones.

Short bones are generally cube-shaped and contain mostly spongy bone. The bones of the wrist and ankle are short bones. *Sesamoid* (ses′ah-moyd) *bones,* which form within tendons, are a special type of short bone. The best-known example is the patella.

Flat bones are thin, flattened, and usually curved. They have two thin layers of compact bone sandwiching a layer of spongy bone between them. Most bones of the skull, the ribs, and the sternum (breastbone) are flat bones.

Bones that do not fit one of the preceding categories are called **irregular bones.** The vertebrae, which make up the spinal column, and the hip bones fall into this group.

DID YOU GET IT?

1. What is the relationship between muscle function and bones?
2. Where are most long bones found in the body?

For answers, see Appendix D.

Structure of a Long Bone

Gross Anatomy

The gross structure of a long bone is shown in Figure 5.2. The **diaphysis** (di-af′ĭ-sis), or shaft, makes up most of the bone's length and is composed of compact bone. The diaphysis is covered and protected by a fibrous connective tissue membrane, the **periosteum** (per-e-ŏs′te-um). Hundreds of connective tissue fibers, called **perforating,** or **Sharpey's, fibers** secure the periosteum to the underlying bone.

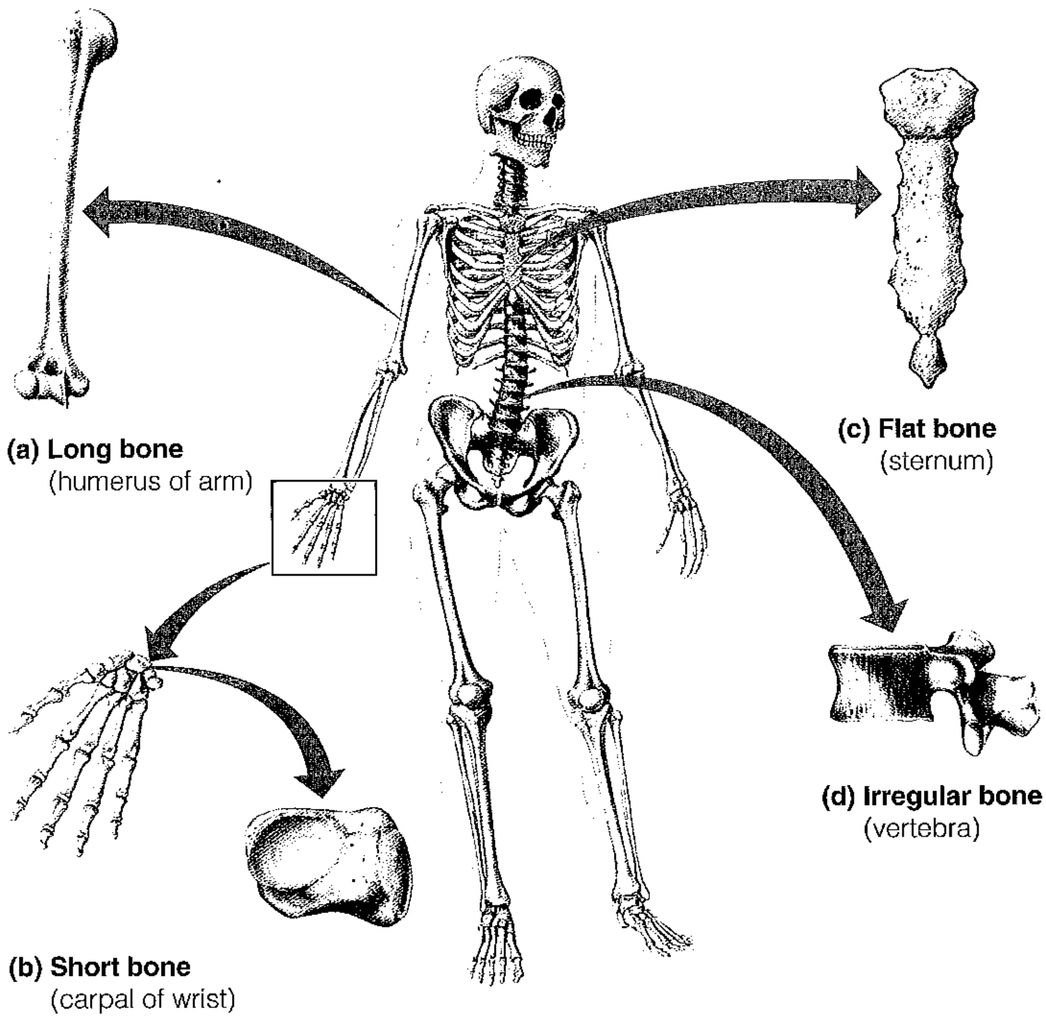

FIGURE 5.1 **Classification of bones on the basis of shape.**

The **epiphyses** (ĕ-pif′ĭ-sēz) are the ends of the long bone. Each epiphysis consists of a thin layer of compact bone enclosing an area filled with spongy bone. **Articular cartilage,** instead of a periosteum, covers its external surface. Because the articular cartilage is glassy hyaline cartilage, it provides a smooth, slippery surface that decreases friction at joint surfaces.

In adult bones, there is a thin line of bony tissue spanning the epiphysis that looks a bit different from the rest of the bone in that area. This is the **epiphyseal line.** The epiphyseal line is a remnant of the **epiphyseal plate** (a flat plate of hyaline cartilage) seen in a young, growing bone. Epiphyseal plates cause the lengthwise growth of a long bone. By the end of puberty, when hormones inhibit long bone growth, epiphyseal plates have been completely replaced by bone, leaving only the epiphyseal lines to mark their previous location.

In adults the cavity of the shaft is primarily a storage area for adipose (fat) tissue. It is called the **yellow marrow,** or **medullary, cavity.** However, in infants this area forms blood cells, and **red marrow** is found there. In adult bones, red marrow is confined to cavities in the spongy bone of flat bones and the epiphyses of some long bones.

Even when looking casually at bones, one can see that their surfaces are not smooth but scarred with bumps, holes, and ridges. These **bone markings,** described and illustrated in Table 5.1, reveal where muscles, tendons, and ligaments were attached and where blood vessels and nerves passed. There are two categories of bone markings:

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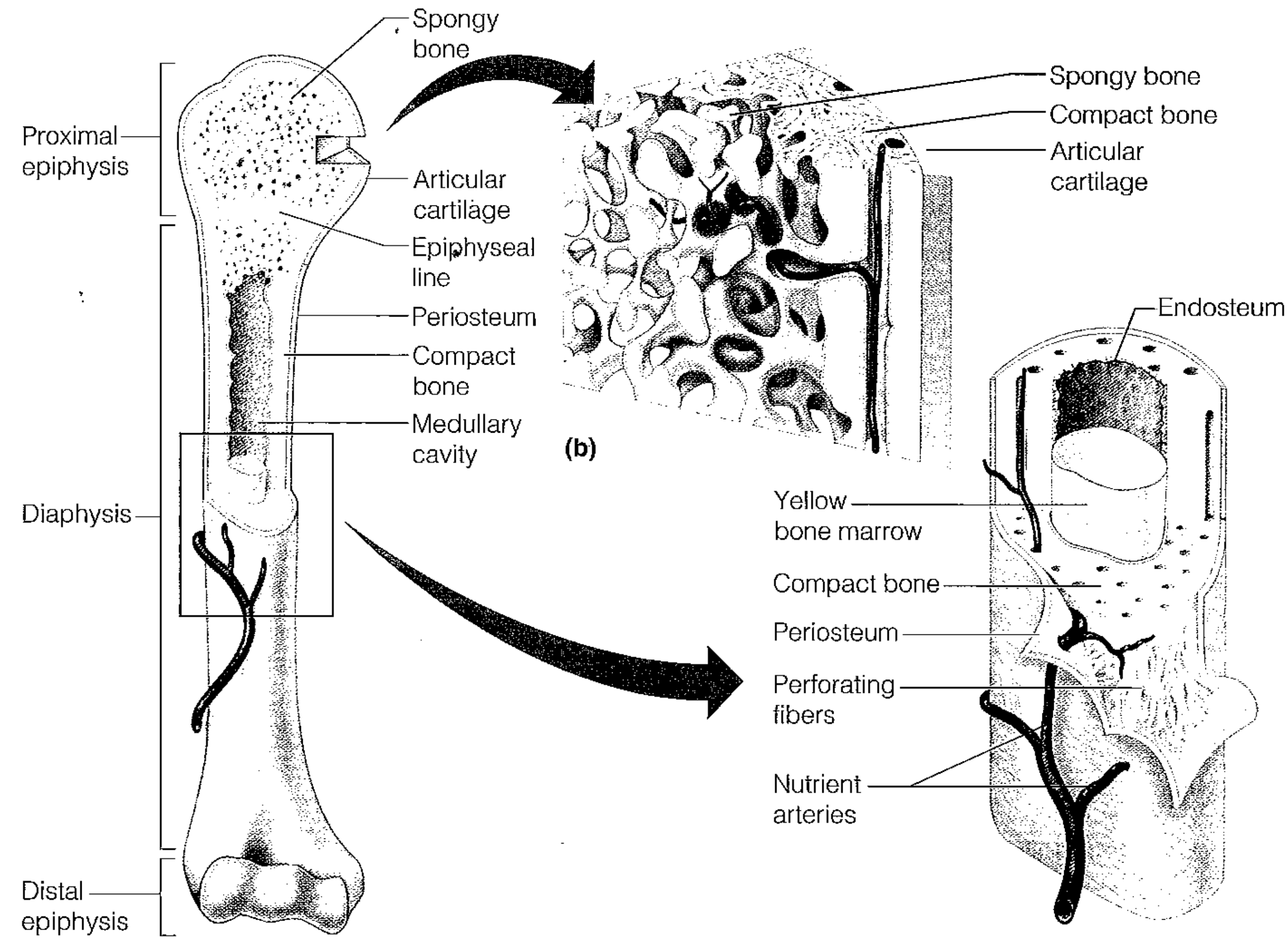


FIGURE 5.2 The structure of a long bone (humerus). **(a)** Anterior view with longitudinal section cut away at the proximal end. **(b)** Pie-shaped, three-dimensional view of spongy bone and compact bone of the epiphysis. **(c)** Cross section of the shaft (diaphysis). Note that the external surface of the diaphysis is covered by a periosteum, but the articular surface of the epiphysis (see b) is covered with hyaline cartilage.

(a) *projections*, or *processes*, which grow out from the bone surface, and (b) *depressions*, or *cavities*, which are indentations in the bone. You do not

Microscopic Anatomy

To the naked eye, spongy bone has a spiky, open

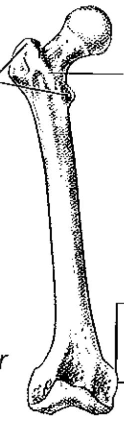
TABLE 5.1 Bone Markings

Projections That Are Sites of Muscle and Ligament Attachment

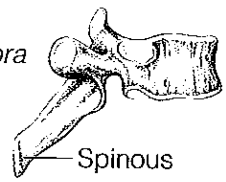
Name of bone marking	Description
Tuberosity	Large, rounded projection; may be roughened
Crest	Narrow ridge of bone; usually prominent
Trochanter (tro-kan'ter)	Very large, blunt, irregularly shaped process (the only examples are on the femur)
Line	Narrow ridge of bone; less prominent than a crest
Tubercle (too'ber-kl)	Small, rounded projection or process
Epicondyle	Raised area on or above a condyle
Spine	Sharp, slender, often pointed projection
Process	Any bony prominence

Illustration

Coxal bone



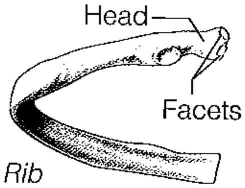
Femur of thigh



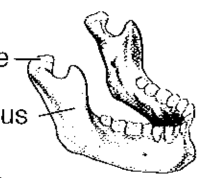
Vertebra

Projections That Help to Form Joints

Name of bone marking	Description
Head	Bony expansion carried on a narrow neck
Facet	Smooth, nearly flat articular surface
Condyle (kon'dīl)	Rounded articular projection
Ramus (ra'mus)	Armlike bar of bone



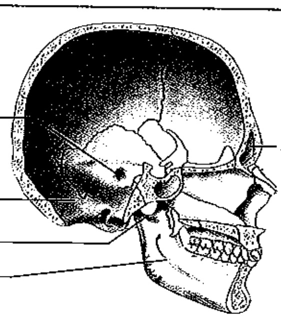
Rib



Mandible

Depressions and Openings Allowing Blood Vessels and Nerves to Pass

Name of bone marking	Description
Meatus (me-a'tus)	Canal-like passageway
Sinus	Cavity within a bone, filled with air and lined with mucous membrane
Fossa (fos'ah)	Shallow, basinlike depression in a bone, often serving as an articular surface
Groove	Furrow
Fissure	Narrow, slitlike opening
Foramen (fo-ra'men)	Round or oval opening through a bone



Skull

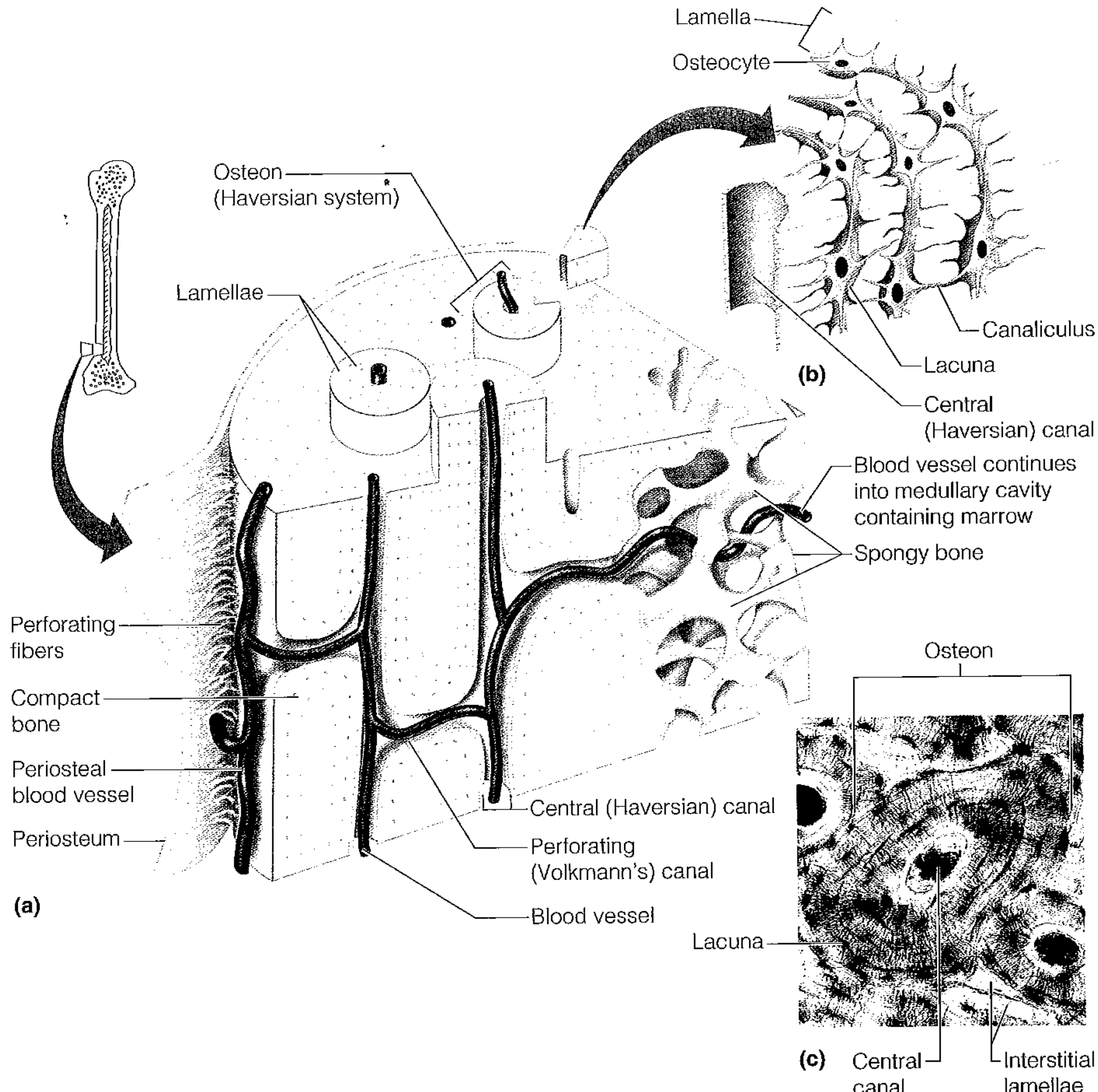


FIGURE 5.3 Microscopic structure of compact bone. Diagram of a pie-shaped segment of compact bone. (The inset shows a more

nourished in spite of the hardness of the matrix, and bone injuries heal quickly and well. The communication pathway from the outside of the bone to its interior (and the central canals) is completed by **perforating (Volkmann's) canals,** which run into the compact bone at right angles to the shaft.

Bone is one of the hardest materials in the body, and although relatively light in weight, it has a remarkable ability to resist tension and other forces acting on it. Nature has given us an extremely strong and exceptionally simple (almost crude) supporting system without giving up mobility. The calcium salts deposited in the matrix give bone its hardness, which resists compression. The organic parts (especially the collagen fibers) provide for bone's flexibility and great tensile strength.

DID YOU GET IT?

3. What is the anatomical name for the shaft of a long bone? For its ends?
4. How does the structure of compact bone differ from the structure of spongy bone when viewed with the naked eye?

For answers, see Appendix D.

Bone Formation, Growth, and Remodeling

The skeleton is formed from two of the strongest and most supportive tissues in the body—cartilage and bone. In embryos, the skeleton is primarily made of hyaline cartilage, but in the young child most of the cartilage has been replaced by bone. Cartilage remains only in isolated areas such as the bridge of the nose, parts of the ribs, and the joints.

Except for flat bones, which form on fibrous membranes, most bones develop using hyaline cartilage structures as their "models." Most simply, this process of bone formation, or **ossification** (os″ĭ-fĭ-ka′shun), involves two major phases (Figure 5.4a). First, the hyaline cartilage model is completely covered with bone matrix (a bone "collar") by bone-forming cells called **osteoblasts.** So, for a short period, the fetus has cartilage "bones" enclosed by "bony" bones. Then, the enclosed hyaline cartilage model is digested away, opening up a medullary cavity within the newly formed bone.

By birth or shortly after, most hyaline cartilage models have been converted to bone except for two regions—the articular cartilages (that cover the bone ends) and the epiphyseal plates. New cartilage is formed continuously on the external face of the articular cartilage and on the epiphyseal plate surface that faces the bone end (is farther away from the medullary cavity). At the same time, the old cartilage abutting the internal face of the articular cartilage and the medullary cavity is broken down and replaced by bony matrix (Figure 5.4b).

Growing bones also must widen as they lengthen. How do they widen? Simply, osteoblasts in the periosteum add bone tissue to the external face of the diaphysis as osteoclasts in the endosteum remove bone from the inner face of the diaphysis wall (see Figure 5.4b). Since these two processes occur at about the same rate, the circumference of the long bone expands and the bone widens. This process by which bones increase in diameter is called *appositional growth.* This process of long-bone growth is controlled by hormones, the most important of which are *growth hormone* and, during puberty, the *sex hormones.* It ends during adolescence, when the epiphyseal plates are completely converted to bone.

Many people mistakenly think that bones are lifeless structures that never change once long-bone growth has ended. Nothing could be further from the truth; bone is a dynamic and active tissue. Bones are remodeled continually in response to changes in two factors: (1) calcium levels in the blood and (2) the pull of gravity and muscles on the skeleton. How these factors influence bones is outlined next.

When blood calcium levels drop below homeostatic levels, the parathyroid glands (located in the throat) are stimulated to release parathyroid hormone (PTH) into the blood. PTH activates **osteoclasts,** giant bone-destroying cells in bones, to break down bone matrix and release calcium ions into the blood. When blood calcium levels are too high (*hypercalcemia* [hi″per-kal-se′me-ah]), calcium is deposited in bone matrix as hard calcium salts.

Bone remodeling is essential if bones are to retain normal proportions and strength during long-bone growth as the body increases in size and weight. It also accounts for the fact that bones become thicker and form large projections to increase their strength in areas where bulky muscles are

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(a) What specific cell types form the bone collar? (b) What do you think a long bone would look like at the end of adolescence if bone remodeling did not occur?

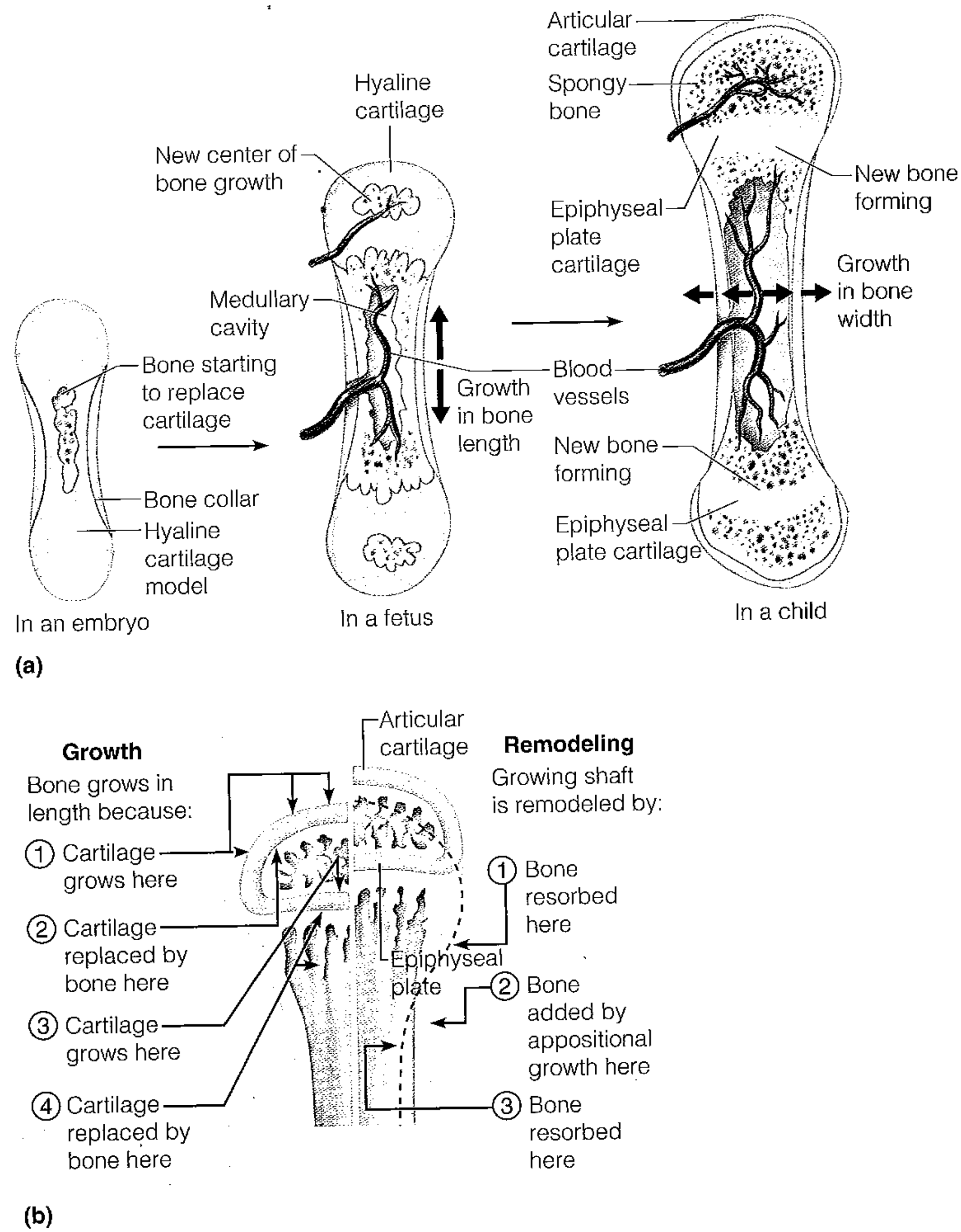
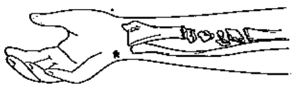


TABLE 5.2 Common Types of Fractures

Fracture type	Illustration	Description	Comment
Comminuted		Bone breaks into many fragments	Particularly common in older people, whose bones are more brittle
Compression		Bone is crushed	Common in porous bones (i.e., osteoporotic bones of older people)
Depressed		Broken bone portion is pressed inward	Typical of skull fracture
Impacted		Broken bone ends are forced into each other	Commonly occurs when one attempts to break a fall with outstretched arms
Spiral		Ragged break occurs when excessive twisting forces are applied to a bone	Common sports fracture
Greenstick		Bone breaks incompletely, much in the way a green twig breaks	Common in children, whose bones are more flexible than those of adults

attached. At such sites, osteoblasts lay down new matrix and become trapped within it. (Once they are trapped, they become osteocytes, or mature bone cells.) In contrast, the bones of bedridden or physically inactive people tend to lose mass and to atrophy because they are no longer subjected to stress.

These two controlling mechanisms—calcium uptake and release and bone remodeling—work together. PTH determines *when* (or *if*) bone is to be broken down or formed in response to the need for more or fewer calcium ions in the blood. The stresses of muscle pull and gravity acting on the skeleton determine *where* bone matrix is to be broken down or formed so that the skeleton can remain as strong and vital as possible.

HOMEOSTATIC IMBALANCE

Rickets is a disease of children in which the bones fail to calcify. As a result, the bones soften, and the weight-bearing bones of the legs show a definite bowing. Rickets is usually due to a lack of calcium in the diet or lack of vitamin D, which is needed to absorb calcium into the bloodstream. Rickets is not seen very often in the United States. Milk, bread, and other foods are fortified with vitamin D, and most children drink enough calcium-rich milk. However, it can happen in infants nursed by mothers who become vitamin D-deficient over the course of a long gray winter, and it remains a problem in some other parts of the world. ▲

Bone Fractures

HOMEOSTATIC IMBALANCE

For their relatively low mass, bones are amazingly strong. Consider, for example, the forces endured in touch football and professional hockey. Despite their remarkable strength, bones are susceptible to **fractures,** or breaks, all through life. During youth, most fractures result from exceptional trauma that twists or smashes the bones. Sports activities such as football, skating, and skiing jeopardize the bones, and automobile accidents certainly take their toll. In old age, bones thin and weaken, and fractures occur more often.

A fracture in which the bone breaks cleanly but does not penetrate the skin is a *closed* (or *simple*) *fracture*. When the broken bone ends penetrate through the skin, the fracture is *open* (or *compound*). Some of the many common types of fractures are illustrated and described in Table 5.2. ▲

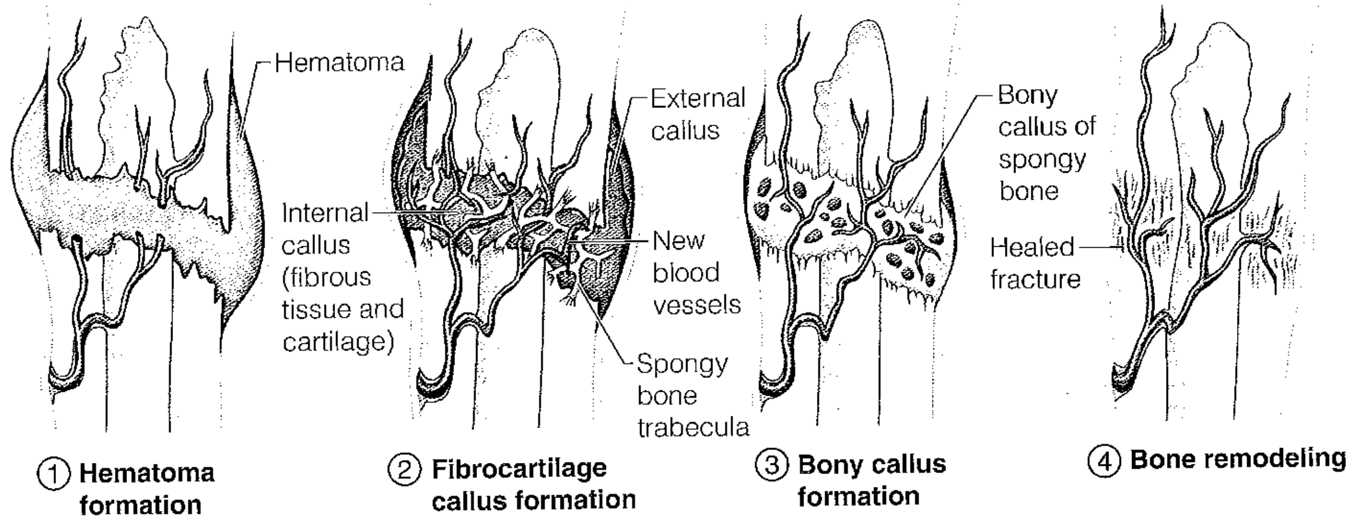


FIGURE 5.5 **Stages in the healing of a bone fracture.**

A fracture is treated by **reduction,** which is the realignment of the broken bone ends. In *closed reduction,* the bone ends are coaxed back into their normal position by the physician's hands. In *open reductions,* surgery is performed and the bone ends are secured together with pins or wires. After the broken bone is reduced, it is immobilized by a cast or traction to allow the healing process to begin. The healing time for a simple fracture is 6 to 8 weeks, but it is much longer for large bones and for the bones of older people (because of their poorer circulation).

The repair of bone fractures involves four major events (Figure 5.5):

1. **A hematoma forms.** Blood vessels are ruptured when the bone breaks. As a result, a blood-filled swelling called a **hematoma** (he-mah-to'mah) forms. Bone cells deprived of nutrition die.
2. **The break is splinted by a fibrocartilage** and acts to "splint" the broken bone, closing the gap.
3. **The bony callus forms.** As more osteoblasts and osteoclasts migrate into the area and multiply, the fibrocartilage callus is gradually replaced by one made of spongy bone, the **bony callus.**
4. **Bone remodeling occurs.** Over the next few weeks to months, depending on the bone's size and site of the break, the bony callus is remodeled in response to the mechanical stresses placed on it, so that it forms a strong permanent "patch" at the fracture site.

DID YOU GET IT?

5. Bones don't begin as bones. What do they begin as?
6. Which stimulus—PTH (a hormone) or mechanical forces acting on the skeleton—is more important

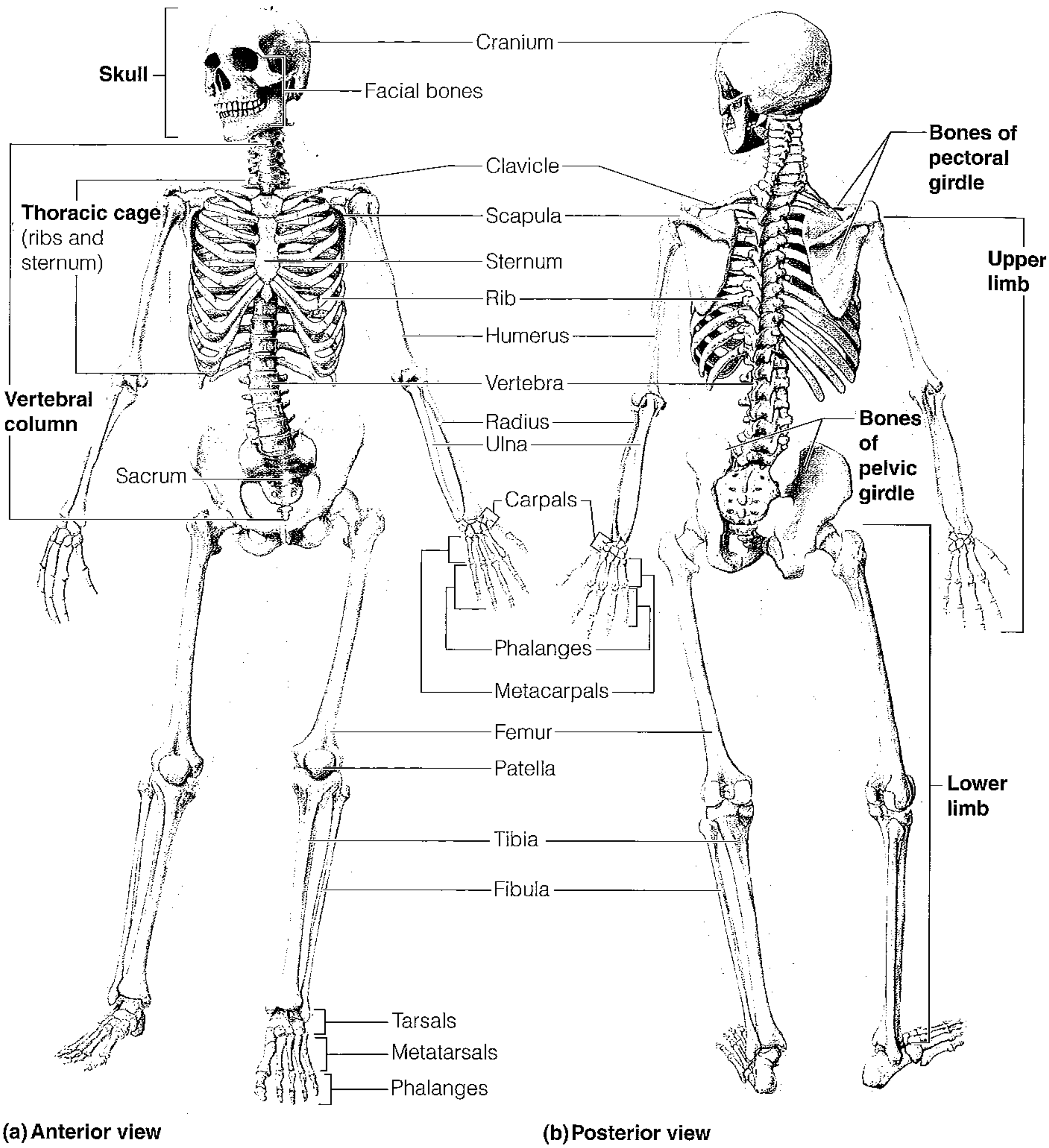


FIGURE 5.6 The human skeleton. The bones of the axial skeleton are colored green. Bones of the appendicular skeleton are gold.

Axial Skeleton

As noted earlier, the skeleton is divided into two parts, the *axial* and *appendicular skeletons.* The axial skeleton, which forms the longitudinal axis of the body, is shown as the green portion of Figure 5.6. It can be divided into three parts—the *skull,* the *vertebral column,* and the *bony thorax.*

Skull

The **skull** is formed by two sets of bones. The **cranium** encloses and protects the fragile brain tissue. The **facial bones** hold the eyes in an anterior position and allow the facial muscles to show our feelings through smiles or frowns. All but one of the bones of the skull are joined together by *sutures,* which are interlocking, immovable joints. Only the mandible (jawbone) is attached to the rest of the skull by a freely movable joint.

Cranium

The boxlike cranium is composed of eight large flat bones. Except for two paired bones (the parietal and temporal), they are all single bones.

Frontal Bone The frontal bone forms the forehead, the bony projections under the eyebrows, and the superior part of each eye's orbit (Figure 5.7).

Parietal Bones The paired parietal bones form most of the superior and lateral walls of the cranium (see Figure 5.7). They meet in the midline of the skull at the **sagittal suture** and form the **coronal suture,** where they meet the frontal bone.

Temporal Bones The temporal bones lie inferior to the parietal bones; they join them at the **squamous sutures.** Several important bone markings appear on the temporal bone (see Figure 5.7):

- The **mastoid** (mas′toid) **process,** which is full of air cavities (mastoid sinuses), is a rough projection posterior and inferior to the external acoustic meatus. It provides an attachment site for some muscles of the neck. The mastoid sinuses are so close to the middle ear—a high-risk spot for infections—that they may become infected too, a condition called *mastoiditis.* Also, this area is so close to the brain that mastoiditis may spread to the brain.
- The **jugular foramen,** at the junction of the occipital and temporal bones (Figures 5.8 and 5.9), allows passage of the jugular vein, the largest vein of the head, which drains the brain. Just anterior to it in the cranial cavity is the **internal acoustic meatus** (see Figure 5.8), which transmits cranial nerves VII and VIII (the facial and vestibulocochlear nerves). Anterior to the jugular foramen on the skull's inferior aspect is the **carotid canal** (see Figure 5.9), through which the internal carotid artery runs, supplying blood to most of the brain.

Occipital Bone If you look at Figures 5.7, 5.8, and 5.9, you can see that the occipital (ok-sip′ĭ-tal) bone is the most posterior bone of the cranium. It forms the floor and back wall of the skull. The occipital bone joins the parietal bones anteriorly at the **lambdoid** (lam′doyd) **suture.** In the base of the occipital bone is a large opening, the **foramen magnum** (literally, "large hole"). The foramen magnum surrounds the lower part of the brain and allows the spinal cord to connect with the brain. Lateral to the foramen magnum on each side are the rockerlike **occipital condyles** (see Figure 5.9), which rest on the first vertebra of the spinal column.

Sphenoid Bone The butterfly-shaped sphenoid (sfe′noid) bone spans the width of the skull and forms part of the floor of the cranial cavity (see

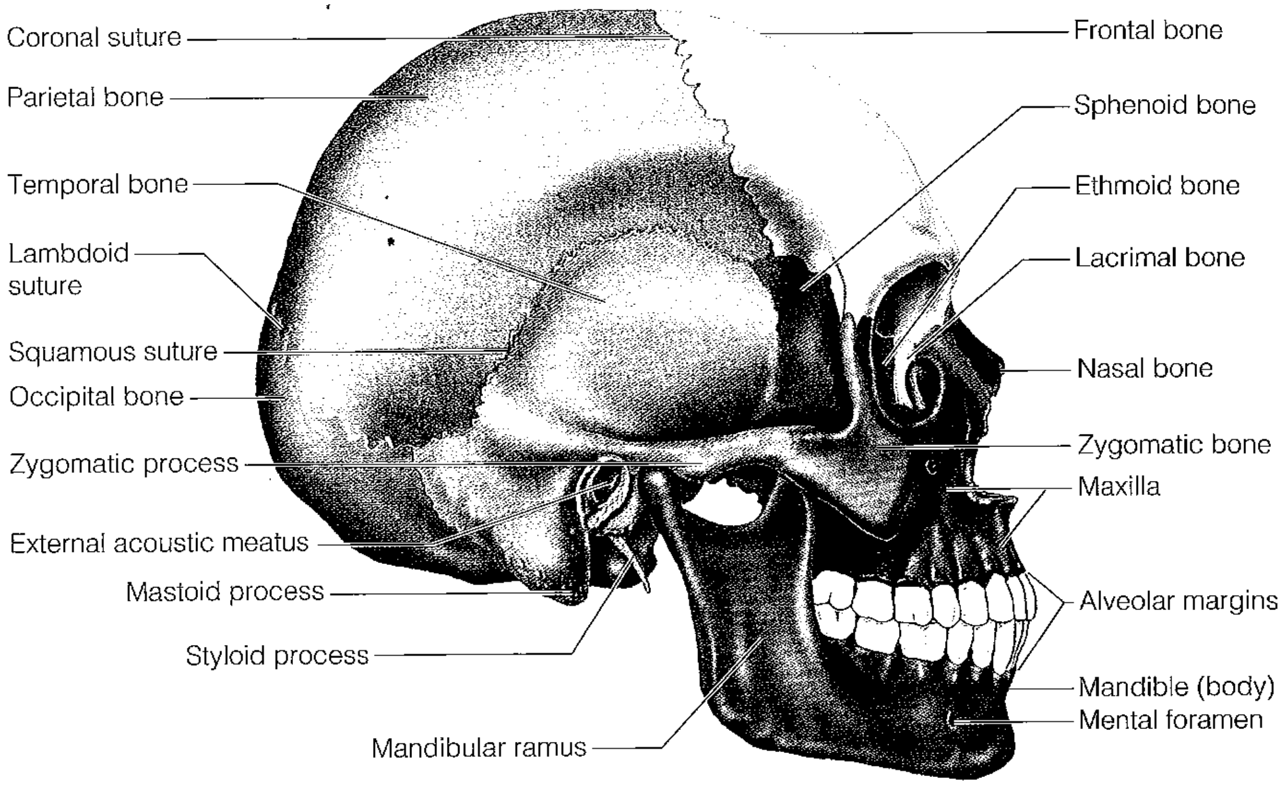


FIGURE 5.7 Human skull, lateral view.

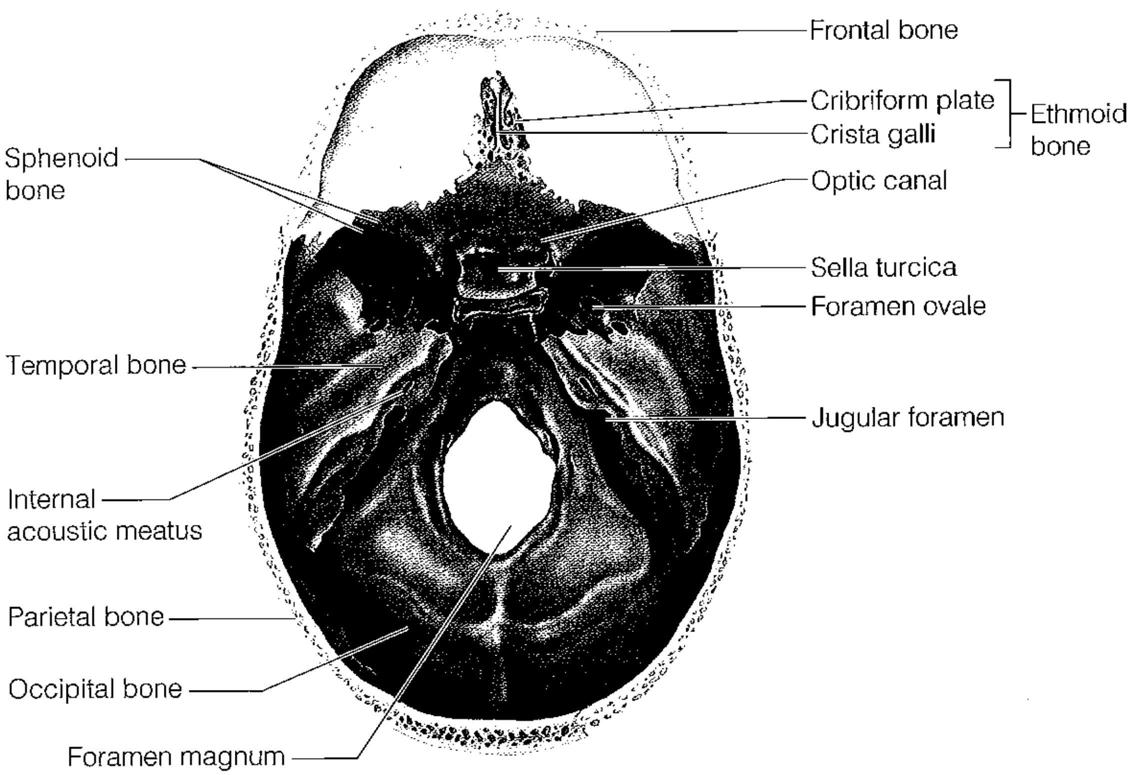


FIGURE 5.8 Human skull, superior view (top of cranium removed).

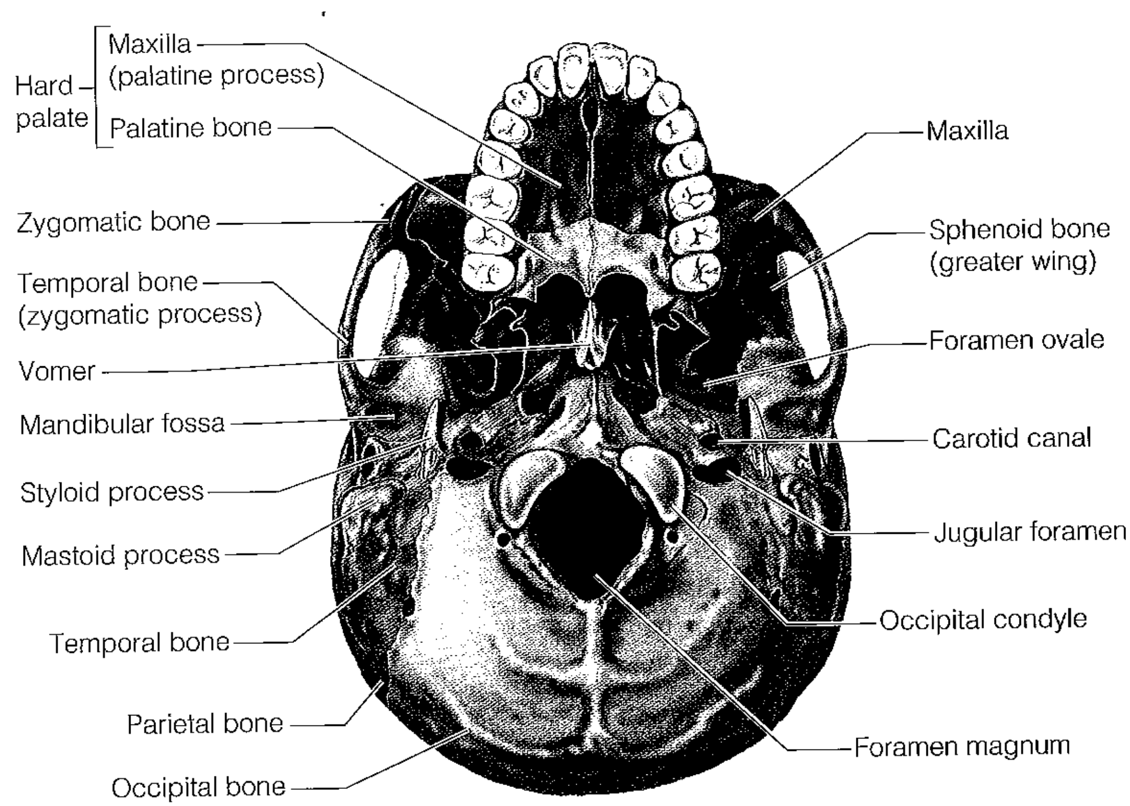
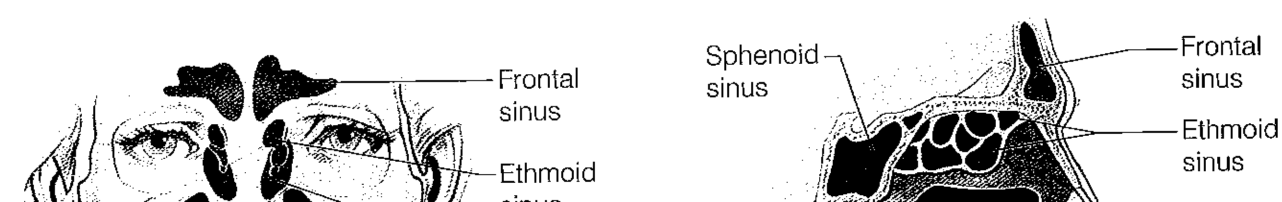


FIGURE 5.9 Human skull, inferior view (mandible removed).

openings, the **optic canal,** which allows the optic nerve to pass to the eye, and the slitlike **superior orbital fissure,** through which the cranial nerves controlling eye movements (III, IV, and VI) pass (see Figures 5.7 and 5.11). The central part of the sphenoid bone is riddled with air cavities, the **sphenoid sinuses** (Figure 5.10).

Ethmoid Bone The ethmoid (eth′moid) bone is very irregularly shaped and lies anterior to the



Q *What bone articulates with every other facial bone?*

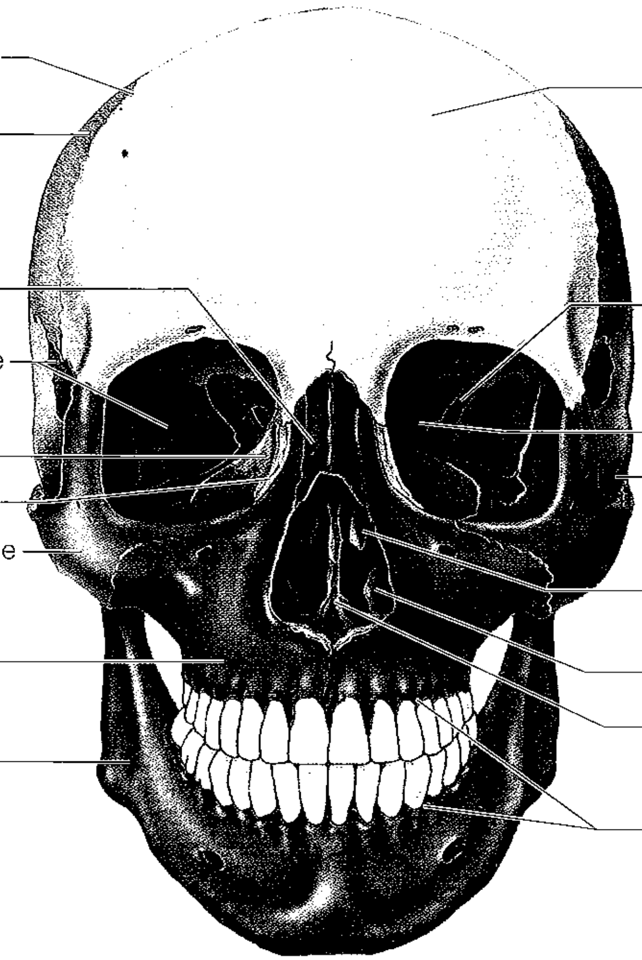


FIGURE 5.11 **Human skull, anterior view.**

sphenoid (Figure 5.11; see also Figures 5.7 and 5.8). It forms the roof of the nasal cavity and part of the medial walls of the orbits. Projecting from its superior surface is the **crista galli** (kris'tah gah'le), literally "cock's comb" (see Figure 5.8). The outermost covering of the brain attaches to this projection. On each side of the crista galli are many small holes. These holey areas, the **cribriform** (krib'rĭ-form) **plates,** allow nerve fibers carrying impulses from the olfactory (smell) receptors of the nose to reach the brain. Extensions of the ethmoid bone, the **superior** and **middle nasal conchae** (kong'ke), form part of the lateral walls of the nasal cavity (see Figure 5.11) and increase the turbulence of air flowing through the nasal passages.

Facial Bones

Fourteen bones compose the face. Twelve are paired; only the mandible and vomer are single. Figures 5.7 and 5.11 show most of the facial bones.

Maxillae The two maxillae (mak-si'le), or **maxillary bones,** fuse to form the upper jaw. All facial bones except the mandible join the maxillae; thus they are the main, or "keystone," bones of the face. The maxillae carry the upper teeth in the **alveolar margin.**

A *The maxilla.*

Extensions of the maxillae called the **palatine** (pal′ah-tīn) **processes** form the anterior part of the hard palate of the mouth (see Figure 5.9). Like many other facial bones, the maxillae contain **sinuses,** which drain into the nasal passages (see Figure 5.10). These **paranasal sinuses,** whose naming reveals their position surrounding the nasal cavity, lighten the skull bones and amplify the sounds we make as we speak. They also cause many people a great deal of misery. Because the mucosa lining these sinuses is continuous with that in the nasal passages and throat, infections in these areas tend to migrate into the sinuses, causing *sinusitis.* Depending on which sinuses are infected, a headache or upper jaw pain is the usual result.

Palatine Bones The paired palatine bones lie posterior to the palatine processes of the maxillae. They form the posterior part of the hard palate (see Figure 5.9). Failure of these or the palatine processes to fuse medially results in *cleft palate.*

Zygomatic Bones The zygomatic bones are commonly referred to as the cheekbones. They also form a good-sized portion of the lateral walls of the orbits, or eye sockets.

Lacrimal Bones The lacrimal (lak′rĭ-mal) bones are fingernail-sized bones forming part of the medial walls of each orbit. Each lacrimal bone has a groove that serves as a passageway for tears (*lacrima* = tear).

Nasal Bones The small rectangular bones forming the bridge of the nose are the nasal bones. (The lower part of the skeleton of the nose is made up of cartilage.)

Vomer Bone The single bone in the median line of the nasal cavity is the vomer. (*Vomer* means "plow," which refers to the bone's shape.) The vomer forms most of the bony nasal septum.

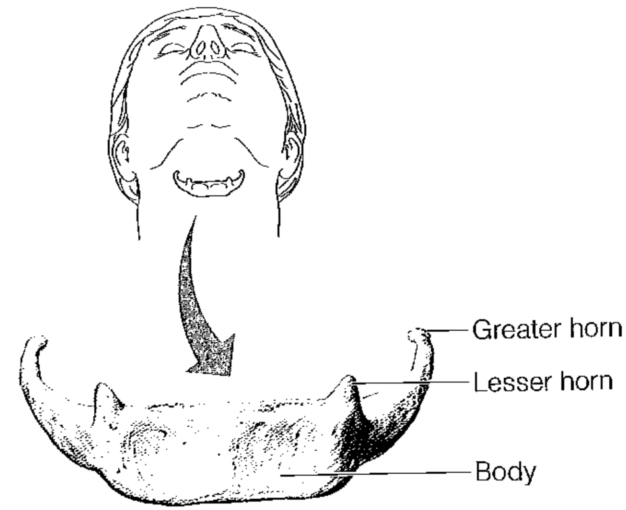


FIGURE 5.12 Anatomical location and structure of the hyoid bone. Anterior view.

over your cheekbones and opening and closing your mouth. The horizontal part of the mandible (the *body*) forms the chin. Two upright bars of bone (the *rami*) extend from the body to connect the mandible with the temporal bone. The lower teeth lie in *alveoli* (sockets) in the **alveolar margin** at the superior edge of the mandibular body.

The Hyoid Bone

Though not really part of the skull, the **hyoid** (hi′oid) **bone** (Figure 5.12) is closely related to the mandible and temporal bones. The hyoid bone is unique in that it is the only bone of the body that does not articulate directly with any other bone. Instead, it is suspended in the midneck region about 2 cm (1 inch) above the larynx, where it is anchored by ligaments to the styloid processes of the temporal bones. Horseshoe-shaped, with a *body* and two pairs of *horns,* or *cornua,* the hyoid

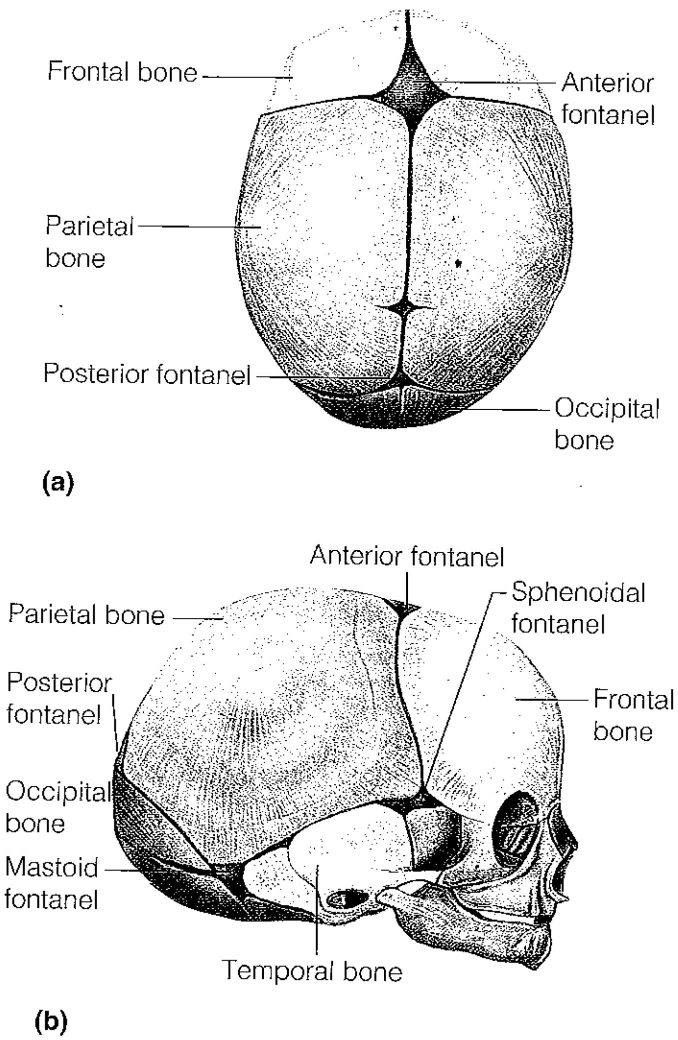


FIGURE 5.13 The fetal skull. (a) Superior view. **(b)** Lateral view.

total body length. The adult skull represents only one-eighth of the total body length, whereas that of a newborn infant is one-fourth as long as its entire body. When a baby is born, its skeleton is still unfinished. As noted earlier, some areas of hyaline cartilage still remain to be ossified, or converted to bone. In the newborn, the skull also has fibrous regions that have yet to be converted to bone. These fibrous membranes connecting the cranial bones are called **fontanels** (fon″tah-nelz′). The rhythm of the baby's pulse can be felt in these "soft spots," which explains their name (*fontanel* = little fountain). The largest fontanel is the diamond-shaped *anterior fontanel*. The fontanels allow the fetal skull to be compressed slightly during birth. In addition, because they are flexible, they allow the infant's brain to grow during the later part of pregnancy and early infancy. This would not be possible if the cranial bones were fused in sutures as in the adult skull. The fontanels are gradually converted to bone during the early part of infancy and can no longer be felt by 22 to 24 months after birth.

DID YOU GET IT?

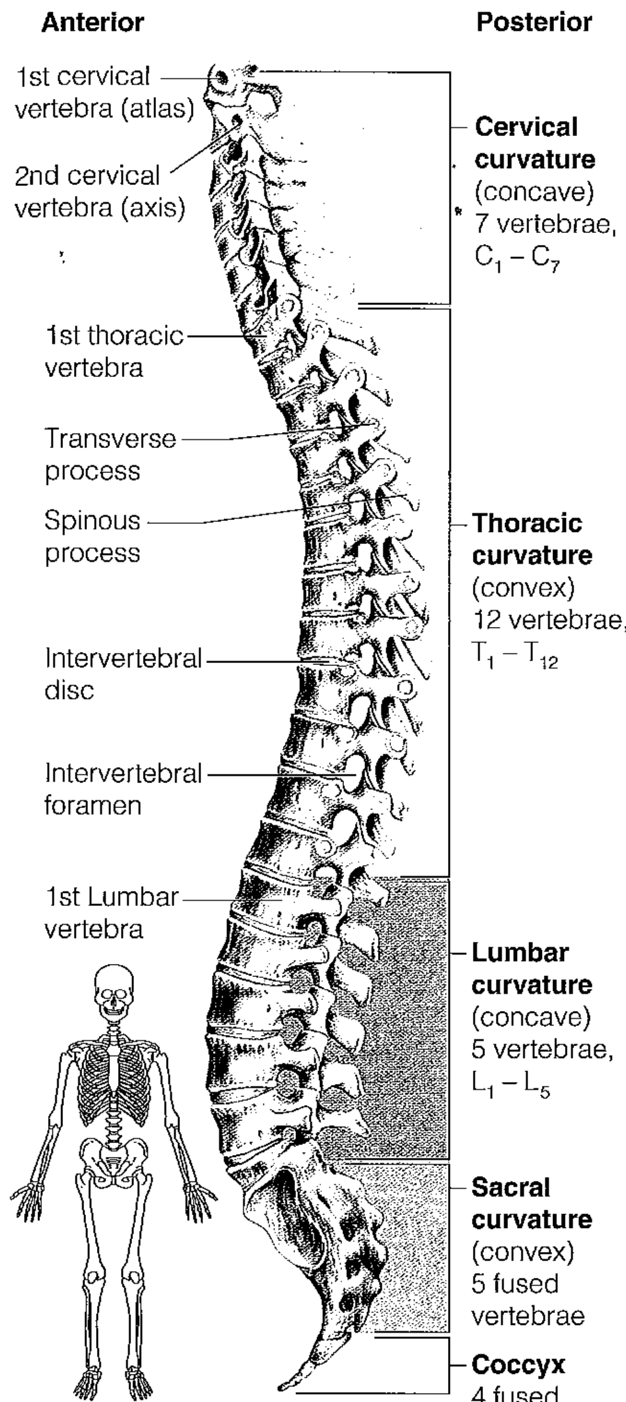
9. What are the three main parts of the axial skeleton?
10. Johnny was vigorously exercising the only joints in the skull that are freely movable. What would you guess he was doing?
11. Which skull bone(s) form the "keystone of the face"?
12. Which bone has the cribriform plate and crista galli?
13. Which bones are connected by the coronal suture? By the sagittal suture?

For answers, see Appendix D.

Vertebral Column (Spine)

Serving as the axial support of the body, the **vertebral column,** or **spine,** extends from the skull, which it supports, to the pelvis, where it transmits the weight of the body to the lower limbs. Some people think of the vertebral column as a rigid supporting rod, but that picture is inaccurate. Instead, the spine is formed from 26 irregular bones connected and reinforced by ligaments in such a way that a flexible, curved structure results (Figure 5.14). Running through the central cavity of the vertebral column is the delicate spinal cord, which the vertebral column surrounds and protects.

Before birth, the spine consists of 33 separate bones called **vertebrae,** but 9 of these eventually fuse to form the two composite bones, the *sacrum* and the *coccyx,* that construct the inferior portion of the vertebral column. Of the 24 single bones, the 7 vertebrae of the neck are *cervical vertebrae,* the next 12 are the *thoracic vertebrae,* and the remaining 5 supporting the lower back are *lumbar vertebrae.*



- Remembering common meal times, 7 AM, 12 noon, and 5 PM, may help you to recall the number of bones in these three regions of the vertebral column.

The individual vertebrae are separated by pads of flexible fibrocartilage—**intervertebral discs**—that cushion the vertebrae and absorb shocks while allowing the spine flexibility. In a young person, the discs have a high water content (about 90 percent) and are spongy and compressible. But as a person ages, the water content of the discs decreases (as it does in other tissues throughout the body), and the discs become harder and less compressible.

HOMEOSTATIC IMBALANCE

Drying of the discs, along with a weakening of the ligaments of the vertebral column, predisposes older people to **herniated** ("slipped") **discs.** However, herniation also may result when the vertebral column is subjected to exceptional twisting forces. If the protruding disc presses on the spinal cord or the spinal nerves exiting from the cord, numbness and excruciating pain can result. ▲

The discs and the S-shaped structure of the vertebral column work together to prevent shock to the head when we walk or run. They also make the body trunk flexible. The spinal curvatures in the thoracic and sacral regions are referred to as **primary curvatures** because they are present when we are born. Together the two primary curvatures produce the C-shaped spine of the newborn baby (Figure 5.15). The curvatures in the

Text continues on p. 154

A CLOSER LOOK

PROTECT YOUR BACK—IT'S THE ONLY ONE YOU'VE GOT!

Regular exercise is vital to keep the spine strong and to protect its beautifully proportioned structure. Unfortunately, most of us neglect our backs until pains and aches demand our attention. Next to sore throats and the common cold. Millions of U.S. citizens suffer from back pain, and back injuries account for a quarter of all disability insurance payments.

Although backache may be symptomatic of many ailments, from spinal tumor to kidney disease, over 80 percent of back problems result from weak muscles or are anxiety-related. This is not surprising; strong abdominal muscles and flexible back and hip muscles play a major role in reinforcing the spine's delicate architecture, and stress causes muscles to "knot." Tense muscles can aggravate a back problem even if they do not cause it. Obese individuals and those who rarely exercise are prime candidates for lower back pain. Indeed, some orthopedists (bone specialists) look upon back pain as an index of affluence. The more gadgets we accumulate to do our work for us, the more we can sit or lie down—and the more our muscles deteriorate. On the other side of the coin, people who work at jobs that require heavy lifting are also at risk for lower back pain if they do not lift properly.

As the saying goes, "An ounce of prevention is worth a pound of cure," and preventing back problems is better than attempting to treat agonizing back pain. Perhaps 70 to 80 percent of all cases of lower back pain are preventable with only 10 minutes of daily exercise, if proper body alignment and certain precautions are observed.

> *"Backaches are among the most common reasons for visits to the physician's office."*

Here are a few well-documented guidelines for protecting your back.

1. Keep your weight down. Just a few extra pounds of weight, particularly the unbalanced weight of a protruding potbelly, exert a strain on the spine that is much greater than that of the weight itself. The protruding abdomen pulls the body forward, forcing the back muscles to contract more strongly to counterbalance the weight. For example, 10 extra pounds located 10 inches anterior to the spine in the abdominal region force the back muscles to exert 50 extra pounds of force to counteract the 10-pound pulling force.
2. Wear high-heeled and negative-heeled shoes or boots infrequently, and avoid them altogether if you have back problems. Both change the alignment of the spine. High-heeled shoes tilt the pelvis forward and increase the stress on the abdominal and back muscles. Negative-heeled shoes tilt the pelvis backward,

Lowering the center of gravity by squatting.

making it difficult for you to transfer your weight during walking.

3. Maintain good posture. Keep your head and back aligned, with abdomen and buttocks tucked inward.

4. Lift heavy objects using proper body mechanics. Every object, including a human body, has a center of gravity around which its mass is equally distributed. In a standing adult, the center of gravity is inside the pelvis, slightly posterior to the anterior border of the joint between the sacrum and the fifth lumbar vertebra. A basic principle of body mechanics is the broader your base of support and the lower your center of gravity, the more stable you are. Applying this principle to lifting demands that you take a wider than normal stance (spread your feet apart slightly), and then bend your knees (rather than your back) to reach for and pick up the object (see the photograph on previous page). The weight is then transmitted to your stronger legs, sparing your more delicate spine. If you must move large objects, push rather than pull them.

5. Avoid sitting for prolonged periods. Sitting puts much more stress on the spine than standing: truck drivers have five times the normal risk for lower back problems and herniated discs. If you must sit for an extended time, resting your feet on a small stool (or the lowest desk drawer) will reduce the stress on your vertebral column.

6. Take 10 minutes a day to stretch your lower back extensor muscles and hip flexor muscles and to strengthen your abdominal muscles. (See instructions and photos **a–c**, which follow.) If you have a history of back problems, avoid any exercise that strains your lower back, including (1) sit-ups with straight legs, (2) double leg raises, and (3) lying on your abdomen and then raising your head, arms, and legs.

Dare to be different! Be good to your spine and you may well be saved from uttering that nearly universal complaint, "Oh, my aching back!"

(a) *Stretching the extensor muscles of the lower back.* Lie on back with knees bent and feet flat on the floor. Keeping your arms at your sides, raise one knee to the chest. Lower the foot to the floor with knee bent, and then slide the foot along the floor until the leg is fully extended. Rotate the leg gently from side to side.

Resume the starting position and repeat the exercise with the alternate leg. Repeat the entire exercise 5 to 6 times.

(b) *Stretching the flexor muscles of the hip.* Lie on back. Exhale as you bring both knees toward the chest. Then, while holding one knee to the chest, slide the opposite leg along the floor until it is fully extended. Attempt to touch the back of the knee (popliteal region) of the extended leg to the floor. Hold for a count of 6.

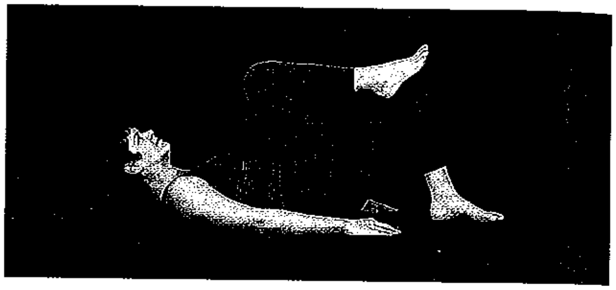
A CLOSER LOOK Protect Your Back *(continued)*

Resume the starting position and repeat the exercise with the alternate leg. Repeat the entire exercise 5 to 6 times.

(c) *Strengthening the abdominal muscles.* Lie on back with knees bent and feet flat on floor. Keeping your arms at your sides, raise one knee toward your chest. Exhale as you lift your head, attempting to touch your raised knee to your forehead. Count to 6. Resume the starting position, and roll your head gently from side to side. Inhale, and repeat the exercise with the alternate leg.

Repeat the entire exercise 8 to 10 times at the beginning; work up to 25 repetitions per day.

(b)



(c)

cervical and lumbar regions are referred to as **secondary curvatures** because they develop some time after birth. In adults, the secondary curvatures allow us to center our body weight on our lower limbs with minimum effort. The cervical curvature appears when a baby begins to raise its head, and the lumbar curvature develops when the baby begins to walk.

HOMEOSTATIC IMBALANCE

Why do they do "spine checks" in middle school? The answer is that they are looking for abnormal spinal curvatures. There are several types of abnormal spinal curvatures. Figure 5.16 shows three of these—**scoliosis** (sko″le-o′sis), **kyphosis** (ki-fo′sis), and **lordosis** (lor-do′sis). These abnormalities may be congenital (present at birth) or result from disease, poor posture, or unequal muscle pull on the spine. As you look at these diagrams, try to pinpoint how each of these conditions differs from the normal healthy spine. ▲

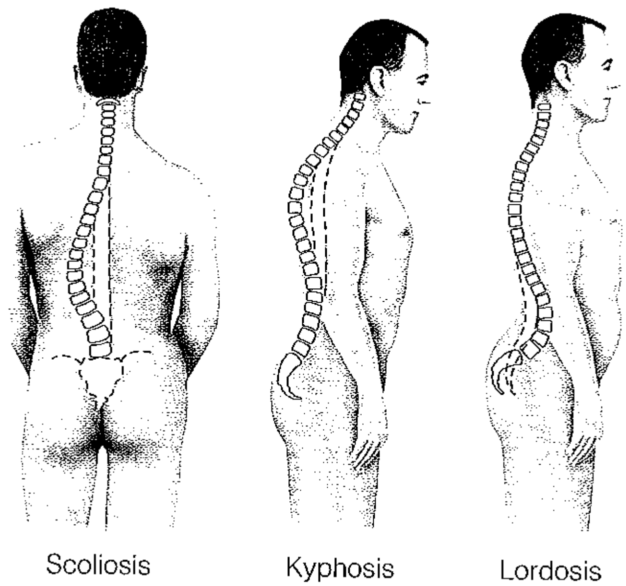


FIGURE 5.16 Abnormal spinal curvatures.

All vertebrae have a similar structural pattern (Figure 5.17). The common features of vertebrae include the following:

- **Body** or **centrum:** disclike, weight-bearing part of the vertebra facing anteriorly in the vertebral column.
- **Vertebral arch:** arch formed from the joining of all posterior extensions, the **laminae** and **pedicles,** from the vertebral body.
- **Vertebral foramen:** canal through which the spinal cord passes.
- **Transverse processes:** two lateral projections from the vertebral arch.
- **Spinous process:** single projection arising from the posterior aspect of the vertebral arch (actually the fused laminae).
- **Superior and inferior articular processes:** paired projections lateral to the vertebral foramen, allowing a vertebra to form joints with adjacent vertebrae (see also Figure 5.18).

In addition to the common features just described, vertebrae in the different regions of the spine have very specific structural characteristics. These unique regional characteristics of the vertebrae are described next.

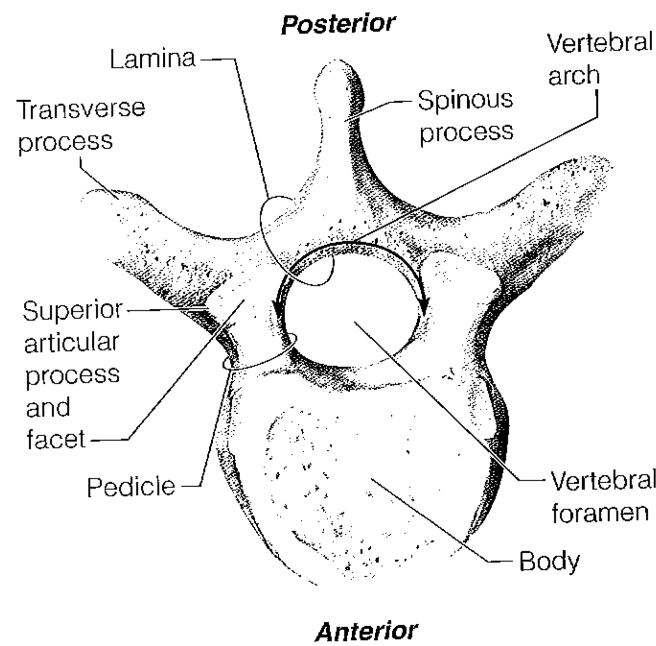


FIGURE 5.17 A typical vertebra, superior view. (Inferior articulating surfaces are not shown.)

Cervical Vertebrae

The seven **cervical vertebrae** (identified as C_1 to C_7) form the neck region of the spine. The first two vertebrae (*atlas* and *axis*) are different because they perform functions not shared by the other cervical vertebrae. As you can see in Figure 5.18a, the **atlas** (C_1) has no body. The superior surfaces of its transverse processes contain large depressions that receive the occipital condyles of the skull. This joint allows you to nod "yes." The **axis** (C_2) acts as a pivot for the rotation of the atlas (and skull) above. It has a large upright process, the **dens,** which acts as the pivot point. The joint between C_1 and C_2 allows you to rotate your head from side to side to indicate "no."

The "typical" cervical vertebrae (C_3 through C_7)

Thoracic Vertebrae

The 12 **thoracic vertebrae** (T_1 to T_{12}) are all typical. They are larger than the cervical vertebrae and are distinguished by the fact that they are the only vertebrae to articulate with the ribs. As seen in Figure 5.18c, the body is somewhat heart-shaped and has two costal facets (articulating surfaces) on each side, which receive the heads of the ribs. The two transverse processes of each thoracic vertebra articulate with the nearby knoblike tubercles of the ribs. The spinous process is long and hooks sharply downward, causing the vertebra to look like a giraffe's head viewed from the side.

Lumbar Vertebrae

The five **lumbar vertebrae** (L_1 to L_5) have mas-

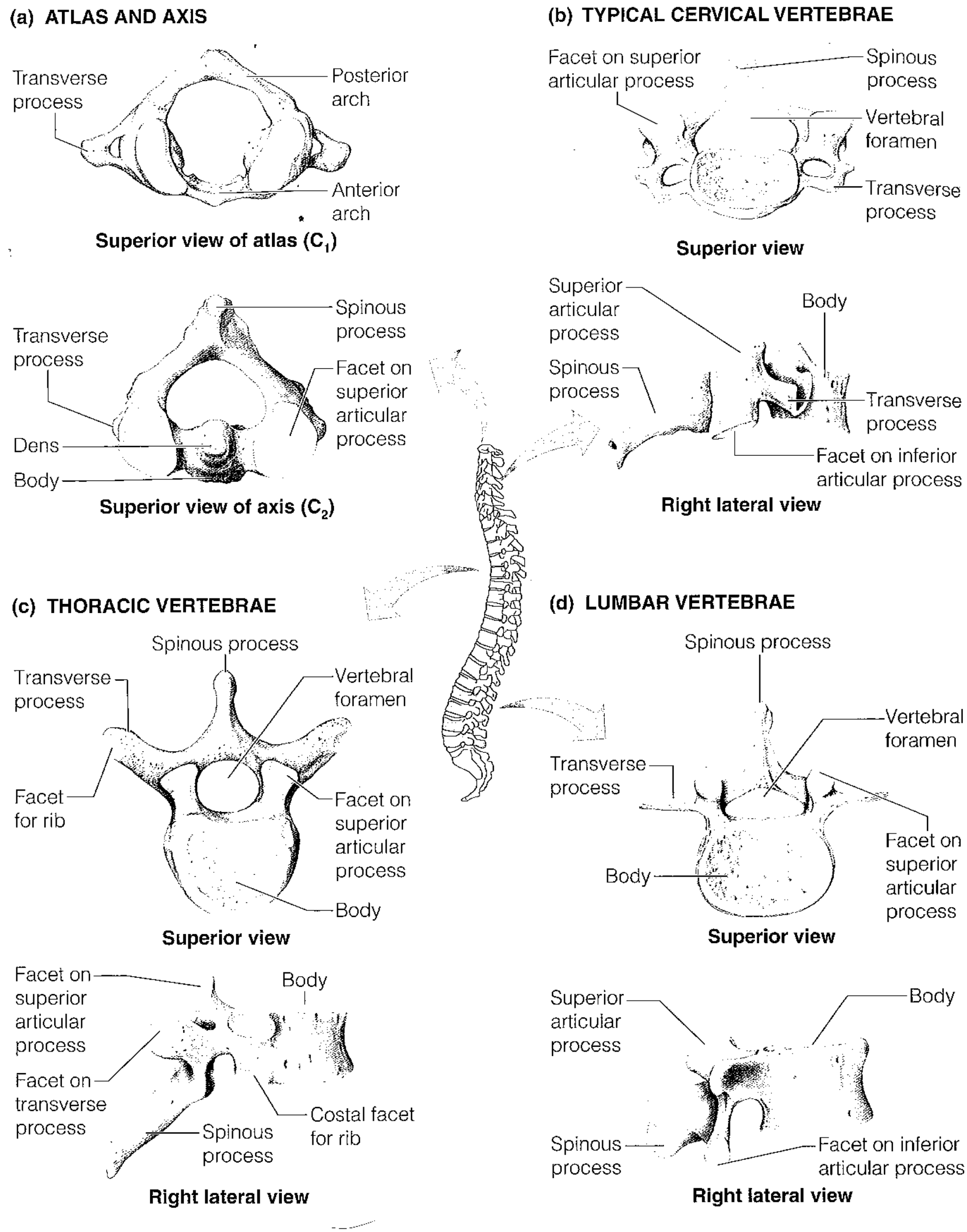


FIGURE 5.18 Regional characteristics of vertebrae.
(a) Superior views of the atlas and axis. **(b)** Typical cervical vertebrae.
(c) Thoracic vertebrae. **(d)** Lumbar vertebrae.

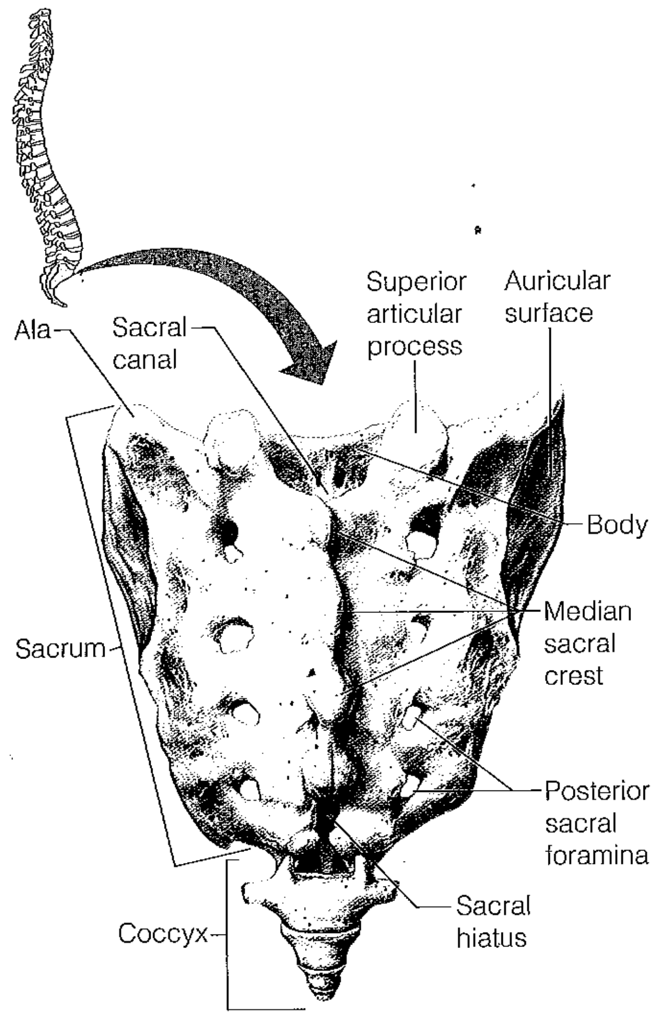


FIGURE 5.19 Sacrum and coccyx, posterior view.

with L_5, and inferiorly it connects with the coccyx. The winglike **alae** articulate laterally with the hip bones, forming the sacroiliac joints. The sacrum forms the posterior wall of the pelvis. Its posterior midline surface is roughened by the **median sacral crest,** the fused spinous processes of the sacral vertebrae. This is flanked laterally by the *posterior*

Thoracic Cage

The sternum, ribs, and thoracic vertebrae make up the **bony thorax.** The bony thorax is routinely called the **thoracic cage** because it forms a protective, cone-shaped cage of slender bones around the organs of the thoracic cavity (heart, lungs, and major blood vessels). The bony thorax is shown in Figure 5.20.

Sternum

The **sternum** (breastbone) is a typical flat bone and the result of the fusion of three bones—the **manubrium** (mah-nu′bre-um), **body,** and **xiphoid** (zif′oid) **process.** It is attached to the first seven pairs of ribs.

The sternum has three important bony landmarks—the jugular notch, the sternal angle, and the xiphisternal joint.

- The **jugular notch** (concave upper border of the manubrium) can be palpated easily; generally it is at the level of the third thoracic vertebra.
- The **sternal angle** results where the manubrium and body meet at a slight angle to each other, so that a transverse ridge is formed at the level of the second ribs. It provides a handy reference point for counting ribs to locate the second intercostal space for listening to certain heart valves.
- The **xiphisternal** (zi′fe-ster″nal) **joint,** the point where the sternal body and xiphoid process fuse, lies at the level of the ninth thoracic vertebra.

Palpate your sternal angle and jugular notch.

Because the sternum is so close to the body surface, it is easy to obtain samples from it of blood-forming (hematopoietic) tissue for the diagnosis of suspected blood diseases. A needle is inserted into the marrow of the sternum, and the sample is withdrawn; this procedure is called a *sternal puncture.* Because the heart lies immediately posterior to the

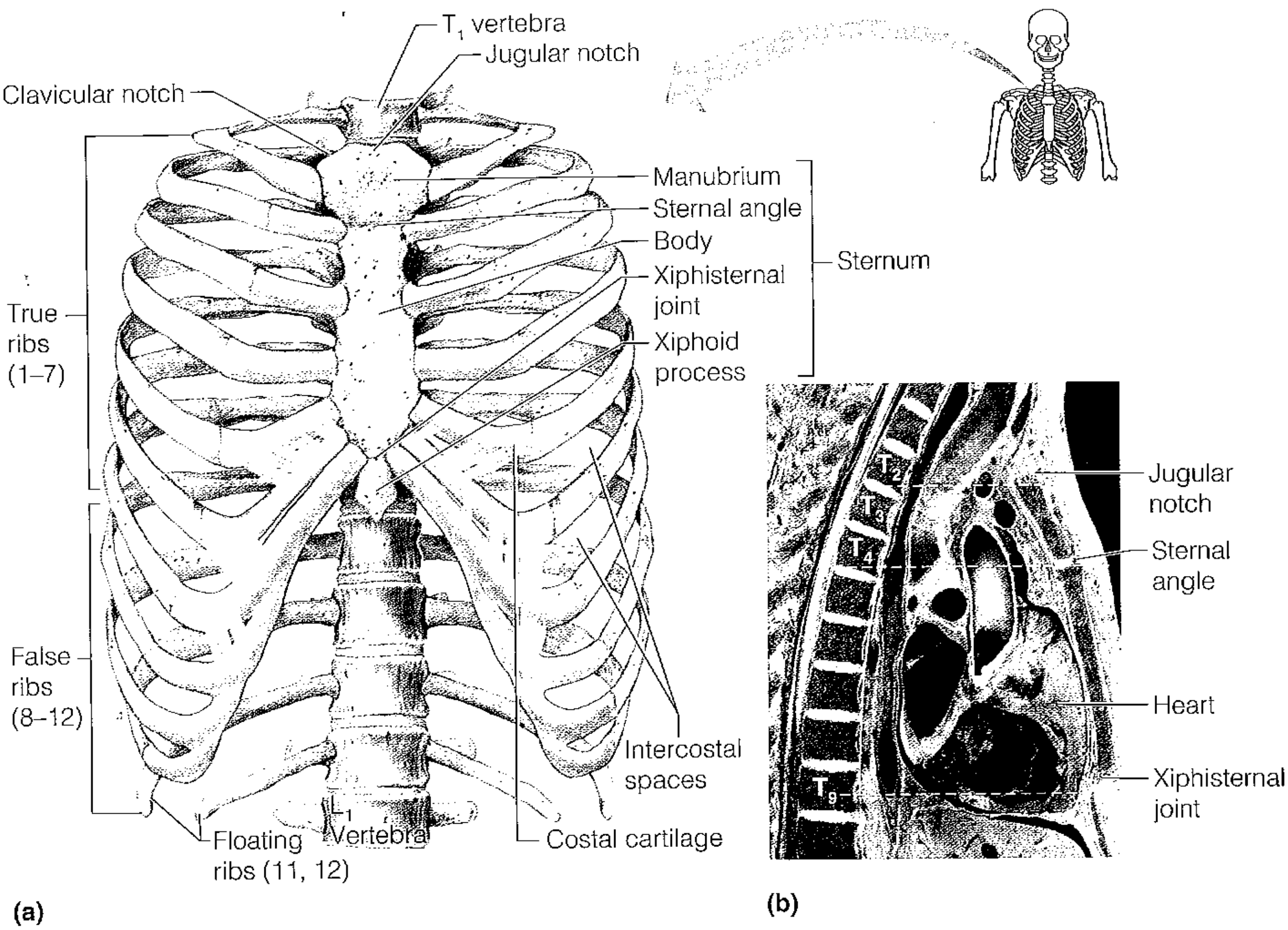


FIGURE 5.20 **The bony thorax (thoracic cage).** **(a)** Anterior view. **(b)** Midsagittal section through the thorax, showing the relationship of the key parts of the sternum to the vertebral column.

directly to the sternum by costal cartilages. **False ribs,** the next five pairs, either attach indirectly to the sternum or are not attached to the sternum at all. The last two pairs of false ribs lack the sternal attachments, so they are also called **floating ribs.**

The intercostal spaces (spaces between the ribs) are filled with the intercostal muscles that aid in breathing.

DID YOU GET IT?

14. What are the five major regions of the vertebral column?
15. How can you distinguish a lumbar vertebra from a cervical vertebra?
16. What is a true rib? A false rib?
17. How would a complete fracture of the dens affect the mobility of the vertebral column?

For answers, see Appendix D.

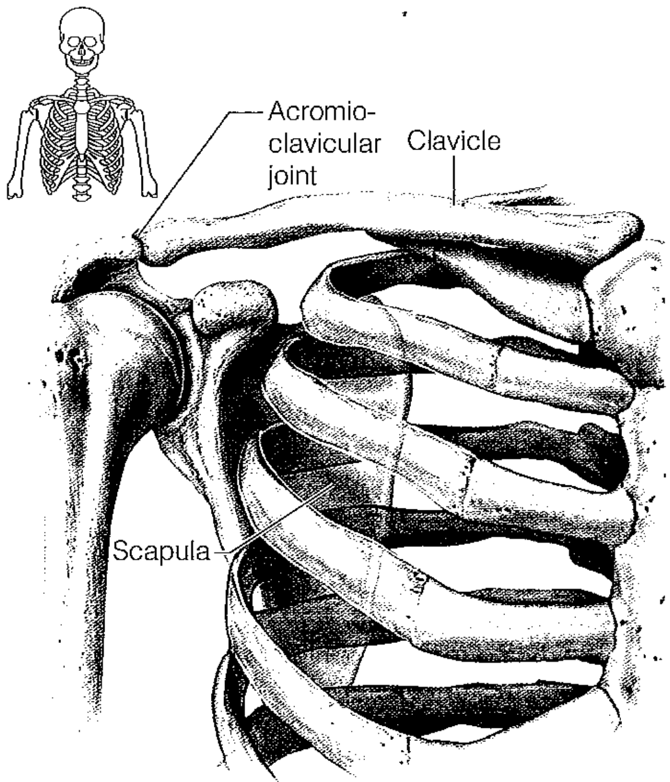
Appendicular Skeleton

The *appendicular skeleton* is shaded gold in Figure 5.6. It is composed of 126 bones of the limbs (appendages) and the pectoral and pelvic girdles, which attach the limbs to the axial skeleton.

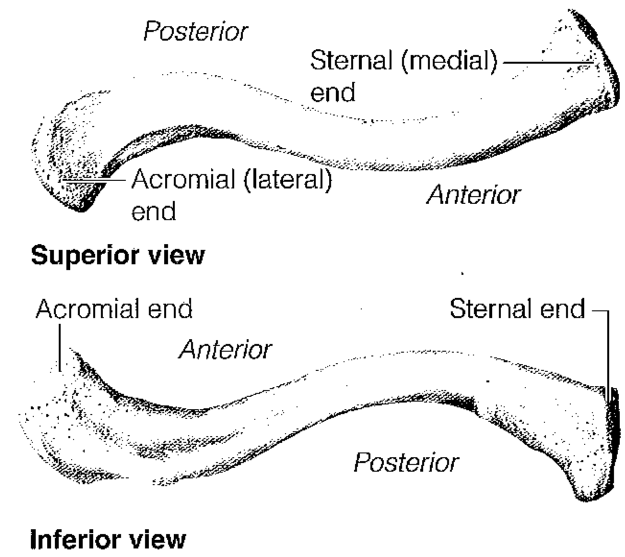
Bones of the Shoulder Girdle

Each **shoulder girdle,** or **pectoral girdle,** consists of two bones—a clavicle and a scapula (Figure 5.21).

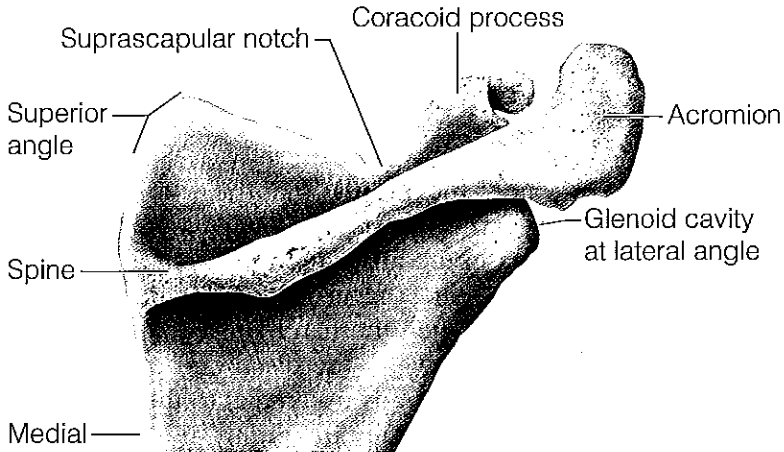
The **clavicle** (klav′ĭ-kl), or *collarbone,* is a slender, doubly curved bone. It attaches to the

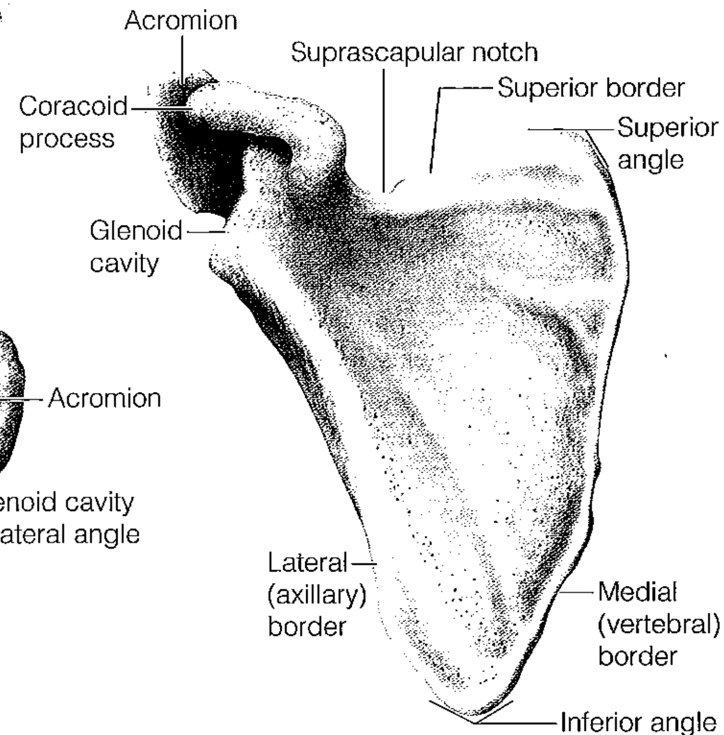


(a) **Articulated right shoulder (pectoral) girdle showing the relationship to bones of the thorax and sternum**



(b) Right clavicle, superior and inferior views





manubrium of the sternum medially (at its sternal end) and to the scapula laterally, where it helps to form the shoulder joint. The clavicle acts as a brace to hold the arm away from the top of the thorax and helps prevent shoulder dislocation. When the clavicle is broken, the whole shoulder region caves in medially, which shows how important its bracing function is.

The **scapulae** (skap'u-le), or *shoulder blades,* are triangular and are commonly called "wings" because they flare when we move our arms posteriorly. Each scapula has a flattened body and two important processes—the **acromion** (ah-kro'me-on), which is the enlarged end of the spine of the scapula, and the beaklike **coracoid** (kor'ah-koid) **process.** The acromion connects with the clavicle laterally at the **acromioclavicular joint.** The coracoid process points over the top of the shoulder and anchors some of the muscles of the arm. Just medial to the coracoid process is the large **suprascapular notch,** which serves as a nerve passageway. The scapula is not directly attached to the axial skeleton; it is loosely held in place by trunk muscles. The scapula has three borders—superior, medial (vertebral), and lateral (axillary). It also has three angles—superior, inferior, and lateral. The **glenoid cavity,** a shallow socket that receives the head of the arm bone, is in the lateral angle.

The shoulder girdle is very light and allows the upper limb to have exceptionally free movement. This is due to the following factors:

1. Each shoulder girdle attaches to the axial skeleton at only one point—the *sternoclavicular joint.*
2. The loose attachment of the scapula allows it to slide back and forth against the thorax as muscles act.
3. The glenoid cavity is shallow, and the shoulder joint is poorly reinforced by ligaments.

However, this exceptional flexibility also has a drawback; the shoulder girdle is very easily dislocated.

Bones of the Upper Limbs

Thirty separate bones form the skeletal framework of each upper limb (Figures 5.22 and 5.23). They form the foundations of the arm, forearm, and hand.

Arm

The arm is formed by a single bone, the **humerus** (hu'mer-us), which is a typical long bone (see Figure 5.22a and b). At its proximal end is a rounded head that fits into the shallow glenoid cavity of the scapula. Immediately inferior to the head is a slight constriction called the **anatomical neck.** Anterolateral to the head are two bony projections separated by the **intertubercular sulcus**—the **greater** and **lesser tubercles,** which are sites of muscle attachment. Just distal to the tubercles is the **surgical neck,** so named because it is the most frequently fractured part of the humerus. In the midpoint of the shaft is a roughened area called the **deltoid tuberosity,** where the large, fleshy deltoid muscle of the shoulder attaches. Nearby, the **radial groove** runs obliquely down the posterior aspect of the shaft. This groove marks the course of the radial nerve, an important nerve of the upper limb. At the distal end of the humerus is the medial **trochlea** (trok'le-ah), which looks somewhat like a spool, and the lateral ball-like **capitulum** (kah-pit'u-lum). Both of these processes articulate with bones of the forearm. Above the trochlea anteriorly is a depression, the **coronoid fossa;** on the posterior surface is the **olecranon** (o-lek'rah-non) **fossa.** These two depressions, which are flanked by **medial** and **lateral epicondyles,** allow the corresponding processes of the ulna to move freely when the elbow is bent and extended.

Forearm

Two bones, the radius and the ulna, form the skeleton of the forearm (see Figure 5.22c). When the body is in the anatomical position, the **radius** is the lateral bone; that is, it is on the thumb side of the forearm. When the hand is rotated so that the palm faces backward, the distal end of the radius crosses over and ends up medial to the ulna. Both proximally and distally the radius and ulna articulate at small **radioulnar joints,** and the two bones are connected along their entire length by the flexible **interosseous membrane.** Both the ulna and the radius have a **styloid process** at their distal end.

The disc-shaped head of the radius also forms a joint with the capitulum of the humerus. Just below the head is the **radial tuberosity,** where the tendon of the biceps muscle attaches.

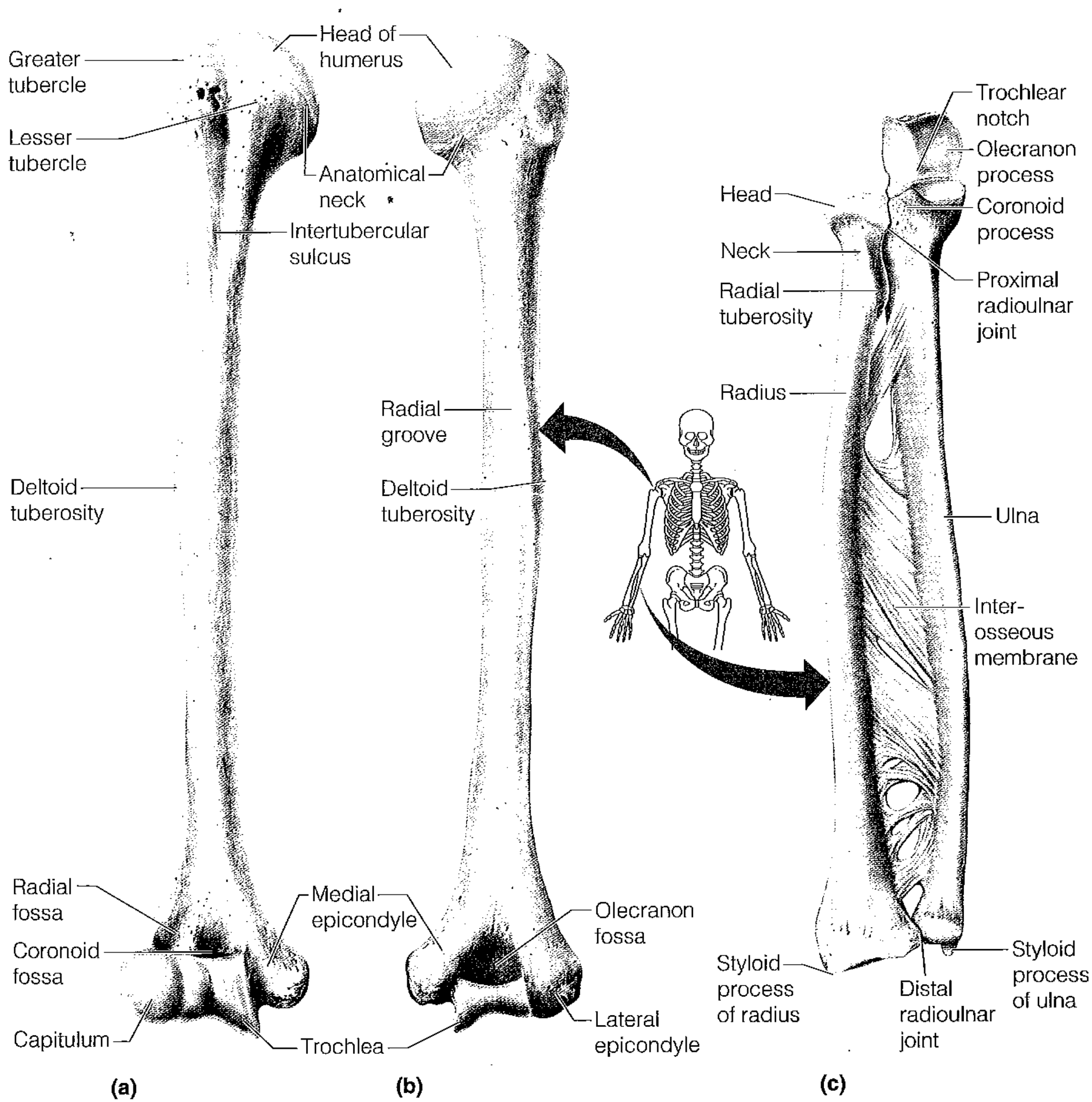


FIGURE 5.22 Bones of the right arm and forearm. (a) Humerus,

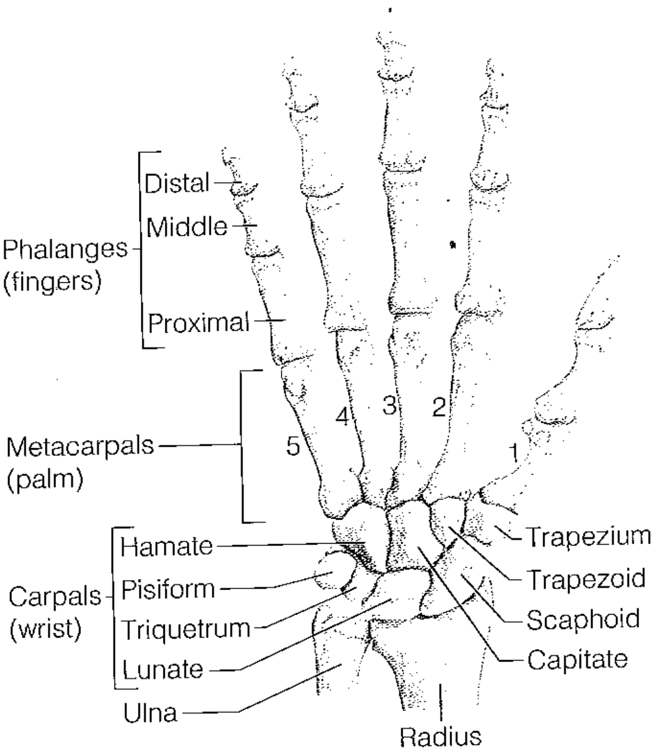


FIGURE 5.23 Bones of the right hand, anterior view.

The eight **carpal bones,** arranged in two irregular rows of four bones each, form the part of the hand called the **carpus** or, more commonly, the *wrist.* The carpals are bound together by ligaments that restrict movements between them. (In case you need to learn their names, the individual carpal bones are identified in Figure 5.23.)

The palm of the hand consists of the **metacarpals.** The **phalanges** (fah-lan'jēz) are the bones of the fingers. The metacarpals are numbered 1 to 5 from the thumb side of the hand toward the little finger. When the fist is clenched, the heads of the metacarpals become obvious as the "knuckles." Each hand contains 14 phalanges. There are three in each finger (proximal, middle, and distal), except in the thumb, which has only two (proximal and distal).

DID YOU GET IT?

18. What is the single point of attachment of the shoulder girdle to the axial skeleton?
19. What bone forms the skeleton of the arm?
20. Where are the carpals found, and what type (long, short, irregular, or flat) of bone are they?
21. Which bones of the upper limb have a styloid process?

For answers, see Appendix D.

Bones of the Pelvic Girdle

The **pelvic girdle** is formed by two **coxal** (kok'sal) **bones,** or **ossa coxae,** commonly called **hip bones.** Together with the sacrum and the coccyx, the hip bones form the *bony pelvis* (Figure 5.24). Note that the terms *pelvic girdle* and *bony pelvis* have slightly different meanings (pelvic girdle = 2 coxal bones; bony pelvis = 2 coxal bones, sacrum, and coccyx).

The bones of the pelvic girdle are large and heavy, and they are attached securely to the axial skeleton. The sockets, which receive the thigh bones, are deep and heavily reinforced by ligaments that attach the limbs firmly to the girdle. Bearing weight is the most important function of this girdle, because the total weight of the upper body rests on the bony pelvis. The reproductive organs, urinary bladder, and part of the large intestine lie within and are protected by the bony pelvis.

Each hip bone is formed by the fusion of three bones: the *ilium, ischium,* and *pubis.* The **ilium** (il'e-um), which connects posteriorly with the sacrum at the **sacroiliac** (sak"ro-il'e-ac) **joint,** is a large, flaring bone that forms most of the hip bone. When you put your hands on your hips, they are resting over the *alae,* or winglike portions, of the ilia. The upper edge of an ala, the **iliac crest,** is an important anatomical landmark that is always kept in mind by those who give intramuscular injections. The iliac crest ends anteriorly in the **anterior superior iliac spine** and posteriorly in the **posterior superior iliac spine.** Small inferior spines are located below these.

The **ischium** (is'ke-um) is the "sit-down bone," so called because it forms the most inferior part of the coxal bone. The **ischial tuberosity** is a roughened area that receives body weight when you are sitting. The **ischial spine,** superior to the tuberosity, is another important anatomical landmark, particularly in the pregnant woman, because it narrows the outlet of the pelvis through which the baby must pass during the birth process. Another important structural feature of the ischium is

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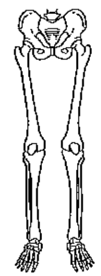

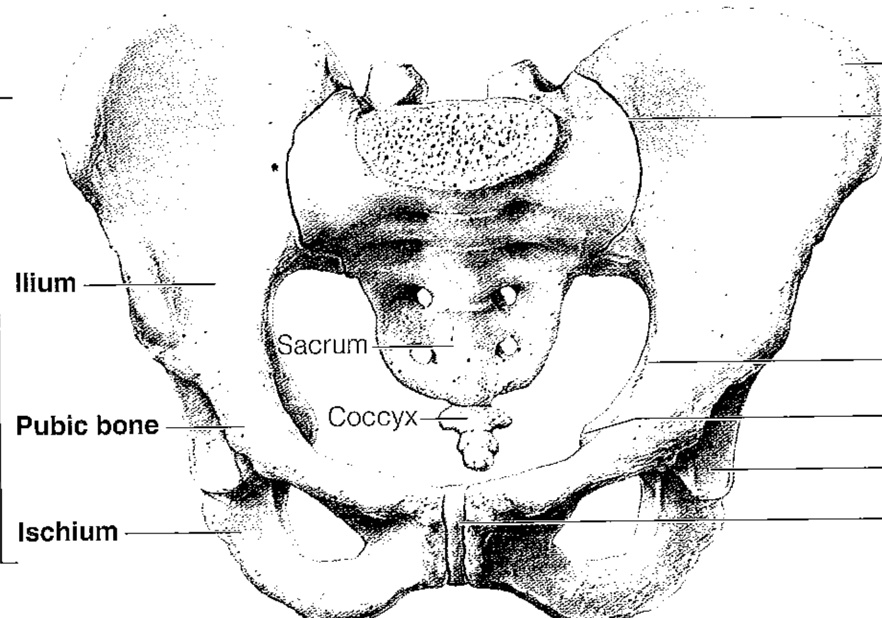

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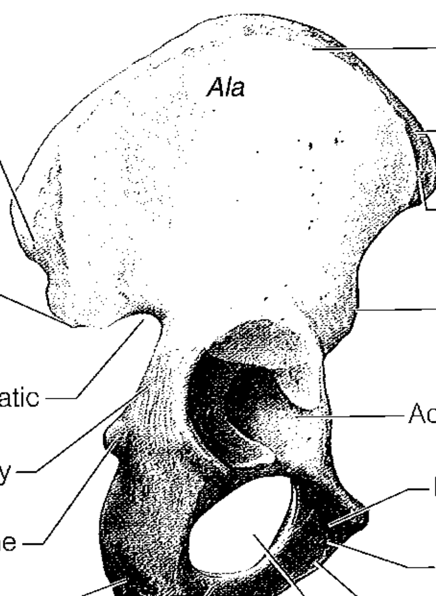
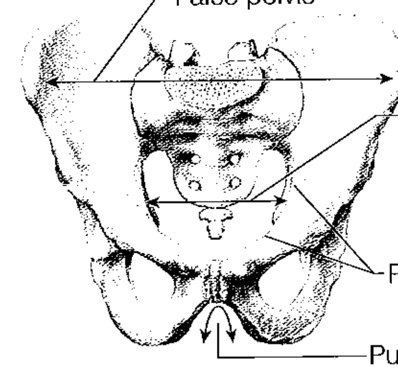
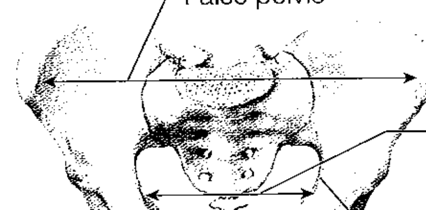






the **greater sciatic notch,** which allows blood vessels and the large sciatic nerve to pass from the pelvis posteriorly into the thigh. Injections in the buttock should always be given well away from this area.

The **pubis** (pu′bis), or **pubic bone,** is the most anterior part of a coxal bone. Fusion of the *rami* of the pubis anteriorly and the ischium posteriorly forms a bar of bone enclosing the **obturator** (ob′tu-ra″tor) **foramen,** an opening that allows blood vessels and nerves to pass into the anterior part of the thigh. The pubic bones of each hip bone fuse anteriorly to form a cartilaginous joint, the **pubic symphysis** (pu′bik sim′fĭ-sis).

The ilium, ischium, and pubis fuse at the deep socket called the **acetabulum** (as″ĕ-tab′u-lum), which means "vinegar cup." The acetabulum receives the head of the thigh bone.

The bony pelvis is divided into two regions. The **false pelvis** is superior to the true pelvis; it is the area medial to the flaring portions of the ilia. The **true pelvis** is surrounded by bone and lies inferior to the flaring parts of the ilia and the pelvic brim. The dimensions of the true pelvis of a woman are very important because they must be large enough to allow the infant's head (the largest part of the infant) to pass during childbirth. The dimensions of the cavity, particularly the **outlet** (the inferior opening of the pelvis measured between the ischial spines), and the **inlet** (superior opening between the right and left sides of the pelvic brim) are critical, and thus they are carefully measured by the obstetrician.

Of course, individual pelvic structures vary, but there are fairly consistent differences between a male and a female pelvis. Look at Figure 5.24c and notice the following characteristics that differ in the pelvis of the man and woman:

- The female inlet is larger and more circular.
- The female pelvis as a whole is shallower, and the bones are lighter and thinner.
- The female ilia flare more laterally.
- The female sacrum is shorter and less curved.
- The female ischial spines are shorter and farther apart; thus the outlet is larger.
- The female pubic arch is more rounded because the angle of the pubic arch is greater.

DID YOU GET IT?

22. What three bones form the hipbone? What bones form the pelvic girdle?
23. In what three ways does the bony pelvis of a woman differ from that of a man?

For answers, see Appendix D.

Bones of the Lower Limbs

The lower limbs carry our total body weight when we are erect. Hence, it is not surprising that the bones forming the three segments of the lower limbs (thigh, leg, and foot) are much thicker and stronger than the comparable bones of the upper limb.

Thigh

The **femur** (fe′mur), or *thigh bone,* is the only bone in the thigh (Figure 5.25a and b). It is the heaviest, strongest bone in the body. Its proximal end has a ball-like head, a neck, and **greater** and **lesser trochanters** (separated anteriorly by the **intertrochanteric line** and posteriorly by the **intertrochanteric crest**). These markings and the **gluteal tuberosity,** located on the shaft, all serve as sites for muscle attachment. The head of the femur articulates with the acetabulum of the hip bone in a deep, secure socket. However, the neck of the femur is a common fracture site, especially in old age.

The femur slants medially as it runs downward to join with the leg bones; this brings the knees in line with the body's center of gravity. The medial course of the femur is more noticeable in women because the female pelvis is wider than that of the male. Distally on the femur are the **lateral** and **medial condyles,** which articulate with the tibia below. Posteriorly these condyles are separated by the deep **intercondylar fossa.** Anteriorly on the distal femur is the smooth **patellar surface,** which forms a joint with the patella, or kneecap.

Leg

Connected along their length by an **interosseous membrane,** two bones, the tibia and fibula, form the skeleton of the leg (see Figure 5.25c). The **tibia,** or *shinbone,* is larger and more medial. At the proximal end, the **medial** and **lateral condyles** (separated by the **intercondylar eminence**) articulate

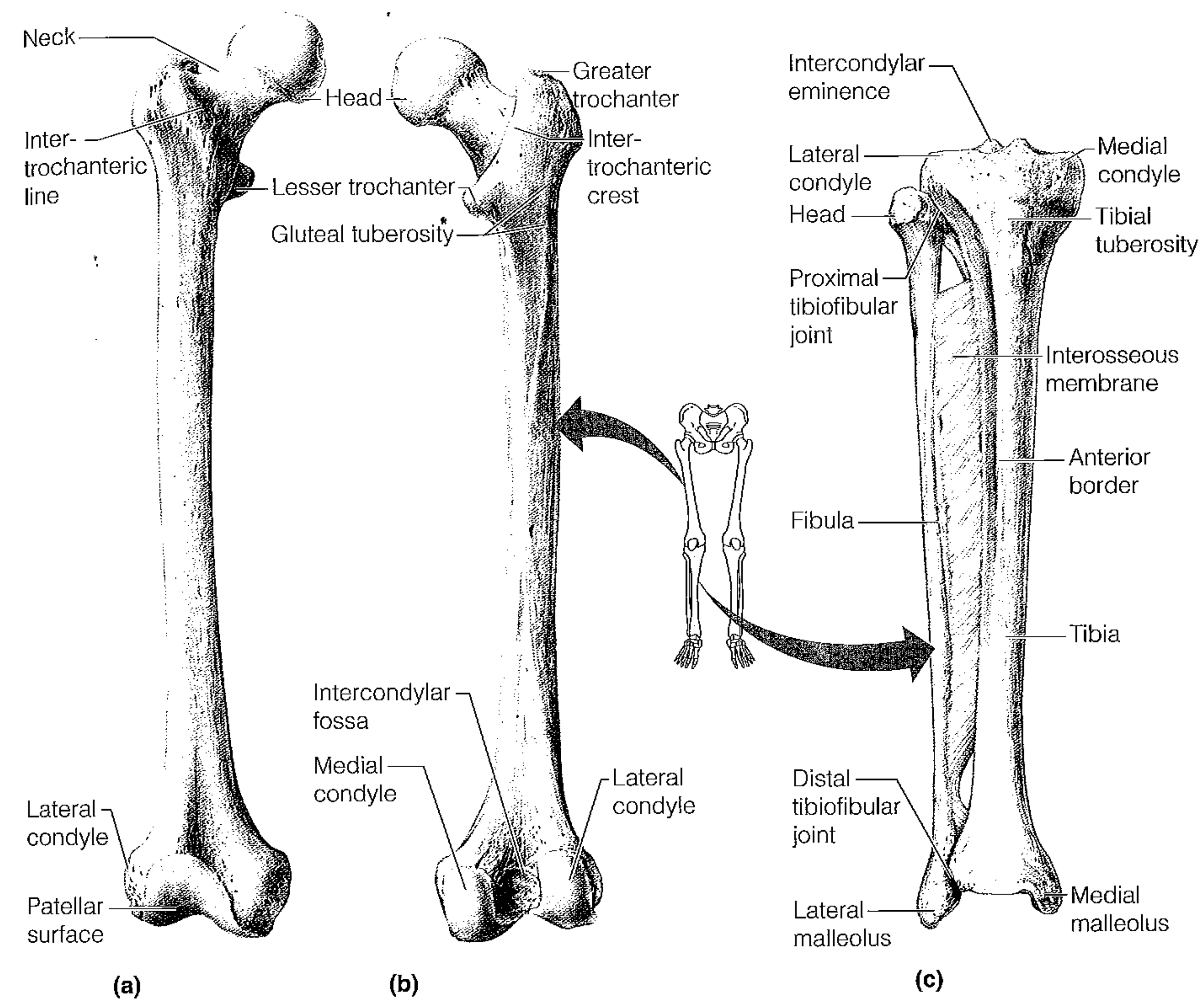


FIGURE 5.25 Bones of the right thigh and leg. (a) Femur (thigh bone), anterior view. **(b)** Femur, posterior view. **(c)** Tibia and fibula of the leg, anterior view.

with the distal end of the femur to form the knee joint. The patellar (kneecap) ligament attaches to the **tibial tuberosity,** a roughened area on the anterior tibial surface. Distally, a process called the **medial malleolus** (mal-le′o-lus) forms the inner bulge of the ankle. The anterior surface of the tibia is a sharp ridge, the **anterior border,** that is unprotected by muscles; thus, it is easily felt beneath the skin.

The **fibula,** which lies alongside the tibia and forms joints with it both proximally and distally, is thin and sticklike. The fibula has no part in forming the knee joint. Its distal end, the **lateral malleolus,** forms the outer part of the ankle.

Foot

The foot, composed of the tarsals, metatarsals, and phalanges, has two important functions. It supports our body weight and serves as a lever that allows us to propel our bodies forward when we walk and run.

The **tarsus,** forming the posterior half of the foot, is composed of seven **tarsal bones** (Figure 5.26). Body weight is carried mostly by the two

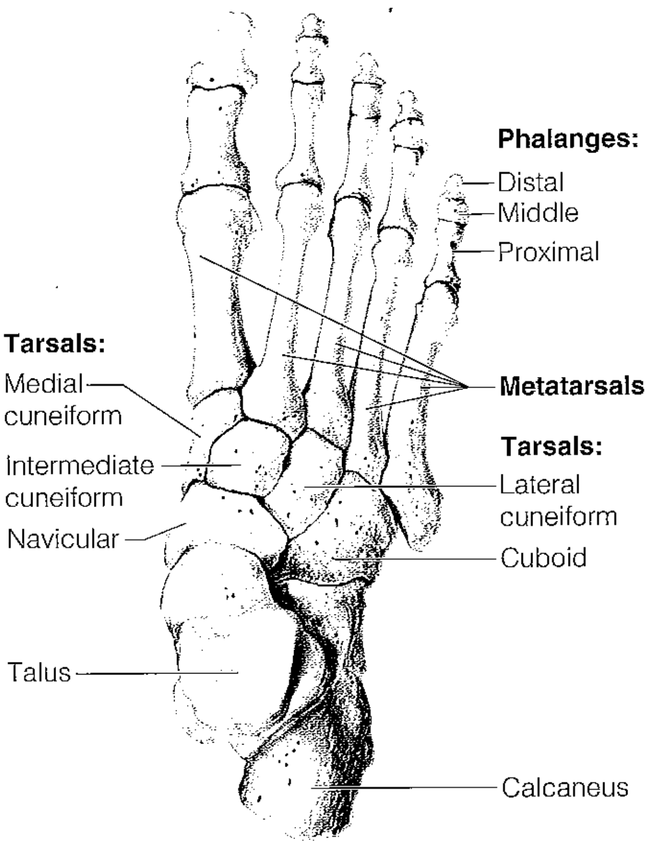


FIGURE 5.26 **Bones of the right foot, superior view.**

largest tarsals, the **calcaneus** (kal-ka′ne-us), or heel-bone, and the **talus** (ta′lus; "ankle"), which lies between the tibia and the calcaneus. Five **metatarsals** form the sole, and 14 **phalanges** form the toes. Like the fingers of the hand, each toe has three phalanges, except the great toe, which has two.

The bones in the foot are arranged to form three strong arches: two longitudinal (medial and lateral) and one transverse (Figure 5.27). *Ligaments,* which bind the foot bones together, and *tendons* of the foot muscles help to hold the bones firmly in the arched position but still allow a certain amount of give or springiness. Weak arches are referred to as "fallen arches" or "flat feet."

DID YOU GET IT?

24. What two bones form the skeleton of the leg?
25. Bo's longitudinal and medial arches have suffered a collapse. What is the name of Bo's condition?

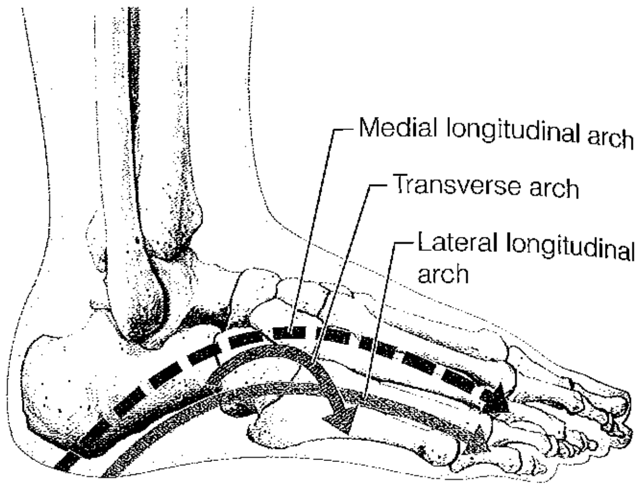


FIGURE 5.27 **Arches of the foot.**

26. Which lower limb bone has an intertrochanteric line and crest and an intercondylar fossa?

For answers, see Appendix D.

Joints

With one exception (the hyoid bone of the neck), every bone in the body forms a joint with at least one other bone. **Joints,** also called **articulations,** have two functions: they hold the bones together securely but also give the rigid skeleton mobility.

The graceful movements of a ballet dancer and the rough-and-tumble grapplings of a football player illustrate the great variety of motion allowed by joints, the sites where two or more bones meet. With fewer joints, we would move like robots. Nevertheless, the bone-binding function of joints is just as important as their role in providing mobility. The immovable joints of the skull, for instance, form a snug enclosure for our vital brain.

Joints are classified in two ways—functionally and structurally. The functional classification focuses on the amount of movement the joint allows. On this basis, there are **synarthroses** (sin″ar-thro′sēz), or immovable joints; **amphiarthroses** (am″fe-ar-thro′sēz), or slightly movable joints; and **diarthroses** (di″ar-thro′sēz), or freely movable joints. Freely movable joints predominate in the limbs, where mobility is important. Immovable and slightly movable joints are restricted mainly to

A CLOSER LOOK

THEM BONES, THEM BONES GOIN' TO WALK AROUND—CLINICAL ADVANCES IN BONE REPAIR

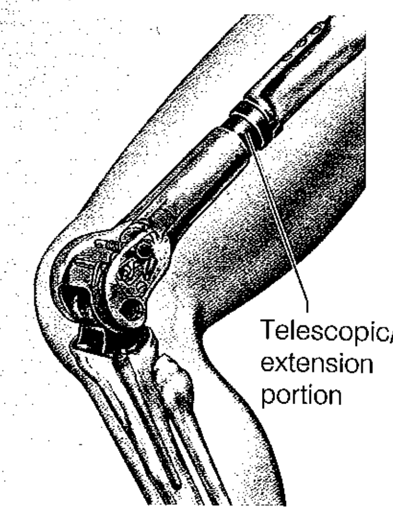
Although bones have remarkable self-regenerative powers, some conditions are just too severe for bones to effect repair. Examples include extensive shattering (as in automobile accidents), poor circulation in old bones, and certain birth defects. Here we address healing problems that bones cannot handle themselves. Let's take a look at some techniques currently used to expedite bone repair.

Electrical stimulation of fracture sites dramatically increases the speed and completeness of healing in large or slowly healing fractures. For years it has been known that bone tissue is deposited in regions of negative electrical charge (its stressed regions) and absorbed in regions of positive charge, but we are still not sure how electricity promotes healing. One theory is that negative fields prevent parathyroid hormone from stimulating the bone-absorbing osteoclast cells at the fracture site, thus allowing bony tissue to accumulate. Another theory is that the fields induce production of growth chemicals that stimulate the

The most troublesome injuries to bones are non-union fractures, in which the two parts of a split bone fail to join. Such fractures traditionally have been treated with grafts, in which sections of bone are taken from the hip and inserted into the gap. However, this requires several painful grafting sessions, and one-third of the grafts fail to heal. A

"Much research has gone into developing bone substitutes."

potential improvement is the **free vascular fibular graft technique,** which uses pieces of the fibula to replace missing bone. One reason that traditional grafts often fail is that a blood supply cannot reach their interior. This new technique grafts normal blood vessels along with the



The self-extending leg implant. Lengthening occurs at the telescopic/extension portion.

telescopic sleeve of these devices (see the figure) undergoes continual automatic elongation of the limb enforced by knee bending. Tension in the surrounding tissue prevents the prosthesis from lengthening too much; tension increases after each elongation and then gradually decreases as the soft tissues grow

A CLOSER LOOK Them Bones *(continued)*

formation of osteoblasts and proteins associated with bone growth.

Much research has gone into developing **bone substitutes** (crushed cadaver bone or synthetic materials) to fill the gaps in non-union defects. Crushed bone from human cadavers is mixed with water to form a paste that can be molded into the desired shape or packed into small, difficult-to-reach spaces. However, cadaver bone is a foreign tissue that the immune system may reject, and the body sometimes fails to replace it with new bone, as it must for healing to occur. Furthermore, there is a slight but real risk that the cadaver bone contains disease organisms.

ProOsteon, made from coral, avoids both problems. The coral is heat-treated to kill its living cells and convert its calcium carbonate to hydroxyapatite, the mineral in bone. The coral graft is then carved to the desired shape, sterilized by irradiation with gamma rays, coated with a natural substance that induces bone formation (bone morphogenic protein), and implanted. Osteoblasts and blood vessels migrate from the adjacent natural bone into the coral implant, gradually replacing it with living bone.

Research has also produced several types of ceramic bone substitutes. One is TCP, a biodegradable ceramic substance soft enough to be shaped but not very strong. TCP's biggest application has been to replace parts of nonweight-bearing bones, such as skull bones.

Norian SRS, a bone cement made of calcium phosphate, provides immediate structural support to fractured or osteoporotic sites. Mixed at the time of surgery, Norian SRS paste is injected into areas of damaged bone to create an internal "cast." The paste hardens in minutes and cures into a substance with greater compressive strength than spongy bone. Because its crystalline structure and chemistry are the same as those of natural bone, it is gradually remodeled and replaced by host bone. However, Norian SRS can be used only on the ends of long bones because it cannot resist the strong compressive and bending stresses occurring at the central shaft.

the axial skeleton, where firm attachments and protection of internal organs are priorities.

Structurally, there are *fibrous, cartilaginous,* and *synovial joints.* These classifications are based on whether fibrous tissue, cartilage, or a joint cavity separates the bony regions at the joint. As a general rule, fibrous joints are immovable, and synovial joints are freely movable. Although cartilaginous joints have both immovable and slightly movable examples, most are amphiarthrotic. Because the structural classification is more clear-cut, we will focus on that classification scheme here. The joint types are shown in Figure 5.28, described next, and summarized in Table 5.3.

Fibrous Joints

In **fibrous joints,** the bones are united by fibrous tissue. The best examples of this type of joint are the *sutures* of the skull (Figure 5.28a). In sutures, the irregular edges of the bones interlock and are bound tightly together by connective tissue fibers, allowing essentially no movement. In **syndesmoses** (sin-dez-mo′sēz), the connecting fibers are longer than those of sutures; thus the joint has more "give." The joint connecting the distal ends of the tibia and fibula is a syndesmosis (Figure 5.28b).

Cartilaginous Joints

In **cartilaginous joints,** the bone ends are connected by cartilage. Examples of this joint type that are slightly movable (amphiarthrotic) are the *pubic symphysis* of the pelvis (Figure 5.28e) and *intervertebral joints* of the spinal column (Figure 5.28d), where the articulating bone surfaces are connected by pads (discs) of fibrocartilage. The hyaline-cartilage epiphyseal plates of growing long bones and the cartilaginous joints between the first ribs and the sternum are immovable (synarthrotic) cartilaginous joints (Figure 5.28c).

Synovial Joints

Synovial joints are joints in which the articulating bone ends are separated by a joint cavity containing

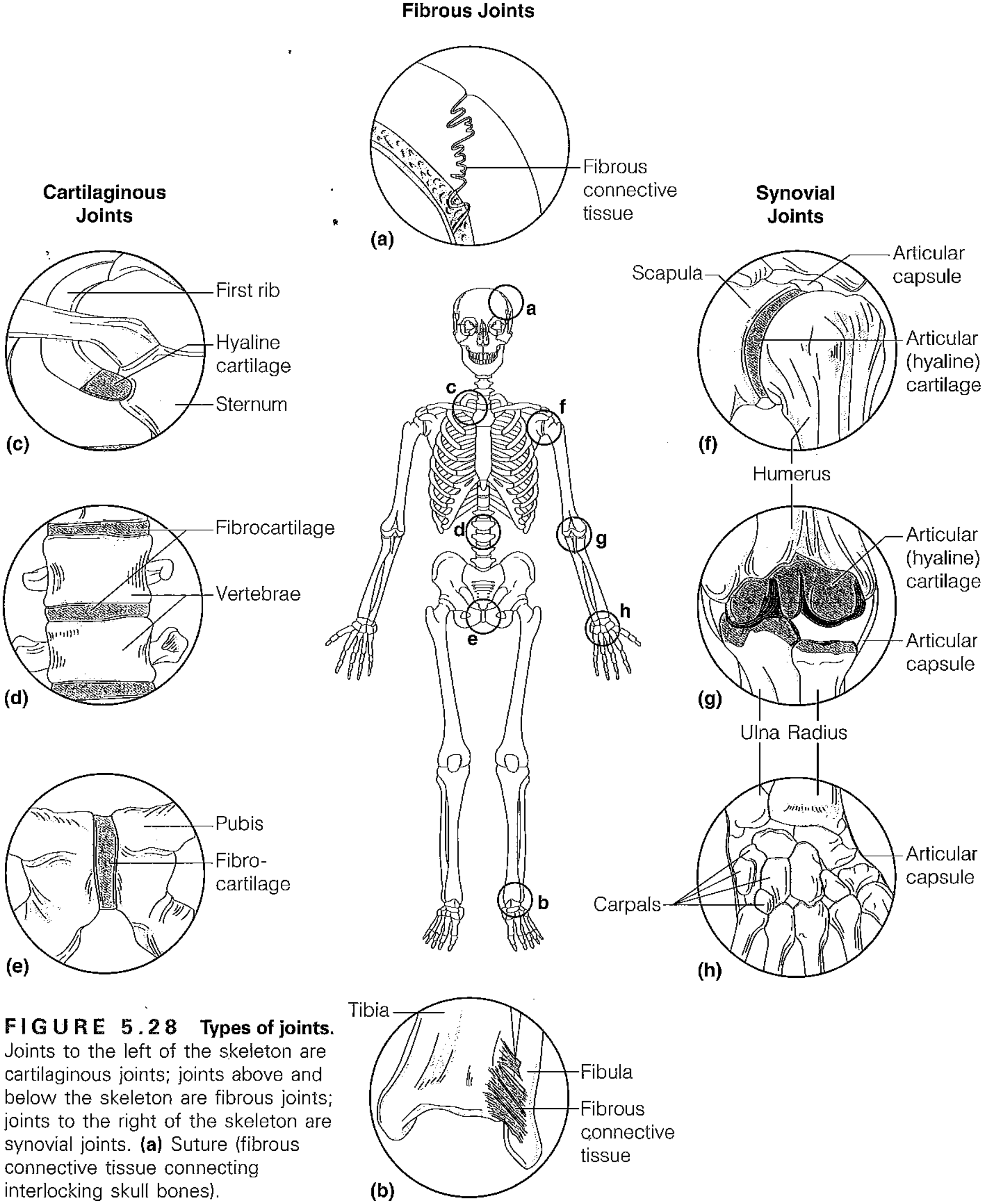


FIGURE 5.28 Types of joints. Joints to the left of the skeleton are cartilaginous joints; joints above and below the skeleton are fibrous joints; joints to the right of the skeleton are synovial joints. **(a)** Suture (fibrous connective tissue connecting interlocking skull bones). **(b)** Syndesmosis (fibrous connective tissue connecting the distal ends of the tibia and fibula). **(c)** Synchondrosis (joint between costal cartilage of rib 1 and the sternum). **(d)** Symphyses (intervertebral discs of fibrocartilage connecting adjacent vertebrae). **(e)** Symphysis (fibrocartilaginous pubic symphysis connecting the pubic bones anteriorly). **(f)** Synovial joint (multiaxial shoulder joint). **(g)** Synovial joint (uniaxial elbow joint). **(h)** Synovial joints (biaxial intercarpal joints of the hand).

TABLE 5.3 Summary of Joint Classes

Structural class	Structural characteristics	Types		Mobility
Fibrous	Bone ends/parts united by collagenic fibers	Suture (short fibers)		Immobile (synarthrosis)
		Syndesmosis (longer fibers)		Slightly mobile (amphiarthrosis) and immobile
		Gomphosis (periodontal ligament)		Immobile
Cartilaginous	Bone ends/parts united by cartilage	Synchondrosis (hyaline cartilage)		Immobile
		Symphysis (fibrocartilage)		Slightly movable
Synovial	Bone ends/parts covered with articular cartilage and enclosed within an articular capsule lined with synovial membrane	Plane Hinge Pivot	Condyloid Saddle Ball and socket	Freely movable (diarthrosis; movements depend on design of joint)

synovial fluid (see Figure 5.28f–h). They account for all joints of the limbs.

All synovial joints have four distinguishing features (Figure 5.29):

1. **Articular cartilage.** Articular (hyaline) cartilage covers the ends of the bones forming the joint.
2. **Fibrous articular capsule.** The joint surfaces are enclosed by a sleeve or capsule of fibrous connective tissue, and the capsule is lined with a smooth *synovial membrane* (the reason these joints are called synovial joints).
3. **Joint cavity.** The articular capsule encloses a cavity, called the joint cavity, which contains lubricating synovial fluid.
4. **Reinforcing ligaments.** The fibrous capsule is usually reinforced with ligaments.

Bursae and tendon sheaths are not strictly part of synovial joints, but they are often found closely associated with them (see Figure 5.29). Essentially bags of lubricant, they act like ball bearings to reduce friction between adjacent structures during joint activity. **Bursae** (ber'se; "purses") are flattened fibrous sacs lined with synovial membrane and containing a thin film of synovial fluid. They are common where ligaments, muscles, skin, tendons, or bones rub together. A **tendon sheath,** also shown in Figure 5.29, is essentially an elongated bursa that wraps completely around a tendon subjected to friction, like a bun around a hot dog.

HOMEOSTATIC IMBALANCE

A **dislocation** happens when a bone is forced out of its normal position in the joint cavity. The process of returning the bone to its proper position, called **reduction,** should be done only by a physician. Attempts by an untrained person to "snap the bone back into its socket" are usually more harmful than helpful. ▲

Types of Synovial Joints Based on Shape

The shapes of the articulating bone surfaces determine what movements are allowed at a joint. Based on such shapes, our synovial joints can be classified as *plane, hinge, pivot, condyloid, saddle,* and *ball-and-socket joints* (Figure 5.30).

- In a **plane joint** (Figure 5.30a), the articular surfaces are essentially flat, and only short

How does this joint type differ structurally from cartilaginous and fibrous joints?

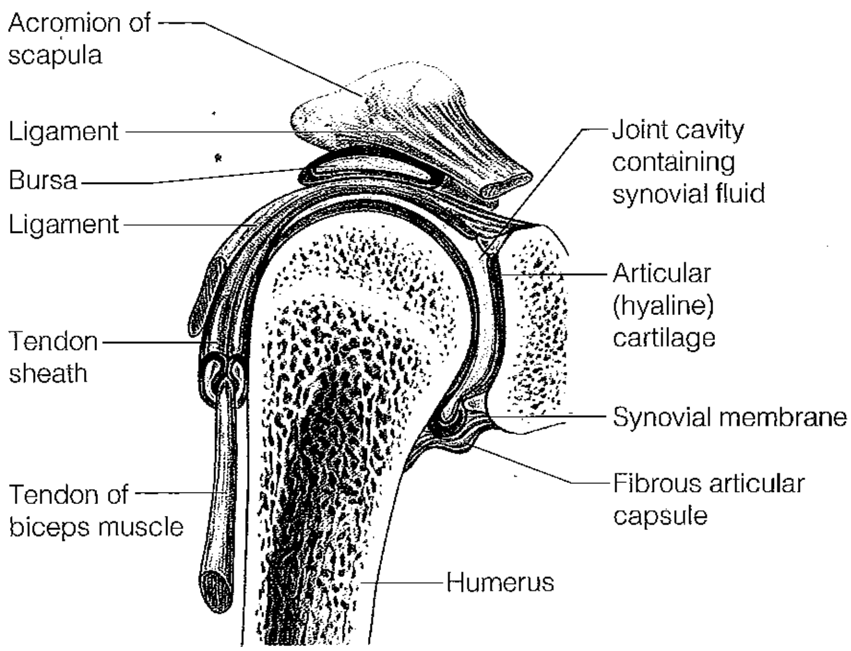


FIGURE 5.29 General structure of a synovial joint.

slipping or gliding movements are allowed. The movements of plane joints are *nonaxial;* that is, gliding does not involve rotation around any axis. The intercarpal joints of the wrist are the best examples of plane joints.

- In a **hinge joint** (Figure 5.30b), the cylindrical end of one bone fits into a trough-shaped surface on another bone. Angular movement is allowed in just one plane, like a mechanical hinge. Examples are the elbow joint, ankle joint, and the joints between the phalanges of the fingers. Hinge joints are classified as *uniaxial* (u″ne-aks′e-al; "one axis"); they allow movement around one axis only, as indicated by the single magenta arrow in Figure 5.30b.
- In a **pivot joint** (Figure 5.30c), the rounded end of one bone fits into a sleeve or ring of bone (and possibly ligaments). Because the rotating bone can turn only around its long axis, pivot joints are also uniaxial joints (see the single arrow in Figure 5.30c). The proximal radioulnar joint and the joint between the atlas and the dens of the axis are examples.
- In a **condyloid joint** (kon′dĭ-loid; "knucklelike"), the egg-shaped articular surface of one bone fits into an oval concavity in another (Figure 5.30d). Both of these articular surfaces are oval. Condyloid joints allow the moving bone to travel (1) from side to side and (2) back and forth, but the bone cannot rotate around its long axis. Movement occurs around two axes, hence these joints are *biaxial* (*bi* = two), as in knuckle (metacarpophalangeal) joints.
- In **saddle joints,** each articular surface has both convex and concave areas, like a saddle (Figure 5.30e). These biaxial joints allow essentially the same movements as condyloid joints. The best examples of saddle joints are the carpometacarpal joints in the thumb, and the movements of these joints are clearly demonstrated by twiddling your thumbs.
- In a **ball-and-socket joint** (Figure 5.30f), the spherical head of one bone fits into a round socket in another. These *multiaxial* joints allow movement in all axes, including rotation

It has a joint cavity instead of cartilage or fibrous tissue separating the articulating bones.

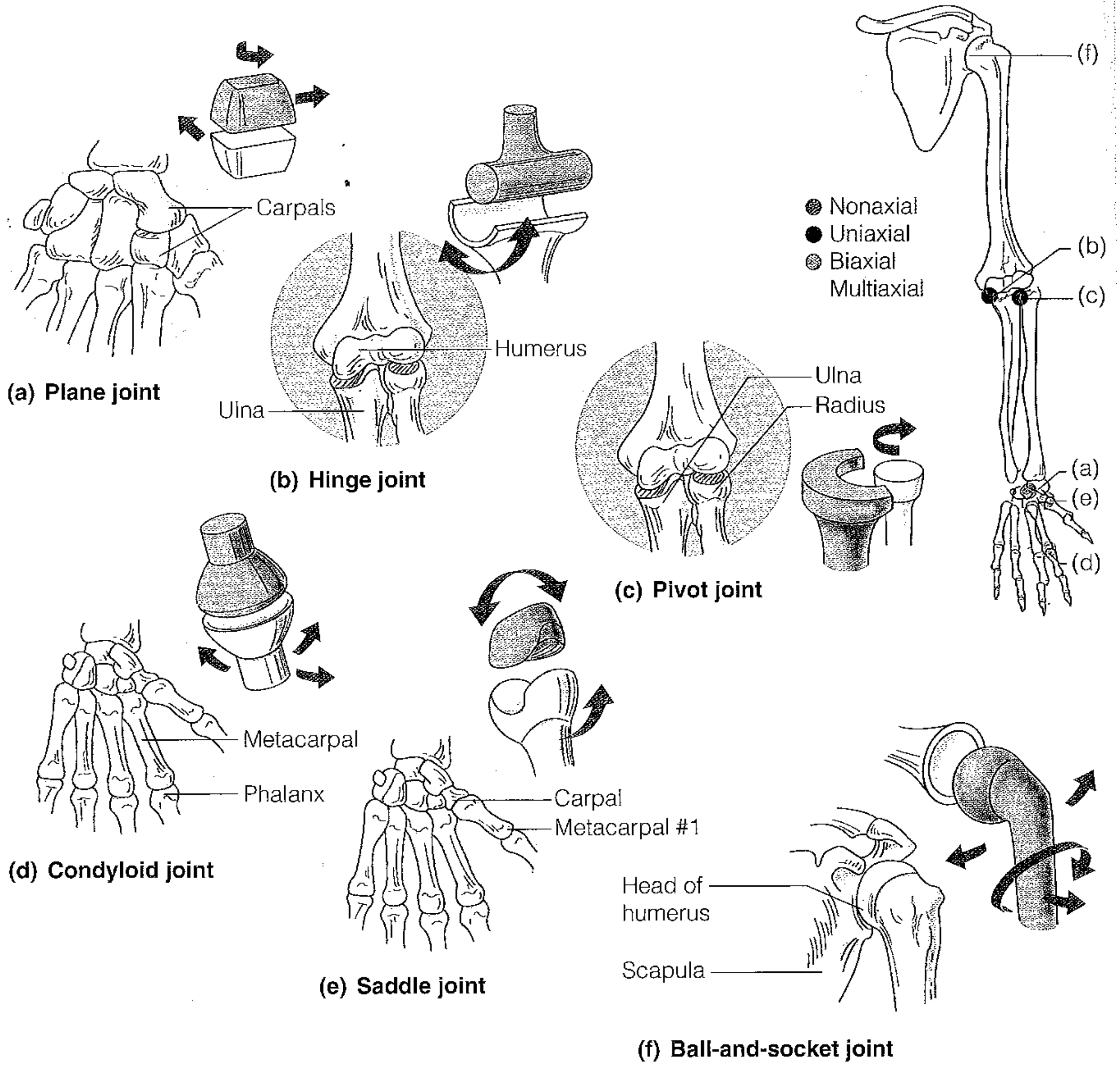


FIGURE 5.30 **Types of synovial joints.** **(a)** Plane joint (intercarpal and intertarsal joints). **(b)** Hinge joint (elbow and interphalangeal joints). **(c)** Pivot joint (proximal joint between the radius and the ulna). **(d)** Condyloid joint (knuckles). **(e)** Saddle joint (carpometacarpal joint of the thumb). **(f)** Ball-and-socket joint (shoulder and hip joints).

(see the three arrows in Figure 5.30f), and are the most freely moving synovial joints. The shoulder and hip are examples.

Because they relate to muscle activity, the various types of movements that occur at synovial joints are discussed in detail in the next chapter.

HOMEOSTATIC IMBALANCE

Few of us pay attention to our joints unless something goes wrong with them. Joint pain and inflammation may be caused by many things. For example, falling on one's knee can cause a painful **bursitis,** called "water on the knee," due to inflammation of bursae or synovial membrane. Sprains and dislocations are other types of joint problems that result in swelling and pain. In a **sprain,** the ligaments or tendons reinforcing a joint are damaged by excessive stretching, or they are torn away from the bone. Both tendons and ligaments are cords of dense fibrous connective tissue with a poor blood supply; thus, sprains heal slowly and are extremely painful.

Few inflammatory joint disorders cause more pain and suffering than arthritis. The term **arthritis** (*arth* = joint; *itis* = inflammation) describes over 100 different inflammatory or degenerative diseases that damage the joints. In all its forms, arthritis is the most widespread, crippling disease in the United States. All forms of arthritis have the same initial symptoms: pain, stiffness, and swelling of the joint. Then, depending on the specific form, certain changes in the joint structure occur.

Acute forms of arthritis usually result from bacterial invasion and are treated with antibiotic drugs. The synovial membrane thickens and fluid production decreases, leading to increased friction and pain. Chronic forms of arthritis include osteoarthritis, rheumatoid arthritis, and gouty arthritis, which differ substantially in their later symptoms and consequences. We will focus on these forms here.

Osteoarthritis (OA), the most common form of arthritis, is a chronic degenerative condition that typically affects the aged. Eighty-five percent of people in the United States develop this condition. OA, also called "wear-and-tear arthritis," affects the articular cartilages. Over the years, the cartilage softens, frays, and eventually breaks down. As the disease progresses, the exposed bone thickens and extra bone tissue, called **bone spurs,** grows around the margins of the eroded cartilage and restricts joint movement. Patients complain of stiffness on arising that lessens with activity, and the affected joints may make a crunching noise **(crepitus)** when moved. The joints most commonly affected are those of the fingers, the cervical and lumbar joints of the spine, and the large, weight-bearing joints of the lower limbs (knees and

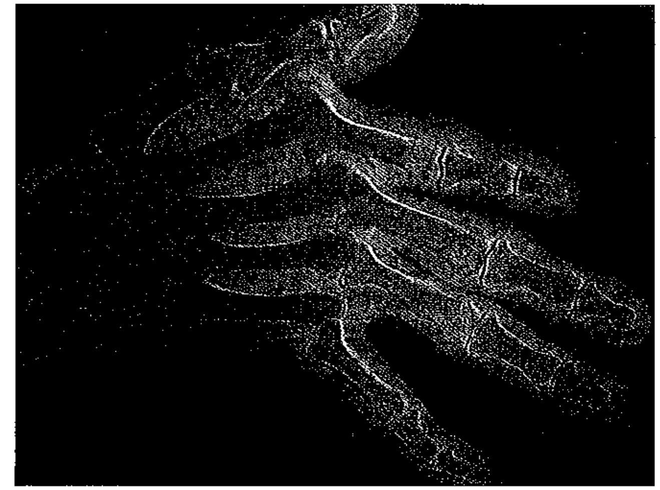


FIGURE 5.31 X-ray image of a hand deformed by rheumatoid arthritis.

Rheumatoid (roo'mah-toid) **arthritis (RA)** is a chronic inflammatory disorder. Its onset is insidious and usually occurs between the ages of 40 and 50, but it may occur at any age. It affects three times as many women as men. Many joints, particularly those of the fingers, wrists, ankles, and feet, are affected at the same time and usually in a symmetrical manner. For example, if the right elbow is affected, most likely the left elbow will be affected also. The course of RA varies and is marked by remissions and flare-ups (*rheumat* = susceptible to change or flux).

RA is an autoimmune disease—a disorder in which the body's immune system attempts to destroy its own tissues. The initial trigger for this reaction is unknown, but some suspect that it results from certain bacterial or viral infections.

RA begins with inflammation of the synovial membranes. The membranes thicken and the joints swell as synovial fluid accumulates. Inflammatory cells (white blood cells and others) enter the joint cavity from the blood and release a deluge of inflamatory

Current therapy for RA involves many different kinds of drugs. Some, like methotrexate, are immunosuppresants. Others, like etanercept (Embrel), neutralize the inflammatory chemicals in the joint space and (hopefully) prevent joint deformity. However, drug therapy often begins with aspirin, which in large doses is an effective anti-inflammatory agent. Exercise is recommended to maintain as much joint mobility as possible. Cold packs are used to relieve the swelling and pain, and heat helps to relieve morning stiffness. Replacement joints or bone removal are the last resort for severely crippled RA patients.

Gouty (gow'te) **arthritis,** or **gout,** is a disease in which uric acid (a normal waste product of nucleic acid metabolism) accumulates in the blood and may be deposited as needle-shaped crystals in the soft tissues of joints. This leads to an agonizingly painful attack that typically affects a single joint, often in the great toe. Gout is most common in men and rarely appears before the age of thirty. It tends to run in families, so genetic factors are definitely implicated.

Untreated gout can be very destructive; the bone ends fuse, and the joint becomes immobilized. Fortunately, several drugs (colchicine, ibuprofen, and others) are successful in preventing acute gout attacks. Patients are advised to lose weight if obese, to avoid foods such as liver, kidneys, and sardines, which are high in nucleic acids, and to avoid alcohol, which inhibits excretion of uric acid by the kidneys. ▲

DID YOU GET IT?

27. What are the functions of joints?
28. What is the major difference between a fibrous joint and a cartilaginous joint?
29. Where is synovial membrane found, and what is its role?
30. What two joints of the body are ball-and-socket joints? What is the best example of a saddle joint?

For answers, see Appendix D.

Developmental Aspects of the Skeleton

As described earlier, the first "long bones" in the very young fetus are formed of hyaline cartilage, and the earliest "flat bones" of the skull are actually

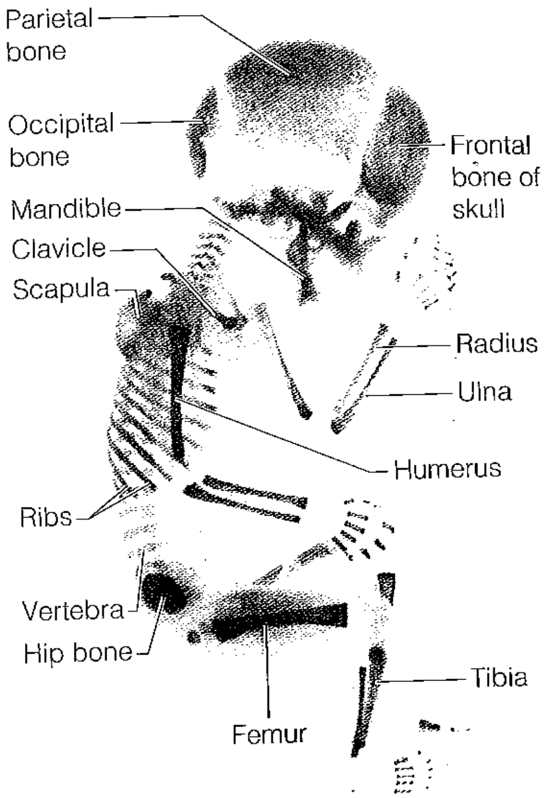


FIGURE 5.32 **Ossification centers in the skeleton of a 12-week-old fetus are indicated by the darker areas. Lighter regions are still fibrous or cartilaginous.**

fibrous membranes. As the fetus develops and grows, both the flat and the long bone models are converted to bone (Figure 5.32). At birth, some fontanels still remain in the skull to allow for brain growth, but these areas are usually fully ossified by 2 years of age. By the end of adolescence, the epiphyseal plates of long bones that provide for longitudinal growth in childhood have become fully ossified, and long-bone growth ends.

The skeleton changes throughout life, but the changes in childhood are most dramatic. At birth, the baby's cranium is huge relative to its face (Figure 5.33a). The rapid growth of the cranium before and after birth is related to the growth of the brain. By 2 years, the skull is three-quarters of its adult size; and, by 8 to 9 years, the skull is almost of adult size and proportions. However,

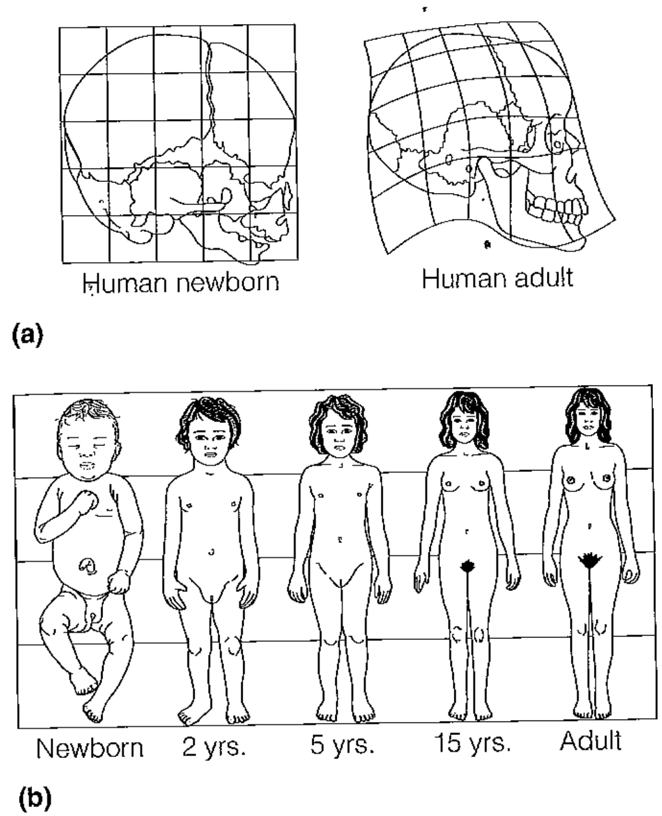


FIGURE 5.33 Differences in the growth rates for some parts of the body compared to others determine body proportions. (a) Differential growth transforms the rounded, foreshortened skull of a newborn to the sloping skull characteristic of adults. **(b)** During growth of a human, the arms and legs grow faster than the head and trunk, as shown in this conceptualization of different-aged individuals all drawn at the same height.

between the ages of 6 and 11, the head appears to enlarge substantially as the face literally grows out from the skull. The jaws increase in size, and the cheekbones and nose become more prominent as respiratory passages expand and the permanent teeth develop.

Most cases of abnormal spinal curvatures, such as scoliosis and lordosis (see Figure 5.16), are congenital, but some can result from injuries. The abnormal curvatures are usually treated by surgery, braces, or casts when diagnosed. Generally speaking, young, healthy people have no skeletal problems, assuming that their diet is nutritious and they stay reasonably active.

During youth, growth of the skeleton not only increases overall body height and size but also changes body proportions (Figure 5.33b). At birth, the head and trunk are approximately 1½ times as long as the lower limbs. The lower limbs grow more rapidly than the trunk from this time on, and by the age of 10, the head and trunk are approximately the same height as the lower limbs and change little thereafter. During puberty, the female pelvis broadens in preparation for childbearing, and the entire male skeleton becomes more robust. Once adult height is reached, a healthy skeleton changes very little until late middle age. In old age, losses in bone mass become obvious.

It cannot be emphasized too strongly that bones have to be physically stressed to remain healthy. When we remain active physically and muscles and gravity pull on the skeleton, the bones respond by becoming stronger. By contrast, if we are totally inactive, they become thin and fragile. **Osteoporosis** is a bone-thinning disease that afflicts half of women over 65 and some 20 percent of men over the age of 70. Osteoporosis makes the bones so fragile that even a hug or a sneeze can cause bones to fracture (Figure 5.34). The bones of the spine and the neck of the femur are particularly susceptible. Vertebral collapse frequently results in a hunched-over posture (kyphosis) familiarly known as dowager's hump (Figure 5.35).

Estrogen helps to maintain the health and normal density of a woman's skeleton, and the estrogen deficiency that occurs after a woman goes

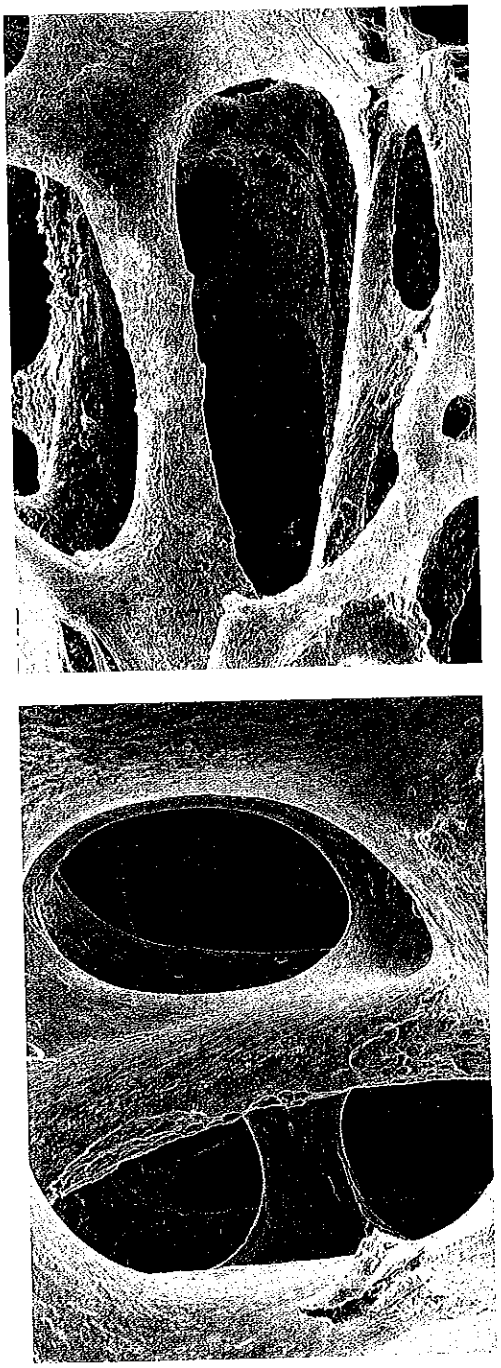


FIGURE 5.34 Osteoporosis. The architecture of osteoporotic bone, at top, is contrasted with that of normal bone, below.

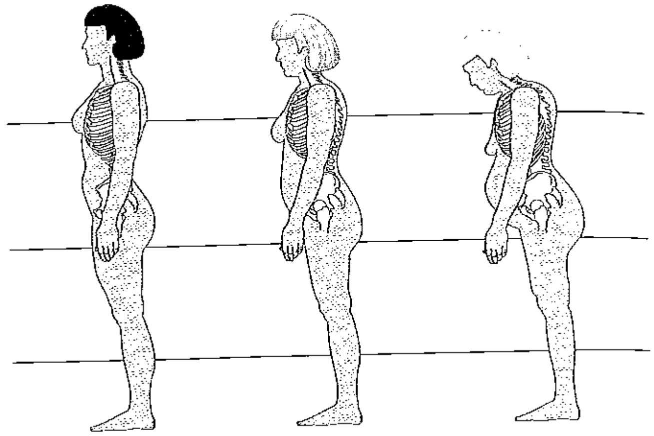


FIGURE 5.35 Vertebral collapse due to osteoporosis. Women with postmenopausal osteoporosis are at risk for fractures in the bones in their spine (vertebrae) as they age. Eventually these vertebrae tend to collapse, causing spinal curvature. Such curvature causes loss of height, a tilted rib cage, a dowager's hump, and a protruding abdomen.

apparent injury), which increase dramatically with age and are the single most common skeletal problem for this age group.

Advancing years also take their toll on joints. Weight-bearing joints in particular begin to degenerate, and *osteoarthritis* is common. Such degenerative, joint changes lead to the complaint often heard from the aging person: "My joints are getting so stiff...."

DID YOU GET IT?

31. Which spinal curvatures are present at birth?
32. How does the shape of a newborn baby's spine differ from that of an adult?
33. Ninety-year-old Mrs. Pelky is groaning in pain. Her grandson has just picked her up and given her a bear hug. What do you think might just have happened to her spine, and what bone condition may she be suffering from?
34. Which two regions of the skeleton grow most rapidly during childhood?

For answers, see Appendix D.

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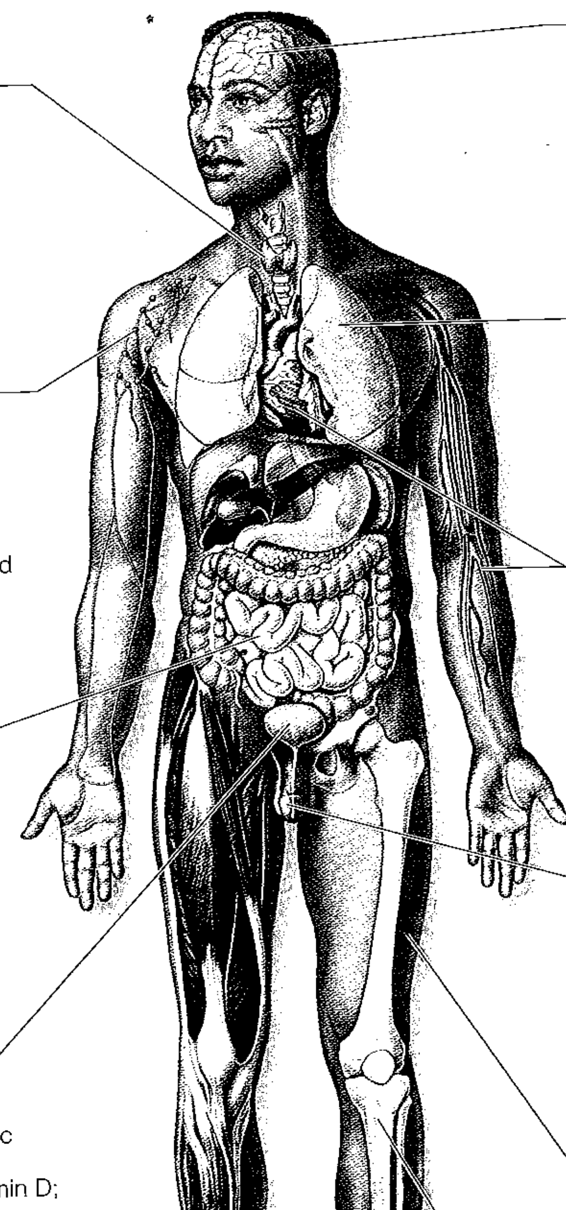
HOMEOSTATIC RELATIONSHIPS BETWEEN THE ***SKELETAL SYSTEM*** *AND OTHER BODY SYSTEMS*



Endocrine System
- Skeletal system provides some bony protection
- Hormones regulate uptake and release of calcium from bone; hormones promote long-bone growth and maturation

- Skeletal system provides some protection to lymphatic organs; lymphocytes involved in immune response originate in bone marrow
- Lymphatic system drains leaked tissue fluids; immune cells protect against pathogens

Digestive System
- Skeletal system provides some bony protection to intestines, pelvic organs, and liver
- Digestive system provides nutrients needed for bone health and growth

Urinary System
- Skeletal system protects pelvic organs (bladder, etc.)
- Urinary system activates vitamin D;

Nervous System
- Skeletal system protects brain and spinal cord; depot for calcium ions needed for neural function
- Nerves innervate bone and joint capsules, providing for pain and joint sense

Respiratory System
- Skeletal system (rib cage) protects lungs by enclosure
- Respiratory system provides oxygen; disposes of carbon dioxide

Cardiovascular System
- Bone marrow cavities provide site for blood cell formation; matrix stores calcium needed for cardiac muscle activity
- Cardiovascular system delivers nutrients and oxygen to bones; carries away wastes

Reproductive System
- Skeletal system protects some reproductive organs by enclosure
- Gonads produce hormones that influence form of skeleton and epiphyseal closure

Integumentary System
- Skeletal system provides

SUMMARY

Media study tools that provide additional review of key topics of Chapter 5 are referenced below.

IP = *InterActive Physiology*
WEB = The A&P Place

Bones: An Overview (pp. 134–144)

1. Bones support and protect body organs; serve as levers for the muscles to pull on to cause movement at joints; store calcium, fats, and other substances for the body; and contain red marrow, the site of blood cell production.

2. Bones are classified into four groups—long, short, flat, and irregular—on the basis of their shape and the amount of compact or spongy bone they contain. Bone markings are important anatomical landmarks that reveal where muscles attach and where blood vessels and nerves pass.

3. A long bone is composed of a shaft (diaphysis) with two ends (epiphyses). The shaft is compact bone; its cavity contains yellow marrow. The epiphyses are covered with hyaline cartilage; they contain spongy bone (where red marrow is found).

   WEB Exercise: Chapter 5, Microscopic Structure of Compact Bone.

4. The organic parts of the matrix make bone flexible; calcium salts deposited in the matrix make bone hard.

5. Bones form on hyaline cartilage "models," or fibrous membranes. Eventually these initial supporting structures are replaced by bone tissue. Epiphyseal plates persist to provide for longitudinal growth of long bones during childhood and become inactive when adolescence ends.

6. Bones change in shape throughout life. This remodeling occurs in response to hormones (for example, PTH, which regulates blood calcium levels) and mechanical stresses acting on the skeleton.

7. A fracture is a break in a bone. Common types of fractures include simple, compound, compression, comminuted, and greenstick. Bone fractures must be reduced to heal properly.

   WEB Exercise: Chapter 5, Common Types of Fractures.

Axial Skeleton (pp. 145–158)

1. The skull is formed by cranial and facial bones. Eight cranial bones protect the brain: frontal, occipital, ethmoid, and sphenoid bones, and the pairs of parietal and temporal bones. The 14 facial bones are all paired (maxillae, zygomatics, palatines, nasals, lacrimals, and inferior nasal conchae), except for the vomer and mandible. The hyoid bone, not really a skull bone, is supported in the neck by ligaments.

   WEB Exercise: Chapter 5, Facial Bones.

2. Skulls of newborns contain fontanels (membranous areas), which allow brain growth. The infant's facial bones are very small compared to the size of the cranium.

3. The vertebral column is formed from 24 vertebrae, the sacrum, and the coccyx. There are 7 cervical vertebrae, 12 thoracic vertebrae, and 5 lumbar vertebrae, which have common as well as unique features. The vertebrae are separated by fibrocartilage discs that allow the vertebral column to be flexible. The vertebral column is S-shaped to allow for upright posture. Primary spinal curvatures present at birth are the thoracic and sacral curvatures; secondary curvatures (cervical and lumbar) develop after birth.

   WEB Exercise: Chapter 5, Typical Vertebra.

4. The bony thorax is formed from the sternum and 12 pairs of ribs. All ribs attach posteriorly to thoracic vertebrae. Anteriorly, the first 7 pairs attach directly to the sternum (true ribs); the last 5 pairs attach indirectly or not at all (false ribs). The bony thorax encloses the lungs, heart, and other organs of the thoracic cavity.

Appendicular Skeleton (pp. 158–166)

1. The shoulder girdle, composed of two bones—the scapula and the clavicle—attaches the upper limb to the axial skeleton. It is a light, poorly reinforced girdle that allows the upper limb a great deal of freedom. There are two shoulder girdles.

   WEB Exercise: Chapter 5, Articulations Case Study.

2. The bones of the upper limb include the humerus of the arm, the radius and ulna of the forearm, and the carpals, metacarpals, and phalanges of the hand.

3. The pelvic girdle is formed by the two coxal bones, or hip bones. Each hip bone is the result of fusion of the ilium, ischium, and pubis bones. The pelvic girdle is securely attached to the sacrum of the axial skeleton, and the socket for the thigh bone is deep and heavily reinforced. This girdle receives the weight of the upper body and transfers it to the lower limbs. The female pelvis is lighter and

broader than the male's; its inlet and outlet are larger, which reflects the childbearing function.

4. The bones of the lower limb include the femur of the thigh, the tibia and fibula of the leg, and the tarsals, metatarsals, and phalanges of the foot.

Joints (pp. 166–174)

1. Joints hold bones together and allow movement of the skeleton.

2. Joints fall into three functional categories: synarthroses (immovable), amphiarthroses (slightly movable), and diarthroses (freely movable).

3. Joints also can be classified structurally as fibrous, cartilaginous, or synovial joints depending on the substance separating the articulating bones.

4. Most fibrous joints are synarthrotic, and most cartilaginous joints are amphiarthrotic. Fibrous and cartilaginous joints occur mainly in the axial skeleton.

5. Most joints of the body are synovial joints, which predominate in the limbs. In synovial joints, the articulating bone surfaces are covered with articular cartilage and enclosed within the joint cavity by a fibrous capsule lined with a synovial membrane. All synovial joints are diarthroses.

   WEB Exercise: Chapter 5, Types of Synovial Joints.

6. The most common joint problem is arthritis, or inflammation of the joints. Osteoarthritis, or degenerative arthritis, is a result of the "wear and tear" on joints over many years and is a common affliction of the aged. Rheumatoid arthritis occurs in both young and older adults; it is believed to be an autoimmune disease. Gouty arthritis, caused by the deposit of uric acid crystals in joints, typically affects a single joint.

Developmental Aspects of the Skeleton (pp. 174–176)

1. Fontanels, which allow brain growth and ease birth passage, are present in the skull at birth. Growth of the cranium after birth is related to brain growth;

4. Fractures are the most common bone problem in elderly people. Osteoporosis, a condition of bone wasting that results mainly from hormone deficit or inactivity, is also common in older individuals.

REVIEW QUESTIONS

Multiple Choice

More than one choice may apply.

1. Which of the following are correctly matched?
   a. Short bone—wrist
   b. Long bone—leg
   c. Irregular bone—sternum
   d. Flat bone—cranium

2. A passageway connecting neighboring osteocytes in an osteon is a
   a. central canal.
   b. lamella.
   c. lacuna.
   d. canaliculus.
   e. perforating canal.

3. Which of the following would you expect to be prominent in osteoclasts?
   a. Golgi apparatus
   b. Lysosomes
   c. Microfilaments
   d. Exocytosis

4. Bone pain behind the external acoustic meatus probably involves the
   a. maxilla.
   b. ethmoid.
   c. sphenoid.
   d. temporal.
   e. lacrimal.

5. Bones that articulate with the sphenoid include
   a. parietal.
   b. vomer.
   c. maxilla.
   d. zygomatic.
   e. ethmoid.

6. Which humeral process articulates with the radius?
   a. Trochlea
   b. Greater tubercle
   d. Capitulum
   e. Olecranon fossa

8. Which of the following bones or bone parts articulate with the femur?
   a. Ischial tuberosity
   b. Pubis
   c. Patella
   d. Fibula
   e. Tibia
9. Which bone of the arm corresponds to the femur of the leg?
   a. Ulna
   b. Humerus
   c. Radius
   d. Tibia
   e. Fibula
10. At what stage of life do the lower limbs attain the same height as the head and trunk?
    a. At birth
    b. By 10 years of age
    c. At puberty
    d. When the epiphyseal plates fuse
    e. Never
11. Match the types of joints to the descriptions that apply to them. (More than one description might apply.)
    a. Fibrous joints
    b. Cartilaginous joints
    c. Synovial joints

____ 1. Have no joint cavity
____ 2. Types are sutures and syndesmoses
____ 3. Dense connective tissue fills the space between the bones
____ 4. Almost all joints of the skull
____ 5. Types are synchondroses and symphyses
____ 6. All are diarthroses
____ 7. The most common type of joint in the body
____ 8. Nearly all are synarthrotic
____ 9. Shoulder, hip, knee, and elbow joints

12. Match the bone markings listed on the right with their function listed on the left.

________ 1. Attachment site for muscle or ligament
________ 2. Forms a joint surface
________ 3. Passageway for vessels or nerves

a. Trochanter
b. Condyle
c. Foramen
d. Process
e. Facet
f. Tuberosity

Short Answer Essay

13. Name three functions of the skeletal system.
14. What is yellow marrow? How do spongy and compact bone look different?
15. Why do bone injuries heal much more rapidly than injuries to cartilage?
16. Compare and contrast the role of PTH (hormone) and mechanical forces acting on the skeleton in bone remodeling.
17. Which fracture types are most common in older people? Why are greenstick fractures more common in children?
18. Name the eight bones of the cranium.
19. With one exception, all skull bones are joined by sutures. What is the exception?
20. What facial bone forms the chin? The cheekbone? The upper jaw? The bony eyebrow ridges?
21. Name two ways in which the fetal skull differs from the adult skull.
22. How many vertebrae are there in each of the three superior regions of the vertebral column?
23. Diagram the normal spinal curvatures and then the curvatures seen in scoliosis and lordosis.
24. What is the function of the intervertebral discs? What is a slipped disc?
25. Name the major components of the thorax.
26. Is a floating rib a true or a false rib? Why are floating ribs easily broken?
27. Name the bones of the shoulder girdle.
28. Name all the bones with which the ulna articulates.
29. What bones make up each hip bone (coxal bone)? Which of these is the largest? Which has tuberosities that we sit on? Which is the most anterior?
30. Name the bones of the lower limb from superior to inferior.
31. Compare the amount of movement possible in synarthrotic, amphiarthrotic, and diarthrotic joints. Relate these terms to the structural classification of joints; that is, to fibrous, cartilaginous, and synovial joints.
32. Describe the structure of a synovial joint.
33. Professor Rogers pointed to the foramen magnum of the skull and said, "The food passes through this hole when you swallow." Some students believed him, but others said that this was a big mistake. What do you think? Support your answer.
34. Yolanda is asked to review a bone slide that has been set up under a microscope. She sees concentric layers surrounding a central cavity or canal. Is this bone section taken from the diaphysis or the epiphyseal plate of the bone specimen?

35. List two factors that keep bones healthy. List two factors that can cause bones to become soft or to atrophy.

CRITICAL THINKING AND CLINICAL APPLICATION QUESTIONS

36. A 75-year-old woman and her 9-year-old granddaughter were in a train crash in which both sustained trauma to the chest while seated next to each other. X-ray images showed that the grandmother had several fractured ribs, but her granddaughter had none. Explain these surprisingly (?) different findings.

37. The pediatrician at the clinic explains to parents of a newborn that their son suffers from cleft palate. She tells them that the normal palate fuses in an anterior-to-posterior pattern. The child's palatine processes have not fused. Have his palatine bones fused normally?

38. After having a severe cold accompanied by nasal congestion, Helen complained that she had a frontal headache and the right side of her face ached. What bony structures probably became infected by the bacteria or viruses causing the cold?

39. Bernice, a 75-year-old woman, stumbled slightly while walking, then felt a terrible pain in her left hip. At the hospital, X rays revealed that the hip was broken. Also, the compact and spongy bone throughout her spine were very thin. What was her probable condition?

40. At work, a box fell from a shelf onto Bertha's acromial region. In the emergency room, the physician felt that the head of her humerus had moved into the axilla. What had happened to Bertha?

41. An X-ray image of the arm of an accident victim reveals a faint line curving around and down the shaft. What kind of fracture might this indicate?

42. Bone X rays are sometimes used to determine whether a person has reached his or her final height. What are the clinicians checking out?

43. A patient complains of pain starting in the jaw and radiating down the neck. When he is questioned further, he states that when he is under stress he grinds his teeth. What joint is causing his pain?

44. Dr. Davis is palpating Jane's vertebral column to determine whether she is beginning to exhibit scoliosis. What part or region of her vertebrae was he feeling as he ran his fingers along her spine?