7 The Skeleton

The word *skeleton* comes from the Greek word meaning "dried-up body" or "mummy," a rather unflattering description. Nonetheless, the human skeleton is a triumph of design and engineering that puts most skyscrapers to shame. It is strong, yet light, and almost perfectly adapted for the protective, locomotor, and manipulative functions it performs.

The **skeleton**, or **skeletal system**, composed of bones, cartilages, joints, and ligaments, accounts for about 20% of body mass (about 30 pounds in a 160-pound person). Bones make up most of the skeleton. Cartilages occur only in isolated areas, such as the nose, parts of the ribs, and the joints. Ligaments connect bones and reinforce joints, allowing required movements while restricting motions in other directions. Joints, the junctions between bones, provide for the remarkable mobility of the skeleton. We discuss joints and ligaments separately in Chapter 8.

PART 1
The Axial Skeleton

✓ Name the major parts of the axial and appendicular skeletons and describe their relative functions.

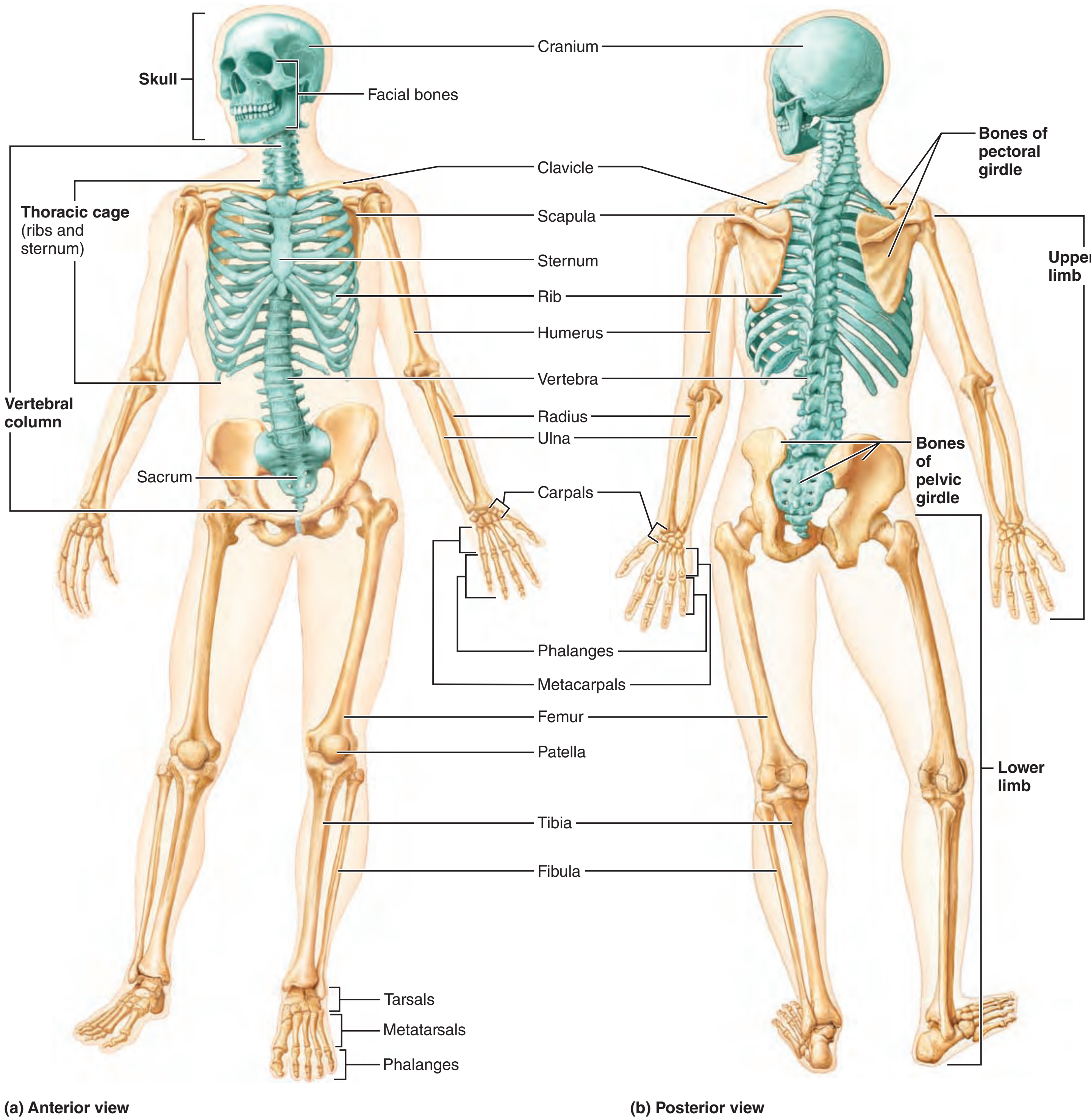
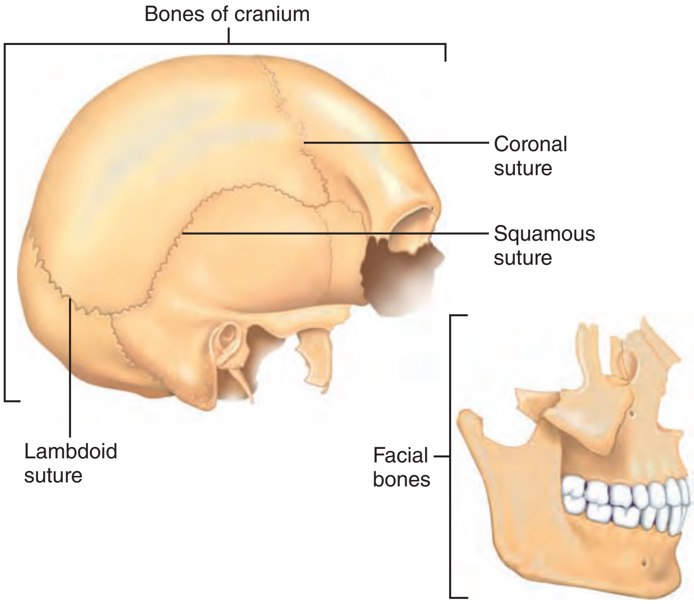
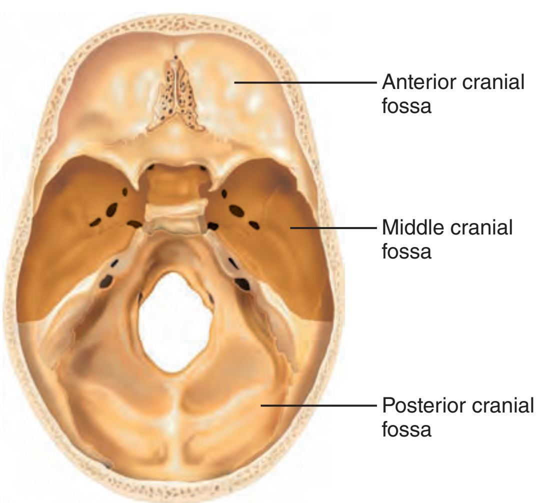


Figure 7.1 The human skeleton. Bones of the axial skeleton are colored green. Bones of the appendicular skeleton are gold.

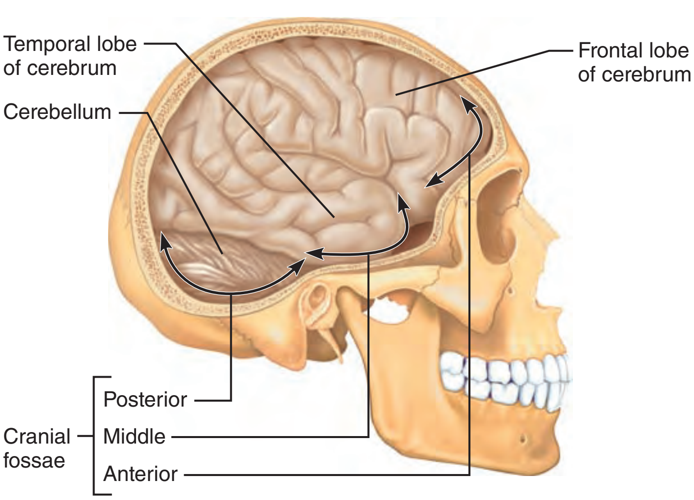
As described in Chapter 6, the skeleton is divided into *axial* and *appendicular* portions (see Figures 6.1 and 7.1). The **axial skeleton** is structured from 80 bones segregated into three major regions: the *skull*, *vertebral column*, and *thoracic cage* **(Figure 7.1)**. This part of the skeleton (1) forms the longitudinal axis of the body, (2) supports the head, neck, and trunk, and (3) protects the brain, spinal cord, and the organs in the thorax. As we will see later in this chapter, the bones of the appendicular skeleton, which allow us to interact with and manipulate our environment, are appended to the axial skeleton.



(a) Cranial and facial divisions of the skull



(b) Superior view of the cranial fossae



(c) Lateral view of cranial fossae showing the contained brain regions

Figure 7.2 The skull: Cranial and facial divisions and fossae.

☑ Check Your Understanding

1. What are the three main parts of the axial skeleton?
2. Which part of the skeleton—axial or appendicular—is important in protecting internal organs?

For answers, see Appendix H.

The Skull

✓ Name, describe, and identify the skull bones. Identify their important markings.

✓ Compare and contrast the major functions of the cranium and the facial skeleton.

The **skull** is the body's most complex bony structure. It is formed by *cranial* and *facial bones*, 22 in all. The cranial bones, or **cranium** (kra′ne-um), enclose and protect the fragile brain and furnish attachment sites for head and neck muscles. The facial bones (1) form the framework of the face, (2) contain cavities for the special sense organs of sight, taste, and smell, (3) provide openings for air and food passage, (4) secure the teeth, and (5) anchor the facial muscles of expression, which we use to show our feelings. As you will see, the individual skull bones are well suited to their assignments.

Most skull bones are flat bones. Except for the mandible, which is connected to the rest of the skull by freely movable joints, all bones of the adult skull are firmly united by interlocking joints called **sutures** (soo′cherz). The suture lines have a saw-toothed or serrated appearance.

The major skull sutures, the *coronal*, *sagittal*, *squamous*, and *lambdoid sutures*, connect cranial bones (Figures 7.2a, 7.4b, and 7.5a). Most other skull sutures connect facial bones and are named according to the specific bones they connect.

Overview of Skull Geography

It is worth surveying basic skull "geography" before describing the individual bones. With the lower jaw removed, the skull resembles a lopsided, hollow, bony sphere. The facial bones form its anterior aspect, and the cranium forms the rest of the skull **(Figure 7.2a)**.

The cranium can be divided into a vault and a base. The *cranial vault*, also called the *calvaria* (kal-va′re-ah; "bald part of skull"), forms the superior, lateral, and posterior aspects of the skull, as well as the forehead. The *cranial base* forms the skull's inferior aspect. Internally, prominent bony ridges divide the base into three distinct "steps" or fossae—the *anterior*, *middle*, and *posterior cranial fossae* (Figure 7.2b and c). The brain sits snugly in these cranial fossae, completely enclosed by the cranial vault. Overall, the brain is said to occupy the *cranial cavity*.

In addition to the large cranial cavity, the skull has many smaller cavities. These include the middle and internal ear cavities (carved into the lateral side of its base) and, anteriorly, the

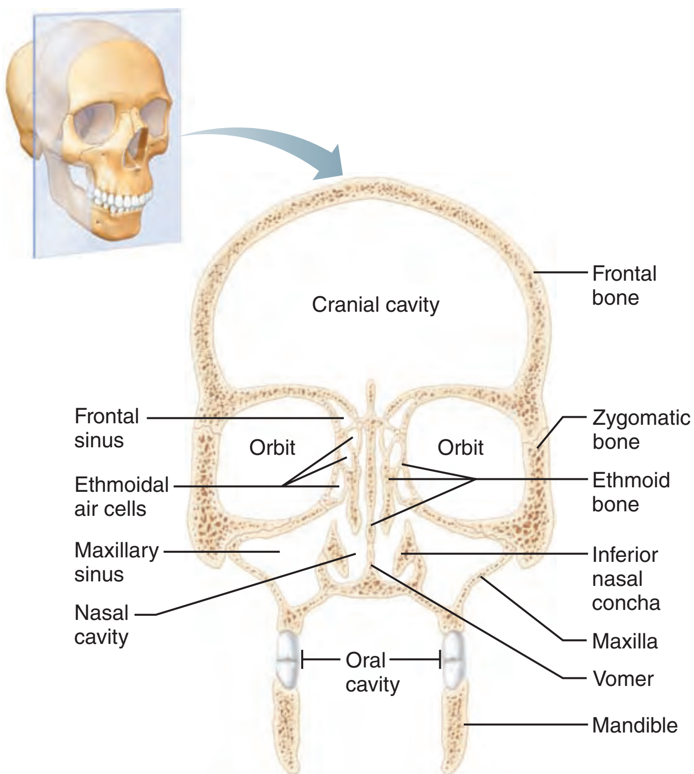


Figure 7.3 Major cavities of the skull, frontal section.

nasal cavity and the orbits **(Figure 7.3)**. The *orbits* house the eyeballs. Several bones of the skull contain air-filled sinuses, which lighten the skull.

The skull also has about 85 named openings (foramina, canals, fissures, etc.). The most important of these provide passageways for the spinal cord, the major blood vessels serving the brain, and the 12 pairs of cranial nerves (numbered I through XII), which transmit information to and from the brain.

As you read about the bones of the skull, locate each bone on the different skull views in **Figures 7.4**, **7.5**, and **7.6**. The skull bones and their important markings are also summarized in **Table 7.1** (pp. 216–217). The color-coded boxes before a bone's name in the text and in Table 7.1 correspond to the color of that bone in the figures. For example, note the color of the frontal bone in Table 7.1 and see how you can easily find it in Figures 7.4 and 7.5.

Cranium

The eight cranial bones are the paired parietal and temporal bones and the unpaired frontal, occipital, sphenoid, and ethmoid bones. Together, these construct the brain's protective bony "helmet." Because its superior aspect is curved, the cranium is self-bracing. This allows the bones to be thin, and, like an eggshell, the cranium is remarkably strong for its weight.

Frontal Bone

The shell-shaped **frontal bone** (Figures 7.4a, 7.5, and 7.7) forms the anterior cranium. It articulates posteriorly with the paired parietal bones via the prominent *coronal suture*.

The most anterior part of the frontal bone is the vertical *squamous part*, commonly called the *forehead*. The frontal squamous region ends inferiorly at the **supraorbital margins**, the thickened superior margins of the orbits that lie under the eyebrows. From here, the frontal bone extends posteriorly, forming the superior wall of the *orbits* and most of the **anterior cranial fossa (Figure 7.7a and b)**. This fossa supports the frontal lobes of the brain. Each supraorbital margin is pierced by a **supraorbital foramen (notch)**, which allows the supraorbital artery and nerve to pass to the forehead (Figure 7.4a).

The smooth portion of the frontal bone between the orbits is the **glabella** (glah-bel′ah). Just inferior to this the frontal bone meets the nasal bones at the *frontonasal suture* (Figure 7.4a). The areas lateral to the glabella are riddled internally with sinuses, called the **frontal sinuses** (Figures 7.5c and 7.3).

Parietal Bones and the Major Sutures

The two large **parietal bones** are curved, rectangular bones that form most of the superior and lateral aspects of the skull; hence they form the bulk of the cranial vault. The four largest sutures occur where the parietal bones articulate (form a joint) with other cranial bones:

- The **coronal suture** (kŏ-ro′nul), where the parietal bones meet the frontal bone anteriorly (Figures 7.2a and 7.5)
- The **sagittal suture**, where the parietal bones meet superiorly at the cranial midline (Figure 7.4b)
- The **lambdoid suture** (lam′doid), where the parietal bones meet the occipital bone posteriorly (Figures 7.2a, 7.4b, and 7.5)
- The **squamous suture** (one on each side), where a parietal and temporal bone meet on the lateral aspect of the skull (Figures 7.2a and 7.5)

Occipital Bone

The **occipital bone** (ok-sip′ĭ-tal) forms most of the skull's posterior wall and base. It articulates anteriorly with the paired parietal and temporal bones via the *lambdoid* and *occipitomastoid sutures*, respectively (Figure 7.5). The basilar part of the occipital bone also joins with the sphenoid bone in the cranial base (Figure 7.6a).

Internally, the occipital bone forms the walls of the **posterior cranial fossa** (Figures 7.7 and 7.2c), which supports the cerebellum of the brain. In the base of the occipital bone is the **foramen magnum** ("large hole") through which the inferior part of the brain connects with the spinal cord. The foramen magnum is flanked laterally by two occipital condyles (Figure 7.6). The rockerlike **occipital condyles** articulate with the first vertebra of the spinal column in a way that permits a nodding ("yes") motion of the head. Hidden medially and superiorly to each occipital condyle is a **hypoglossal canal** (Figure 7.7a), through which a cranial nerve (XII) passes.

Just superior to the foramen magnum is a median protrusion called the **external occipital protuberance** (Figures 7.4b, 7.5, and 7.6). You can feel this knoblike projection just below

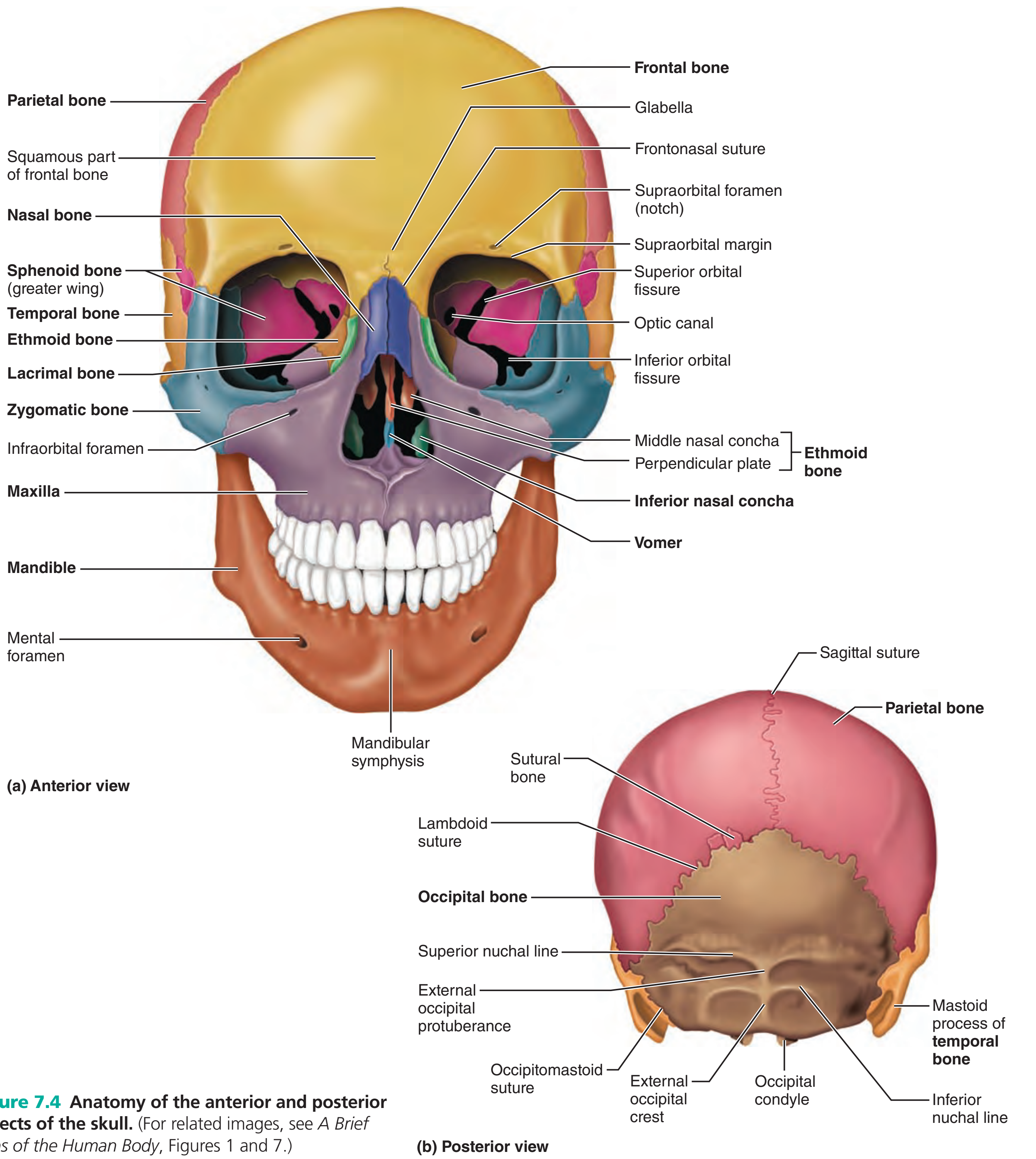
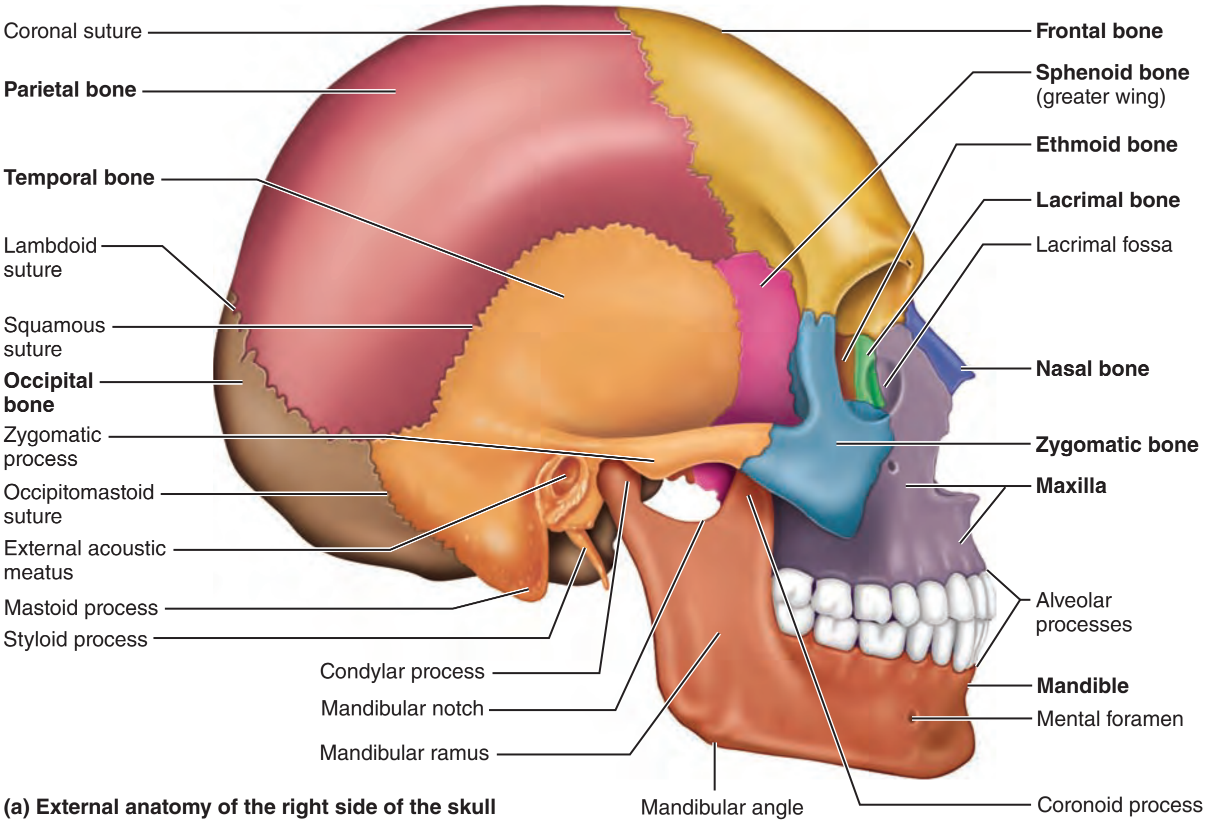


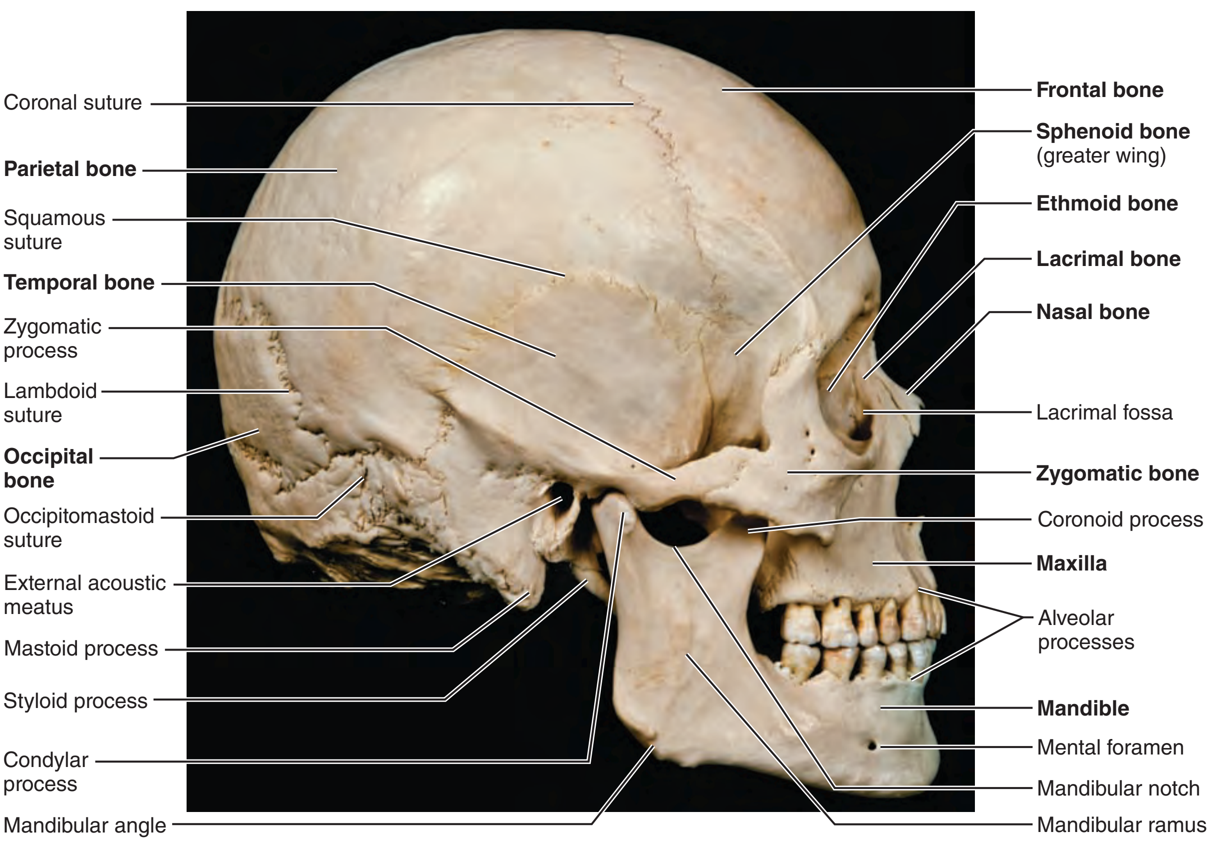
Figure 7.4 Anatomy of the anterior and posterior aspects of the skull. (For related images, see *A Brief Atlas of the Human Body*, Figures 1 and 7.)

the most bulging part of your posterior skull. A number of inconspicuous ridges, the *external occipital crest* and the *superior* and *inferior nuchal lines* (nu′kal), mark the occipital bone near the foramen magnum. The external occipital crest secures the *ligamentum nuchae* (lig″ah-men′tum noo′ke; *nucha* = back of the neck), a sheetlike elastic ligament that connects the vertebrae of the neck to the skull. The nuchal lines, and the bony regions between them, anchor many neck and back muscles. The superior nuchal line marks the upper limit of the neck.

(Text continues on p. 208.)

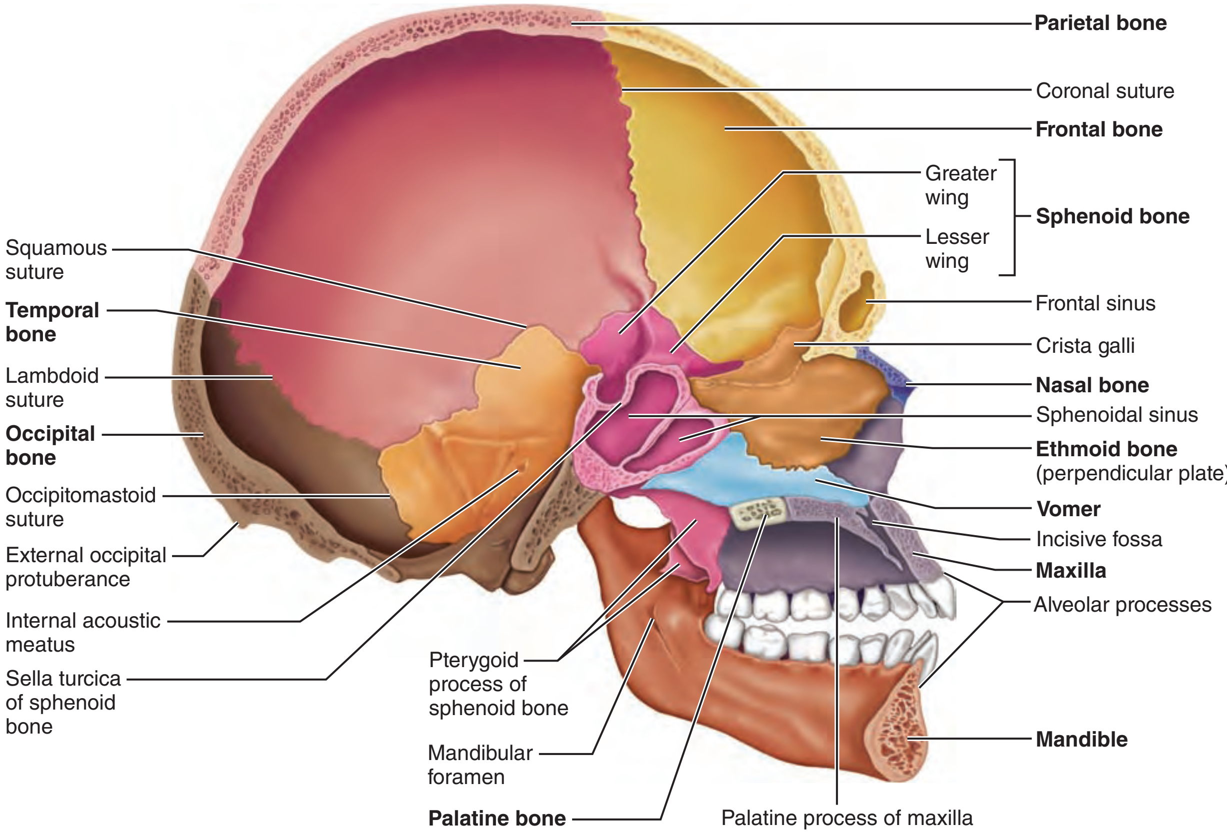


(a) External anatomy of the right side of the skull

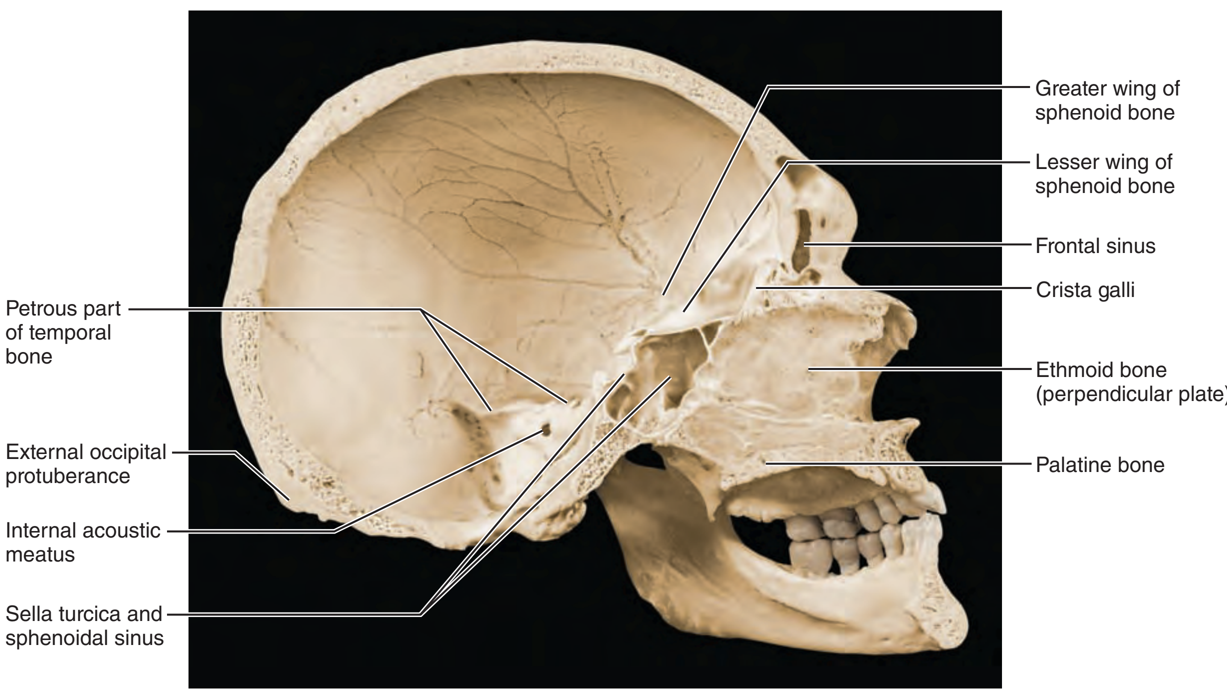


(b) Photograph of right side of skull

Figure 7.5 Bones of the lateral aspect of the skull, external and internal views.
(For related images, see *A Brief Atlas of the Human Body,* Figures 2 and 3.)



(c) Midsagittal section showing the internal anatomy of the left half of skull



(d) Photo of skull cut through the midline, same view as in (c)

Figure 7.5 *(continued)*

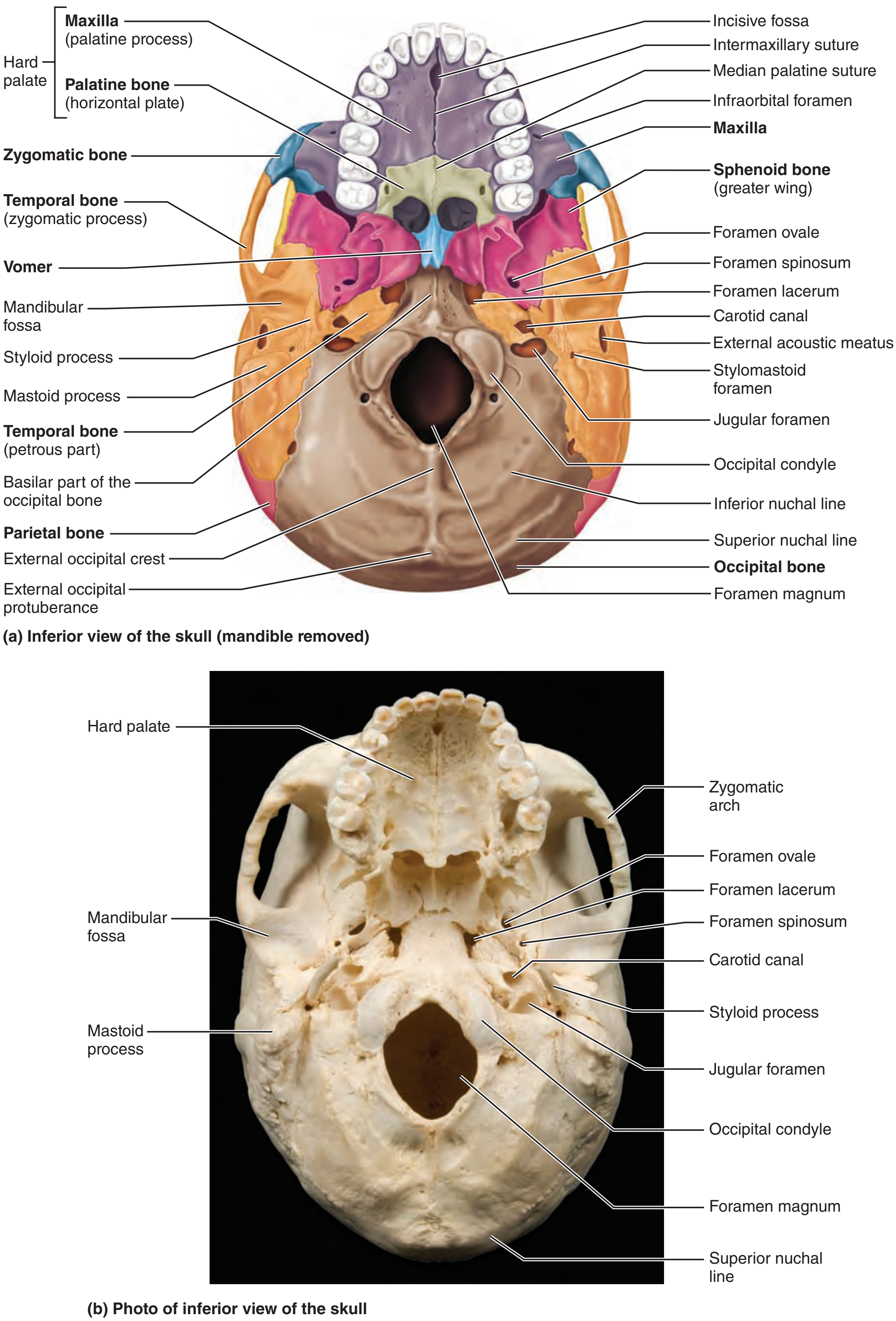
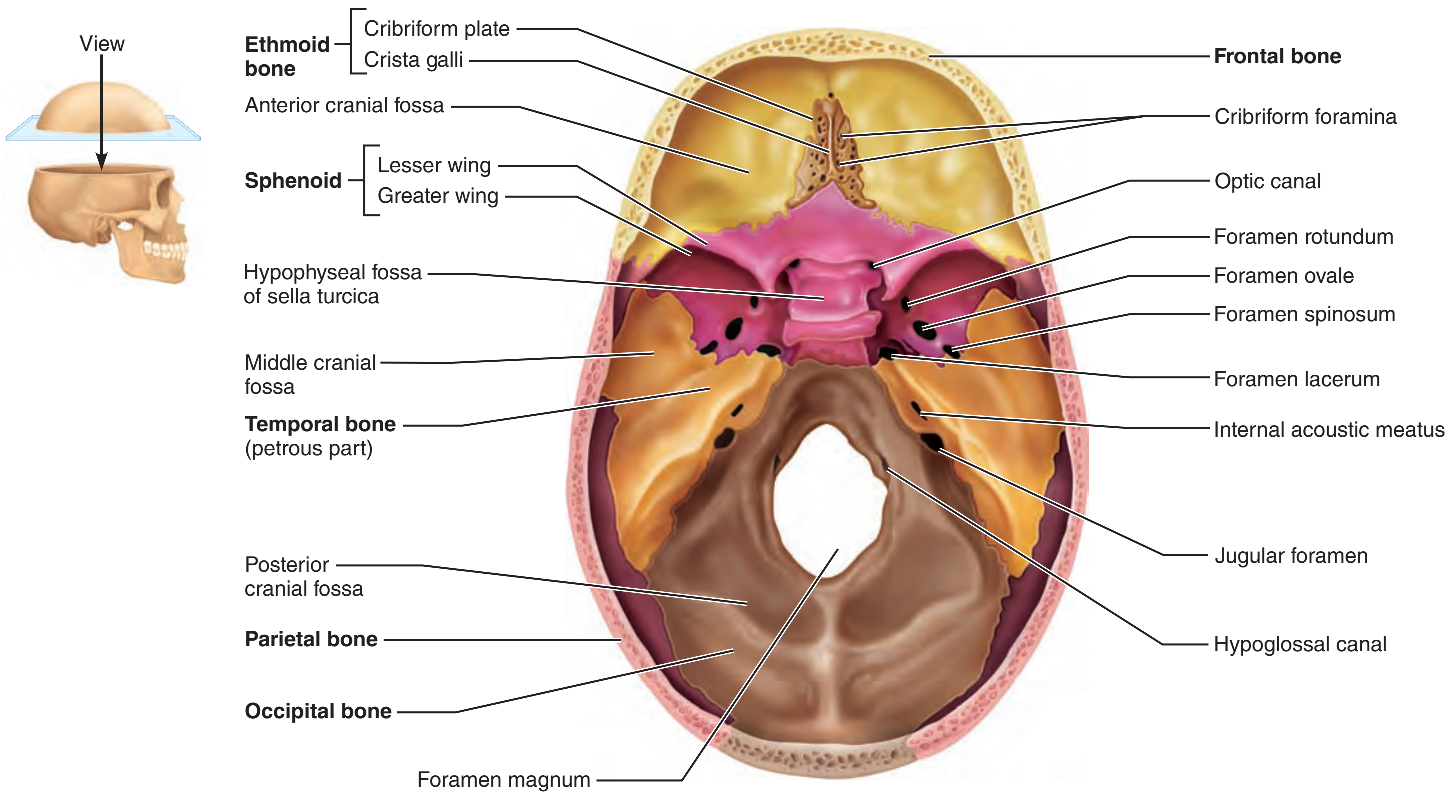
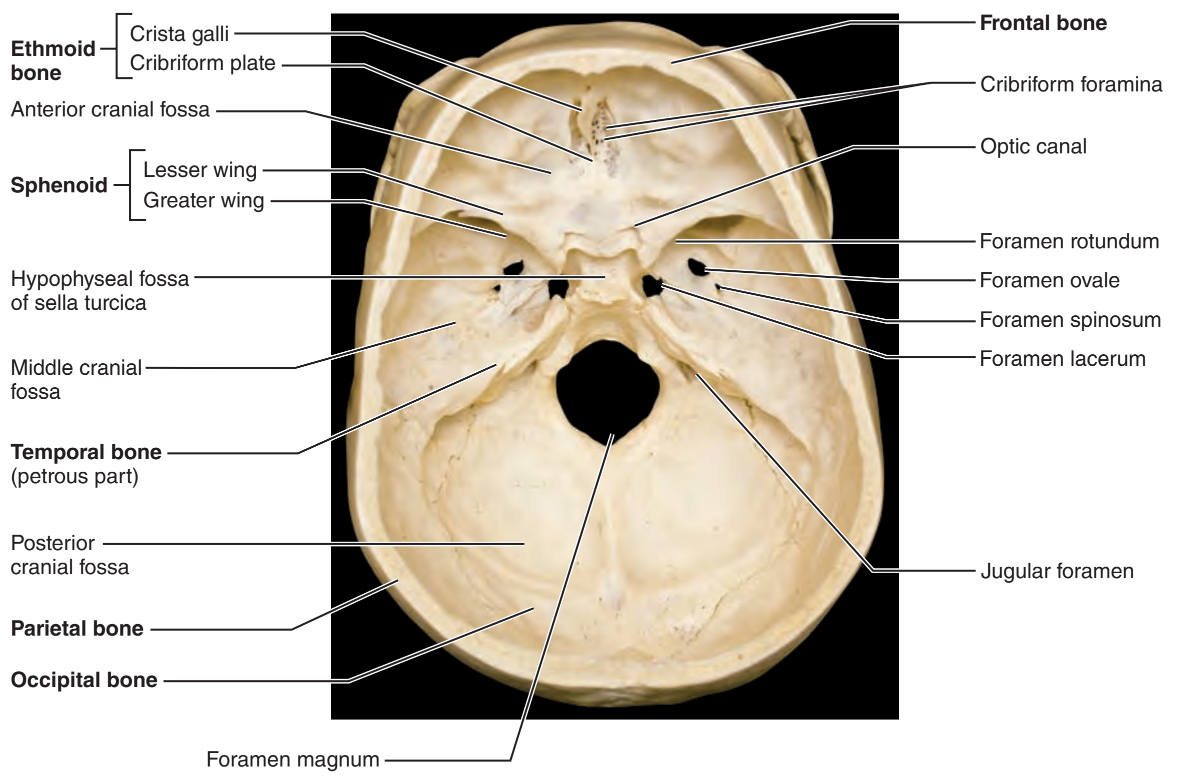


Figure 7.6 Inferior aspect of the skull, mandible removed. (For related images, see *A Brief Atlas of the Human Body*, Figure 4.)



(a) Superior view of the skull, calvaria removed



(b) Superior view of the skull, calvaria removed

Figure 7.7 The base of the cranial cavity. (For related images, see *A Brief Atlas of the Human Body*, Figure 5.)

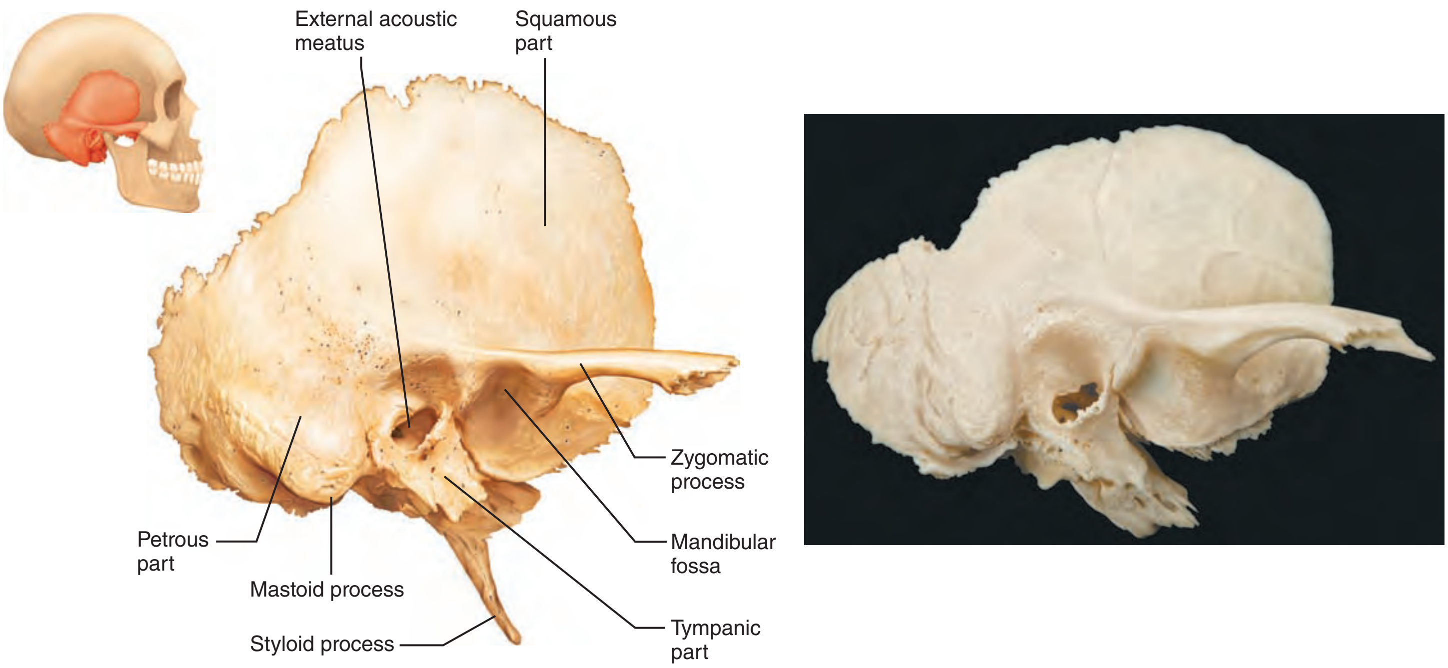


Figure 7.8 The temporal bone. Right lateral view. (For related images, see *A Brief Atlas of the Human Body*, Figures 2 and 8.)

Temporal Bones

The two **temporal bones** are best viewed on the lateral skull surface (Figure 7.5). They lie inferior to the parietal bones and meet them at the squamous sutures. The temporal bones form the inferolateral aspects of the skull and parts of the cranial base. The use of the terms *temple* and *temporal*, from the Latin word *temporum*, meaning "time," came about because gray hairs, a sign of time's passing, usually appear first at the temples.

Each temporal bone has a complicated shape **(Figure 7.8)** and is described in terms of its three major parts, the *squamous*, *tympanic*, and *petrous parts*. The flaring **squamous part** abuts the squamous suture. It has a barlike **zygomatic process** that meets the zygomatic bone of the face anteriorly. Together, these two bony structures form the **zygomatic arch**, which you can feel as the projection of your cheek (*zygoma* = cheekbone). The small, oval **mandibular fossa** (man-dib′u-lar) on the inferior surface of the zygomatic process receives the condylar process of the mandible (lower jawbone), forming the freely movable *temporomandibular joint*.

The **tympanic part** (tim-pan′ik; "eardrum") (Figure 7.8) of the temporal bone surrounds the **external acoustic meatus**, or external ear canal, through which sound enters the ear. The external acoustic meatus and the eardrum at its deep end are part of the *external ear*. In a dried skull, the eardrum has been removed and part of the middle ear cavity deep to the external meatus can also be seen.

The thick **petrous part** (pet′rus) of the temporal bone houses the *middle* and *internal ear cavities*, which contain sensory receptors for hearing and balance. Extending from the occipital bone posteriorly to the sphenoid bone anteriorly, it contributes to the cranial base (Figures 7.6 and 7.7). In the floor of the cranial cavity, the petrous part of the temporal bone looks like a miniature mountain ridge (*petrous* = rocky). The posterior slope of this ridge lies in the posterior cranial fossa; the anterior slope is in the middle cranial fossa. Together, the sphenoid bone and the petrous portions of the temporal bones construct the **middle cranial fossa** (Figures 7.7 and 7.2b), which supports the temporal lobes of the brain.

Several foramina penetrate the bone of the petrous region (Figure 7.6). The large **jugular foramen** at the junction of the occipital and petrous temporal bones allows passage of the internal jugular vein and three cranial nerves (IX, X, and XI). The **carotid canal** (kar-rot′id), just anterior to the jugular foramen, transmits the internal carotid artery into the cranial cavity. The two internal carotid arteries supply blood to over 80% of the cerebral hemispheres of the brain; their closeness to the internal ear cavities explains why, during excitement or exertion, we sometimes hear our rapid pulse as a thundering sound in the head. The **foramen lacerum** (la′ser-um) is a jagged opening (*lacerum* = torn or lacerated) between the petrous temporal bone and the sphenoid bone. It is almost completely closed by cartilage in a living person, but it is conspicuous in a dried skull, and students usually ask its name. The **internal acoustic meatus**, positioned superolateral to the jugular foramen (Figures 7.5c and d, and 7.7), transmits cranial nerves VII and VIII.

A conspicuous feature of the petrous part of the temporal bone is the **mastoid process** (mas′toid; "breast"), which acts as an anchoring site for some neck muscles (Figures 7.5, 7.6, and 7.8). This process can be felt as a lump just posterior to the ear. The needle-like **styloid process** (sti′loid; "stakelike") is an attachment point for several tongue and neck muscles and for a ligament that secures the hyoid bone of the neck to the skull (see Figure 7.15). The **stylomastoid foramen**, between the styloid and mastoid processes, allows cranial nerve VII (the facial nerve) to leave the skull (Figure 7.6).

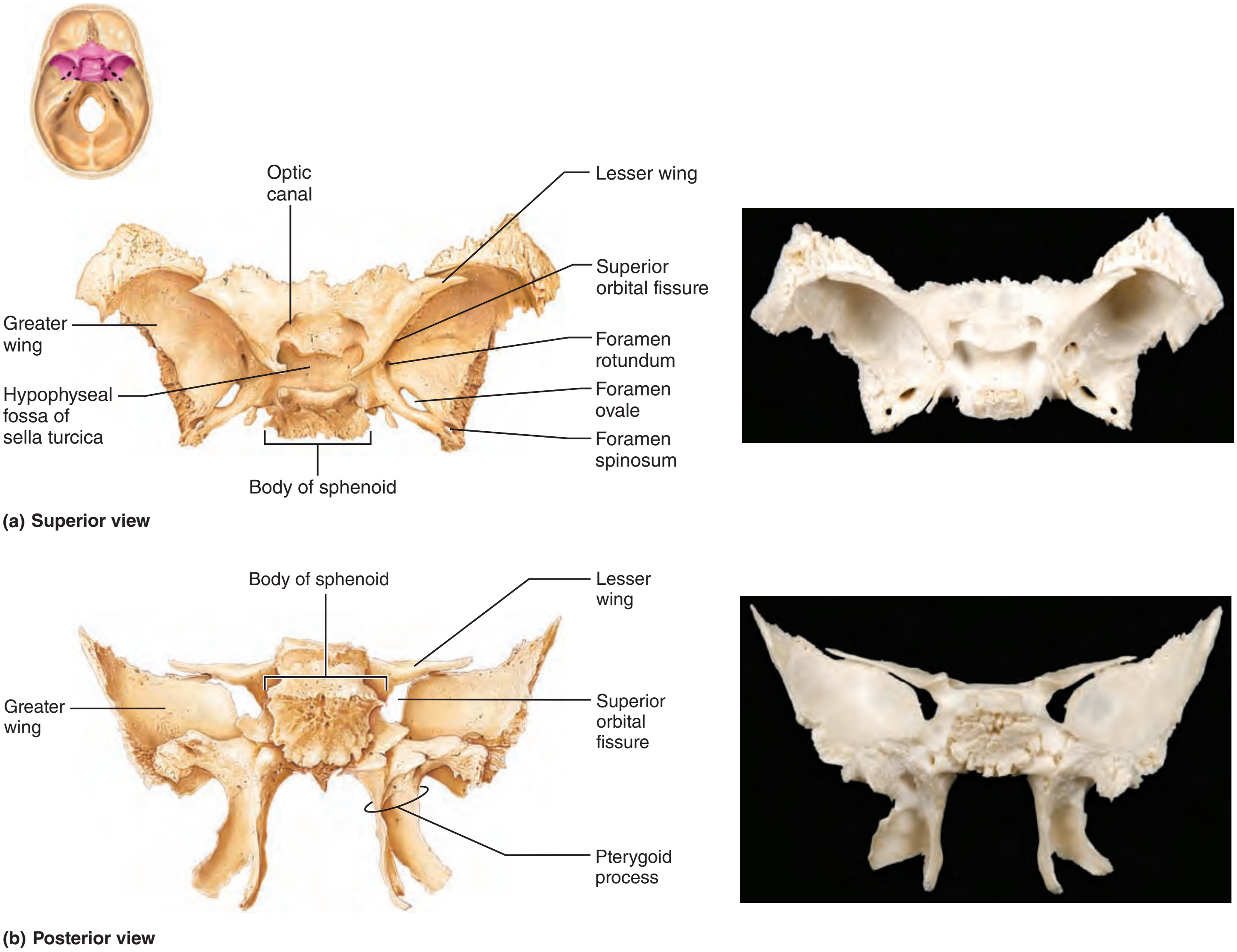


Figure 7.9 The sphenoid bone. (For related images, see *A Brief Atlas of the Human Body*, Figures 5 and 9).

Homeostatic Imbalance 7.1

The mastoid process is full of air cavities (sinuses) called **mastoid air cells**. Their position adjacent to the middle ear cavity (a high-risk area for infections spreading from the throat) puts them at risk for infection themselves. A mastoid sinus infection, or *mastoiditis*, is notoriously difficult to treat. Because the mastoid air cells are separated from the brain by only a very thin bony plate, mastoid infections may spread to the brain as well. Surgical removal of the mastoid process was once the best way to prevent life-threatening brain inflammations in people susceptible to repeated bouts of mastoiditis. Today, antibiotic therapy is the treatment of choice. ✚

Sphenoid Bone

The bat-shaped **sphenoid bone** (sfe′noid; *sphen* = wedge) spans the width of the middle cranial fossa (Figure 7.7). The sphenoid is considered the keystone of the cranium because it forms a central wedge that articulates with all other cranial bones. It is a challenging bone to study because of its complex shape. As shown in **Figure 7.9**, it consists of a central body and three pairs of processes: the greater wings, lesser wings, and pterygoid processes (ter′ĭ-goid). Within the **body** of the sphenoid are the paired **sphenoidal sinuses** (see Figures 7.5c and d, and 7.14).

The superior surface of the body bears a saddle-shaped prominence, the **sella turcica** (sel′ah ter′sĭ-kah), meaning "Turk's saddle." The seat of this saddle, called the **hypophyseal fossa**, forms a snug enclosure for the pituitary gland (hypophysis).

The **greater wings** project laterally from the sphenoid body, forming parts of (1) the middle cranial fossa (Figures 7.7 and 7.2b), (2) the posterior walls of the orbits (Figure 7.4a), and (3) the external wall of the skull, where they are seen as flag-shaped, bony areas medial to the zygomatic arch (Figure 7.5). The hornlike **lesser wings** form part of the floor of the anterior cranial fossa (Figure 7.7) and part of the medial walls of the orbits. The trough-shaped **pterygoid processes** project inferiorly

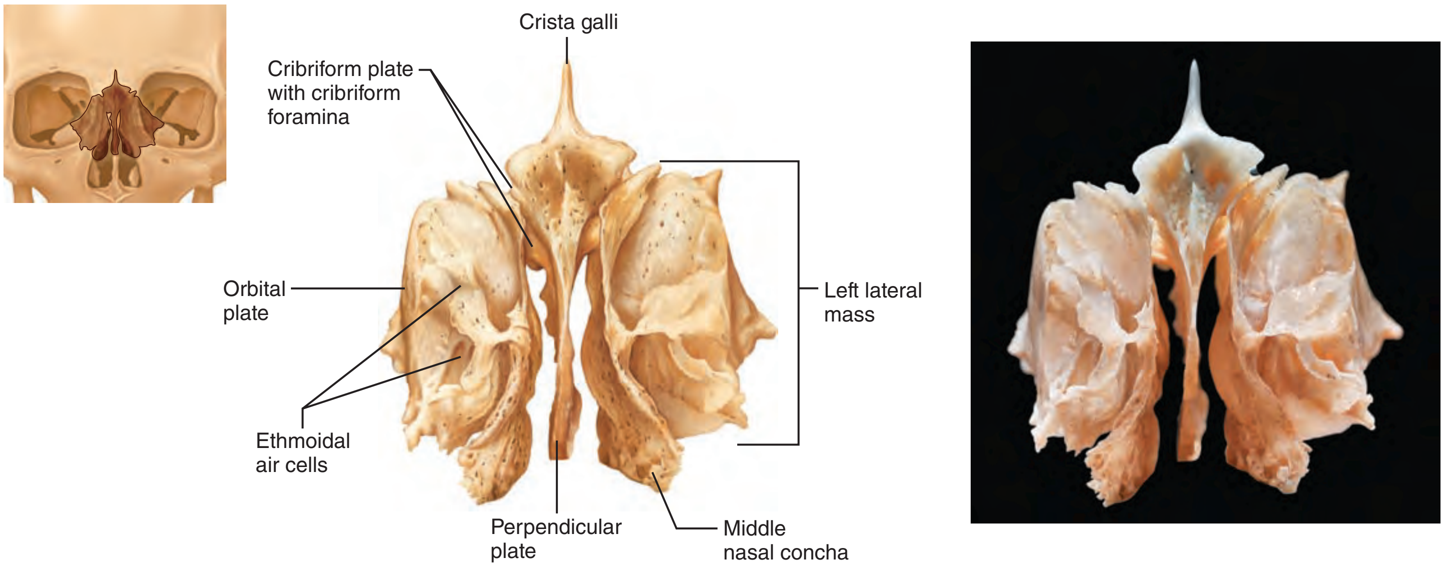


Figure 7.10 The ethmoid bone. Anterior view. (For related images, see *A Brief Atlas of the Human Body*, Figures 3 and 10.)

from the junction of the body and greater wings (Figure 7.9b). They anchor the pterygoid muscles, which are important in chewing.

A number of openings in the sphenoid bone are visible in Figures 7.7 and 7.9. The **optic canals** lie anterior to the sella turcica; they allow the optic nerves (cranial nerves II) to pass to the eyes. On each side of the sphenoid body is a crescent-shaped row of four openings. The anteriormost of these, the **superior orbital fissure**, is a long slit between the greater and lesser wings. It allows cranial nerves that control eye movements (III, IV, VI) to enter the orbit. This fissure is most obvious in an anterior view of the skull (Figure 7.4; see also Figure 7.9b). The **foramen rotundum** and **foramen ovale** (o-va′le) provide passageways for branches of cranial nerve V (the maxillary and mandibular nerves, respectively) to reach the face (Figure 7.7). The foramen rotundum is in the medial part of the greater wing and is usually oval, despite its name meaning "round opening." The foramen ovale, a large, oval foramen posterior to the foramen rotundum, is also visible in an inferior view of the skull (Figure 7.6). Posterolateral to the foramen ovale is the small **foramen spinosum** (Figure 7.7); it transmits the *middle meningeal artery*, which serves the internal faces of some cranial bones.

Ethmoid Bone

Like the temporal and sphenoid bones, the delicate **ethmoid bone** has a complex shape **(Figure 7.10)**. Lying between the sphenoid and the nasal bones of the face, it is the most deeply situated bone of the skull. It forms most of the bony area between the nasal cavity and the orbits.

The superior surface of the ethmoid is formed by the paired horizontal **cribriform plates** (krib′rĭ-form) (see also Figure 7.7), which help form the roof of the nasal cavities and the floor of the anterior cranial fossa. The cribriform plates are punctured by tiny holes (*cribr* = sieve) called *cribriform foramina* that allow the filaments of the olfactory nerves to pass from the smell receptors in the nasal cavities to the brain. Projecting superiorly between the cribriform plates is a triangular process called the **crista galli** (kris′tah gah′le; "rooster's comb"). The outermost covering of the brain (the dura mater) attaches to the crista galli and helps secure the brain in the cranial cavity.

The **perpendicular plate** of the ethmoid bone projects inferiorly in the median plane and forms the superior part of the nasal septum, which divides the nasal cavity into right and left halves (Figure 7.5c and d). Flanking the perpendicular plate on each side is a **lateral mass** riddled with sinuses called **ethmoidal air cells** (Figures 7.10 and 7.14), for which the bone itself is named (*ethmos* = sieve). Extending medially from the lateral masses, the delicately coiled **superior** and **middle nasal conchae** (kong′ke; *concha* = shell), named after the conch shells found on warm ocean beaches, protrude into the nasal cavity (Figures 7.10 and 7.13a). The lateral surfaces of the ethmoid's lateral masses are called **orbital plates** because they contribute to the medial walls of the orbits.

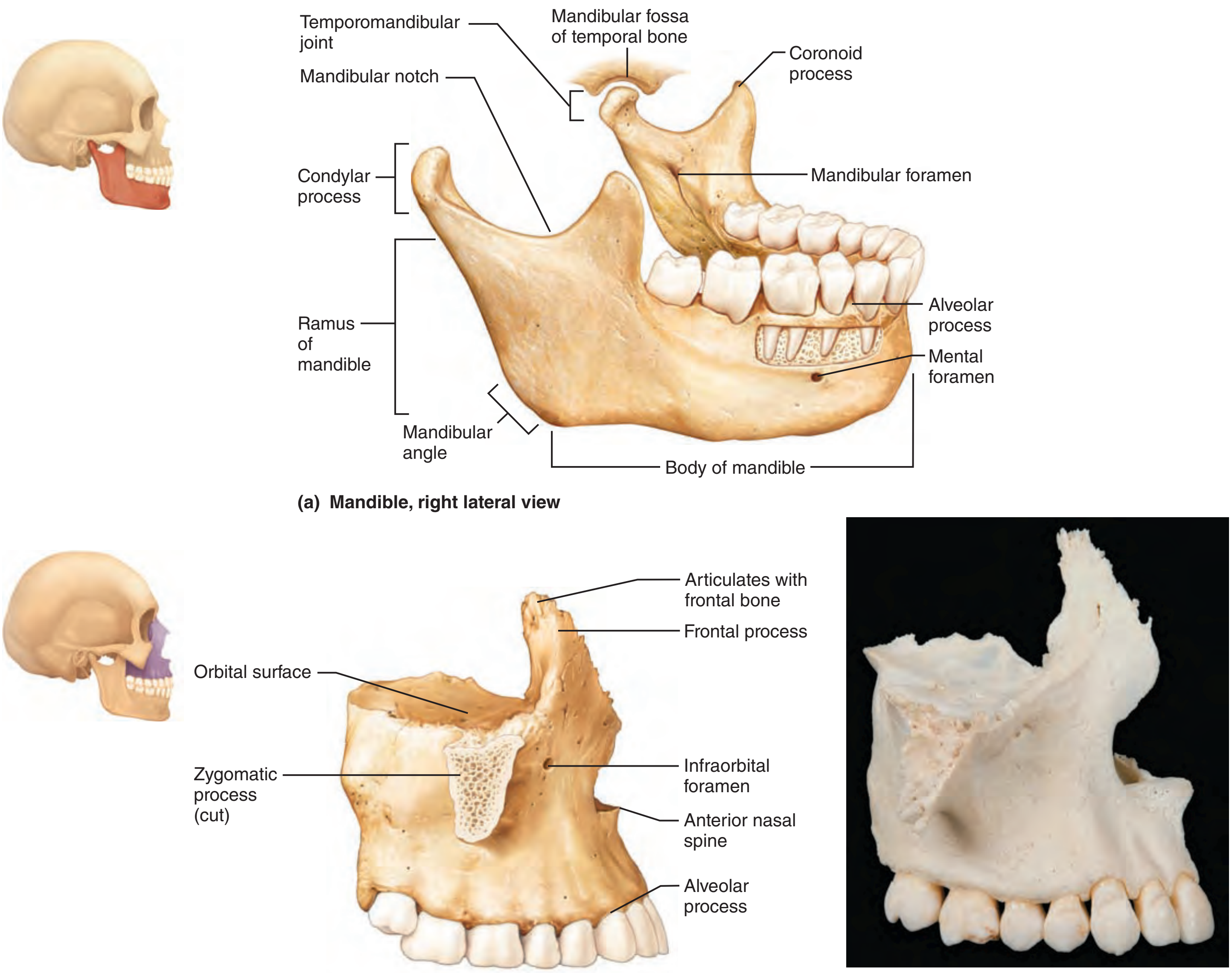
Sutural Bones

Sutural bones are tiny, irregularly shaped bones or bone clusters that occur within sutures, most often in the lambdoid suture (Figure 7.4b). Structurally unimportant, their number varies, and not all skulls exhibit them. The significance of these tiny bones is unknown.

☑ Check Your Understanding

3. Look at Figure 7.4. Which of the skull bones illustrated in view (a) are cranial bones?
4. Which bone forms the crista galli?
5. Which skull bones house the external ear canals?
6. What bones abut one another at the sagittal suture? At the lambdoid suture?

For answers, see Appendix H.



(a) Mandible, right lateral view

(b) Maxilla, right lateral view

(c) Maxilla, photo of right lateral view

Figure 7.11 Detailed anatomy of the mandible and the maxilla. (For related images, see *A Brief Atlas of the Human Body,* Figures 11 and 12.)

Facial Bones

The facial skeleton is made up of 14 bones (see Figures 7.4a and 7.5a), of which only the mandible and the vomer are unpaired. The maxillae, zygomatics, nasals, lacrimals, palatines, and inferior nasal conchae are paired bones. As a rule, the facial skeleton of men is more elongated than that of women. Women's faces tend to be rounder and less angular.

Mandible

The U-shaped **mandible** (man′dĭ-bl), or lower jawbone (Figures 7.4a and 7.5, and **Figure 7.11a**), is the largest, strongest bone of the face. It has a body, which forms the chin, and two upright *rami* (*rami* = branches). Each ramus meets the body posteriorly at a **mandibular angle**. At the superior margin of each ramus are two processes separated by the **mandibular notch**. The anterior **coronoid process** (kor′o-noid; "crown-shaped") is an insertion point for the large temporalis muscle that elevates the lower jaw during chewing. The posterior **condylar process** articulates with the mandibular fossa of the temporal bone, forming the *temporomandibular joint* on the same side.

The mandibular **body** anchors the lower teeth. Its superior border, called the **alveolar process** (al-ve′o-lar), contains the sockets (*dental alveoli*) in which the teeth are embedded. In the midline of the mandibular body is a slight ridge, the **mandibular symphysis** (sim′fih-sis), indicating where the two mandibular bones fused during infancy (Figure 7.4a).

Large **mandibular foramina**, one on the medial surface of each ramus, permit the nerves responsible for tooth sensation to pass to the teeth in the lower jaw. Dentists inject lidocaine into these foramina to prevent pain while working on the lower teeth. The **mental foramina**, openings on the lateral aspects of the mandibular body, allow blood vessels and nerves to pass to the skin of the chin (*ment* = chin) and lower lip.

Maxillary Bones

The **maxillary bones**, or **maxillae** (mak-sil′le; "jaws") (Figures 7.4 to 7.6 and 7.11b and c), are fused medially. They form the upper jaw and the central portion of the facial skeleton. All facial bones except the mandible articulate with the maxillae. Hence, the maxillae are considered the keystone bones of the facial skeleton.

The maxillae carry the upper teeth in their **alveolar processes**. Just inferior to the nose the maxillae meet medially, forming the pointed **anterior nasal spine** at their junction. The **palatine processes** (pă′lah-tīn) of the maxillae project posteriorly from the alveolar processes and fuse medially at the *intermaxillary suture*, forming the anterior two-thirds of the hard palate, or bony roof of the mouth (Figures 7.5c and d and 7.6). Just posterior to the teeth is a midline foramen, called the **incisive fossa**, which serves as a passageway for blood vessels and nerves.

7

The **frontal processes** extend superiorly to the frontal bone, forming part of the lateral aspects of the bridge of the nose (Figures 7.4a and 7.11b). The regions that flank the nasal cavity laterally contain the **maxillary sinuses** (see Figure 7.14), the largest of the paranasal sinuses. They extend from the orbits to the roots of the upper teeth. Laterally, the maxillae articulate with the zygomatic bones via their **zygomatic processes**.

The **inferior orbital fissure** is located deep within the orbit (Figure 7.4a) at the junction of the maxilla with the greater wing of the sphenoid. It permits the zygomatic nerve, the maxillary nerve (a branch of cranial nerve V), and blood vessels to pass to the face. Just below the eye socket on each side is an **infraorbital foramen** that allows the infraorbital nerve (a continuation of the maxillary nerve) and artery to reach the face.

Zygomatic Bones

The irregularly shaped **zygomatic bones** (Figures 7.4a, 7.5a, and 7.6) are commonly called the cheekbones (*zygoma* = cheekbone). They articulate with the zygomatic processes of the temporal bones posteriorly, the zygomatic processes of the frontal bone superiorly, and with the zygomatic processes of the maxillae anteriorly. The zygomatic bones form the prominences of the cheeks and part of the inferolateral margins of the orbits.

Nasal Bones

The thin, basically rectangular **nasal bones** (na′zal) are fused medially, forming the bridge of the nose (Figures 7.4a and 7.5a). They articulate with the frontal bone superiorly, the maxillary bones laterally, and the perpendicular plate of the ethmoid bone posteriorly. Inferiorly they attach to the cartilages that form most of the skeleton of the external nose.

Lacrimal Bones

The delicate, fingernail-shaped **lacrimal bones** (lak′rĭ-mal) contribute to the medial walls of each orbit (Figures 7.4a and 7.5a). They articulate with the frontal bone superiorly, the ethmoid bone posteriorly, and the maxillae anteriorly. Each lacrimal bone contains a deep groove that helps form a **lacrimal fossa**. The lacrimal fossa houses the *lacrimal sac*, part of the passageway that allows tears to drain from the eye surface into the nasal cavity (*lacrima* = tears).

Palatine Bones

Each L-shaped **palatine bone** is fashioned from two bony plates, the *horizontal* and *perpendicular* (see Figures 7.13a and 7.6a), and has three important articular processes, the *pyramidal*, *sphenoidal*, and *orbital*. The **horizontal plates**, joined at the median palatine suture, complete the posterior portion of the hard palate. The superiorly projecting **perpendicular (vertical) plates** form part of the posterolateral walls of the nasal cavity and a small part of the orbits.

Vomer

The slender, plow-shaped **vomer** (vo′mer; "plow") lies in the nasal cavity, where it forms part of the nasal septum (see Figures 7.4a and 7.13b). It is described below in connection with the nasal cavity.

Inferior Nasal Conchae

The paired **inferior nasal conchae** are thin, curved bones in the nasal cavity. They project medially from the lateral walls of the nasal cavity, just inferior to the middle nasal conchae of the ethmoid bone (see Figures 7.4a and 7.13a). They are the largest of the three pairs of conchae and, like the others, they form part of the lateral walls of the nasal cavity.

☑ Check Your Understanding

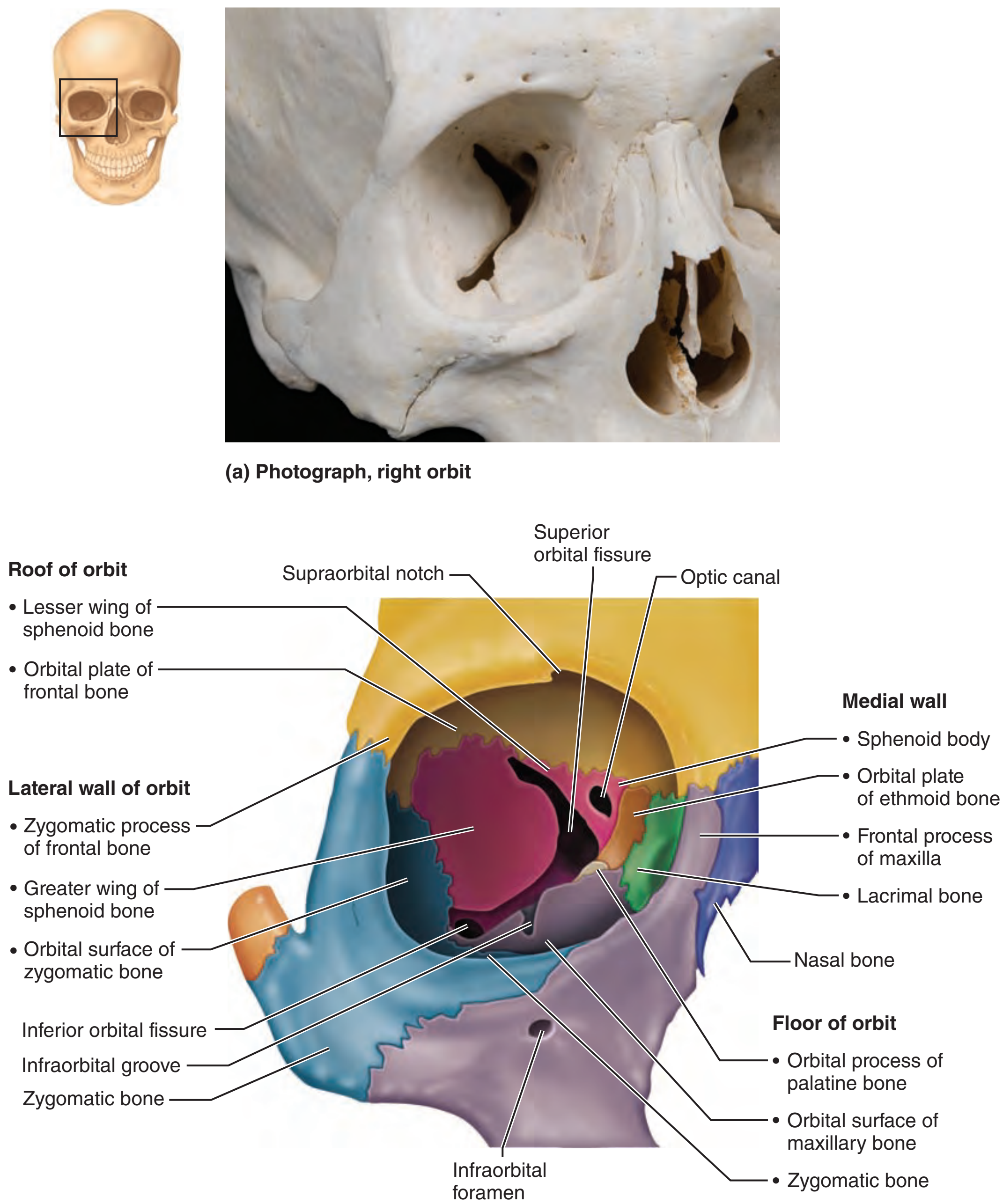
7. Women with prominent (high) cheekbones are often considered beautiful by the modeling industry. What bones are the "cheekbones"?
8. Johnny was vigorously exercising the only joints in the skull that are freely movable. What would you guess he was doing?
9. What bones are the keystone bones of the facial skeleton?

For answers, see Appendix H.

Special Characteristics of the Orbits and Nasal Cavity

✓ Define the bony boundaries of the orbits, nasal cavity, and paranasal sinuses.

Two restricted skull regions, the orbits and the nasal cavity, are formed from an amazing number of bones. Even though we have already described the individual bones forming these structures, we give a brief summary here to pull the parts together.



(a) Photograph, right orbit

(b) Contribution of each of the seven bones forming the right orbit

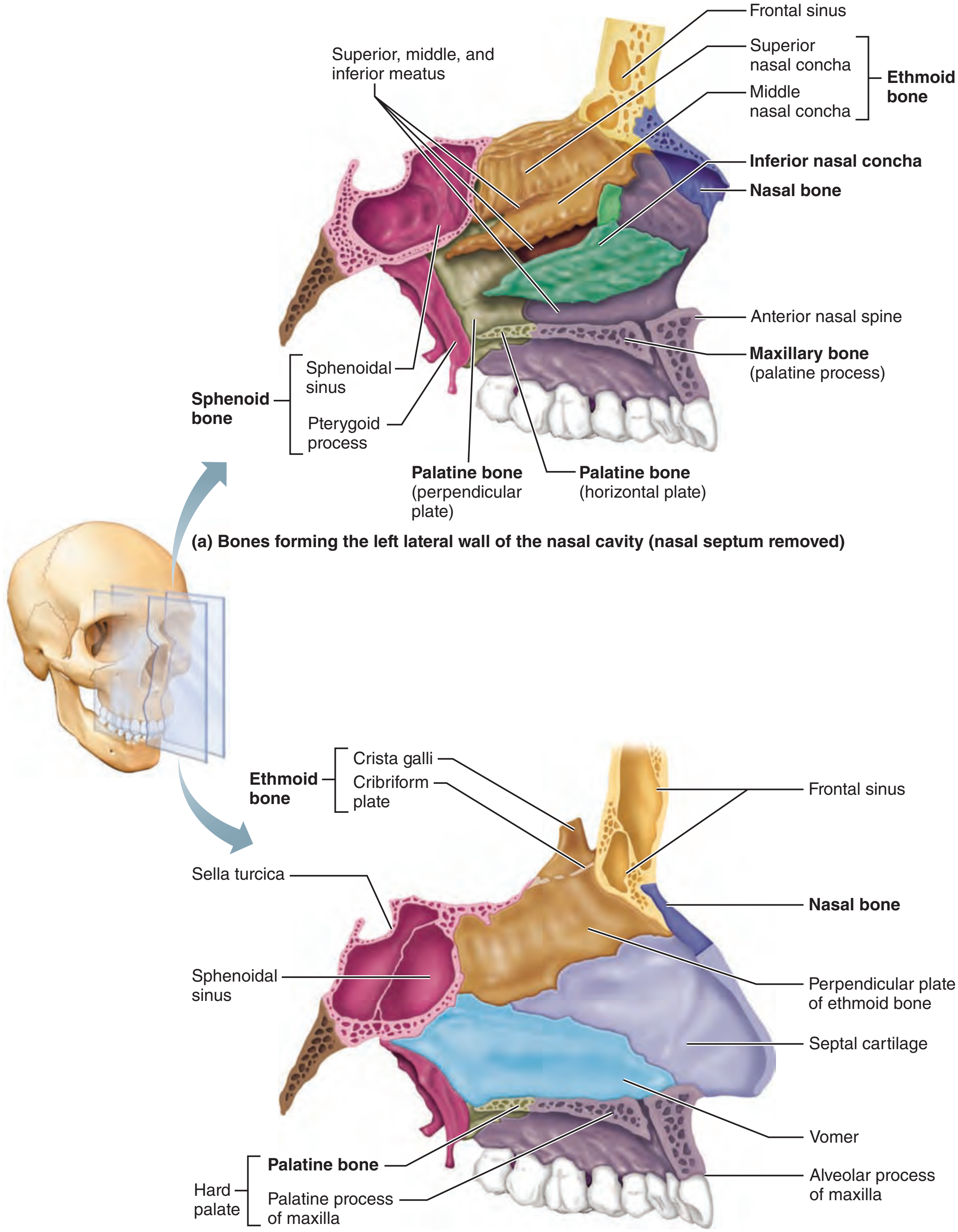
Figure 7.12 Bones that form the orbits. (For a related image, see *A Brief Atlas of the Human Body,* Figure 14.)

The Orbits

The cone-shaped **orbits** are bony cavities in which the eyes are firmly encased and cushioned by fatty tissue. The muscles that move the eyes and the tear-producing lacrimal glands are also housed in the orbits. The walls of each orbit are formed by parts of seven bones—the frontal, sphenoid, zygomatic, maxilla, palatine, lacrimal, and ethmoid bones. Their relationships are shown in **Figure 7.12**. Also seen in the orbits are the superior and inferior orbital fissures and the optic canals, described earlier.

The Nasal Cavity

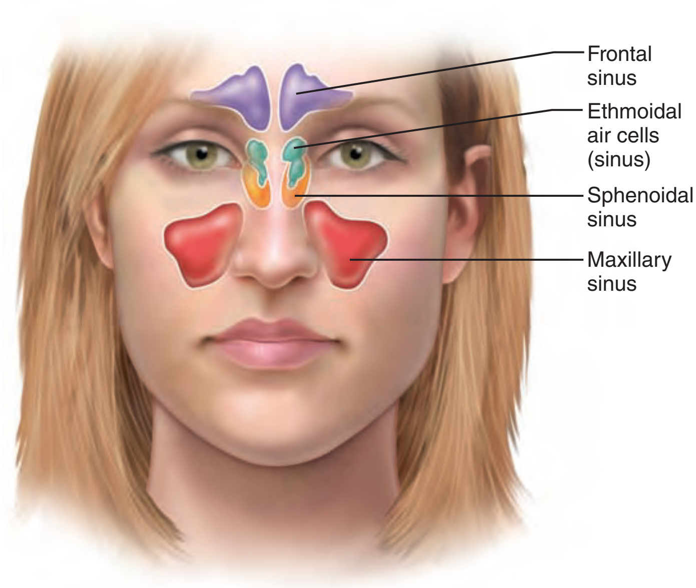
The **nasal cavity** is constructed of bone and hyaline cartilage **(Figure 7.13)**. The *roof* of the nasal cavity is formed by the cribriform plates of the ethmoid. The *lateral walls* are largely shaped by the superior and middle conchae of the ethmoid bone, the perpendicular plates of the palatine bones, and the inferior nasal conchae. The depressions under cover of the conchae on the lateral walls are called *meatuses* (*meatus* = passage), so there are superior, middle, and inferior meatuses. The *floor* of the nasal cavity is formed by the palatine processes of the



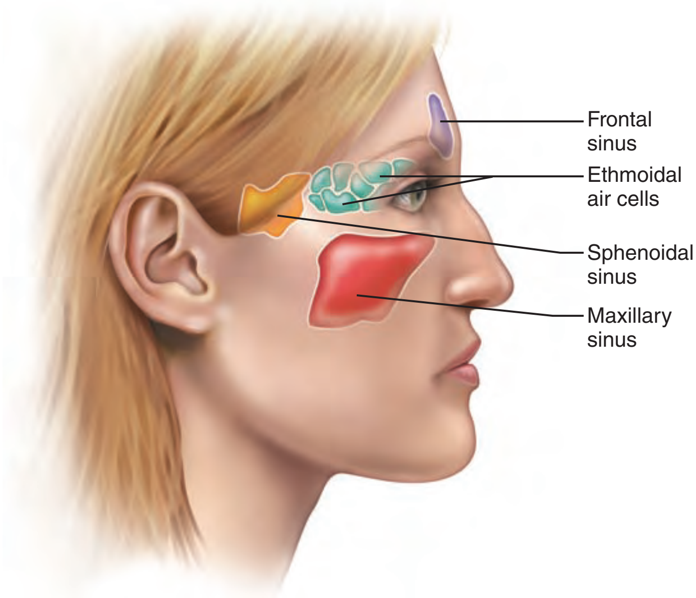
(a) Bones forming the left lateral wall of the nasal cavity (nasal septum removed)

(b) Nasal cavity with septum in place showing the contributions of the ethmoid bone, the vomer, and septal cartilage

Figure 7.13 Bones of the nasal cavity. (For a related image, see *A Brief Atlas of the Human Body*, Figure 15.)



(a) Anterior aspect



(b) Medial aspect

Figure 7.14 Paranasal sinuses.

maxillae and the palatine bones. The nasal cavity is divided into right and left parts by the *nasal septum*. The bony portion of the septum is formed by the vomer inferiorly and the perpendicular plate of the ethmoid bone superiorly (Figure 7.13b). A sheet of cartilage called the *septal cartilage* completes the septum anteriorly.

The nasal septum and conchae are covered with a mucus-secreting mucosa that moistens and warms the entering air and helps cleanse it of debris. The scroll-shaped conchae increase the turbulence of air flowing through the nasal cavity. This swirling forces more of the inhaled air into contact with the warm, damp mucosa and encourages trapping of airborne particles (dust, pollen, bacteria) in the sticky mucus.

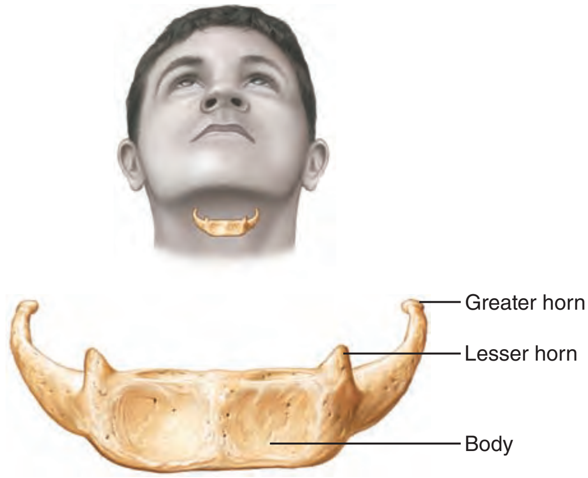


Figure 7.15 The hyoid bone, anterior view.

7

Paranasal Sinuses

Five skull bones—the frontal, sphenoid, ethmoid, and paired maxillary bones—contain mucosa-lined, air-filled sinuses that give them a rather moth-eaten appearance in an X-ray image. These particular sinuses are called **paranasal sinuses** because they cluster around the nasal cavity **(Figure 7.14)**.

Small openings connect the sinuses to the nasal cavity and act as "two-way streets": Air enters the sinuses from the nasal cavity, and mucus formed by the sinus mucosae drains into the nasal cavity. The mucosa of the sinuses also helps to warm and humidify inspired air. The paranasal sinuses lighten the skull and enhance the resonance of the voice.

☑ Check Your Understanding

10. What bones contain the paranasal sinuses?
11. The perpendicular plates of the palatine bones and the superior and middle conchae of the ethmoid bone form a substantial part of the nasal cavity walls. Which bone forms the roof of that cavity?
12. What bone forms the bulk of the orbit floor and what sense organ is found in the orbit of a living person?

For answers, see Appendix H.

The Hyoid Bone

Though not really part of the skull, the **hyoid bone** (hi′oid; "U-shaped") lies just inferior to the mandible in the anterior neck, and looks like a miniature version of it **(Figure 7.15)**. 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 anchored by the narrow *stylohyoid ligaments* to the styloid processes of the temporal bones. Horseshoe-shaped, with a body and two pairs of *horns*, or *cornua*, the hyoid bone acts as a movable base for the tongue. Its body and greater horns are attachment points for neck muscles that raise and lower the larynx during swallowing and speech.

(Text continues on p. 218.)

Table 7.1 Bones of the Skull

BONE COLOR CODE*	COMMENTS	IMPORTANT MARKINGS
Cranial Bones		
Frontal (1) (Figures 7.4a, 7.5, and 7.7)	Forms forehead, superior part of orbits, and most of the anterior cranial fossa; contains sinuses	**Supraorbital foramina (notches):** allow the supraorbital arteries and nerves to pass
Parietal (2) (Figures 7.4 and 7.5)	Form most of the superior and lateral aspects of the skull	
Occipital (1) (Figures 7.4b, 7.5, 7.6, and 7.7)	Forms posterior aspect and most of the base of the skull	**Foramen magnum:** allows passage of the spinal cord from the brain stem to the vertebral canal **Hypoglossal canals:** allow passage of the hypoglossal nerves (cranial nerve XII) **Occipital condyles:** articulate with the atlas (first vertebra) **External occipital protuberance** and **nuchal lines:** sites of muscle attachment **External occipital crest:** attachment site of ligamentum nuchae
Temporal (2) (Figures 7.5, 7.6, 7.7, and 7.8)	Form inferolateral aspects of the skull and contribute to the middle cranial fossa; have squamous, tympanic, and petrous parts	**Zygomatic process:** helps to form the zygomatic arch, which forms the prominence of the cheek **Mandibular fossa:** articular point of the condylar process of the mandible **External acoustic meatus:** canal leading from the external ear to the eardrum **Styloid process:** attachment site for several neck muscles and for a ligament to the hyoid bone **Mastoid process:** attachment site for several neck and tongue muscles **Stylomastoid foramen:** allows cranial nerve VII (facial nerve) to pass **Jugular foramen:** allows passage of the internal jugular vein and cranial nerves IX, X, and XI **Carotid canal:** allows passage of the internal carotid artery
Sphenoid (1) (Figures 7.4a, 7.5, 7.6, 7.7, and 7.9)	Keystone of the cranium; contributes to the middle cranial fossa and orbits; main parts are the body, greater wings, lesser wings, and pterygoid processes	**Sella turcica:** hypophyseal fossa portion is the seat of the pituitary gland **Optic canals:** allow passage of optic nerves (cranial nerves II) and the ophthalmic arteries **Superior orbital fissures:** allow passage of cranial nerves III, IV, VI, part of V (ophthalmic division), and ophthalmic vein **Foramen rotundum (2):** allows passage of the maxillary division of cranial nerve V **Foramen ovale (2):** allows passage of the mandibular division of cranial nerve V **Foramen spinosum (2):** allows passage of the middle meningeal artery

The Vertebral Column

General Characteristics

✓ Describe the structure of the vertebral column, list its components, and describe its curvatures.

✓ Indicate a common function of the spinal curvatures and the intervertebral discs.

Some people think of the **vertebral column** as a rigid supporting rod, but this is inaccurate. Also called the **spine** or **spinal column**, the vertebral column consists of 26 irregular bones connected in such a way that a flexible, curved structure results **(Figure 7.16)**.

Serving as the axial support of the trunk, the spine extends from the skull to the pelvis, where it transmits the weight of the trunk to the lower limbs. It also surrounds and protects the delicate spinal cord and provides attachment points for the ribs and for the muscles of the back and neck.

In the fetus and infant, the vertebral column consists of 33 separate bones, or **vertebrae** (ver′tĕ-bre). Inferiorly, nine of these eventually fuse to form two composite bones, the sacrum and the tiny coccyx. The remaining 24 bones persist as individual vertebrae separated by intervertebral discs.

7

Regions and Curvatures

The vertebral column is about 70 cm (28 inches) long in an average adult and has five major regions (Figure 7.16). The seven vertebrae of the neck are the **cervical vertebrae** (ser′vĭ-kal), the next 12 are the **thoracic vertebrae** (tho-ras′ik), and the five supporting the lower back are the **lumbar vertebrae** (lum′bar). Remembering common meal times—7 AM, 12 noon, and 5 PM—will help you recall the number of bones in these three regions of the spine. The vertebrae become progressively larger from the cervical to the lumbar region, as they must support greater and greater weight.

Inferior to the lumbar vertebrae is the **sacrum** (sa′krum), which articulates with the hip bones of the pelvis. The terminus of the vertebral column is the tiny **coccyx** (kok′siks).

All of us have the same number of cervical vertebrae. Variations in numbers of vertebrae in other regions occur in about 5% of people.

When you view the vertebral column from the side, you can see the four curvatures that give it its S, or sinusoid, shape. The **cervical** and **lumbar curvatures** are concave posteriorly; the **thoracic** and **sacral curvatures** are convex posteriorly. These curvatures increase the resilience and flexibility of the spine, allowing it to function like a spring rather than a rigid rod.

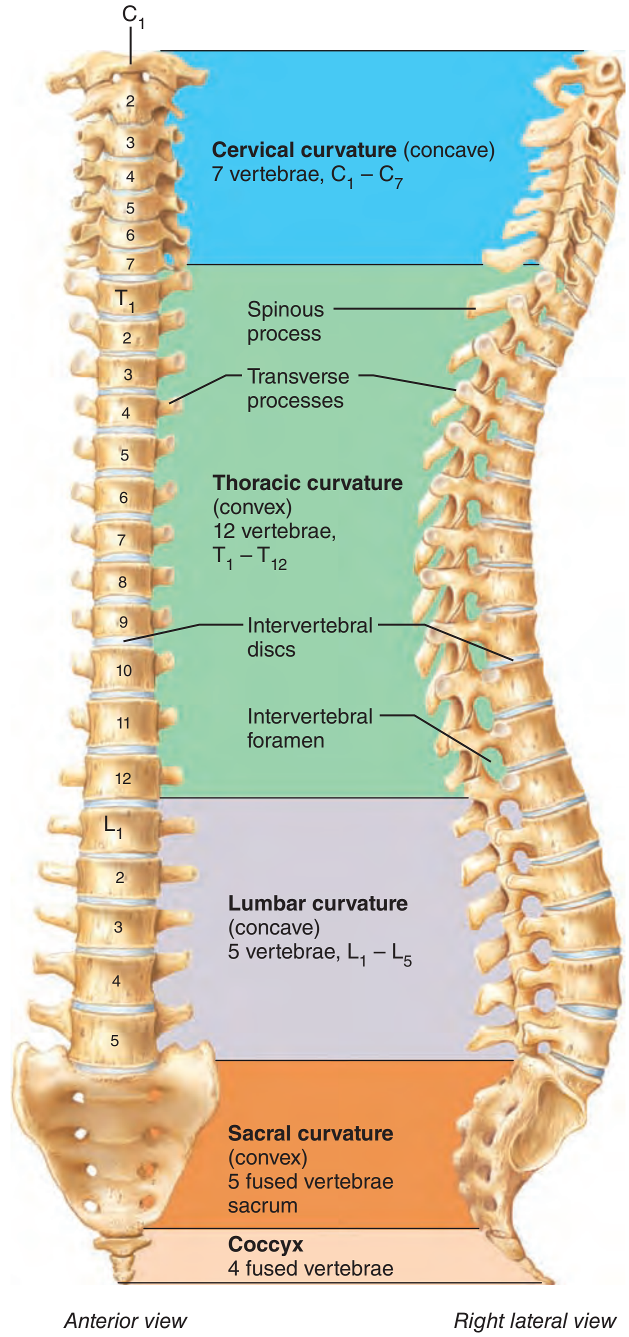
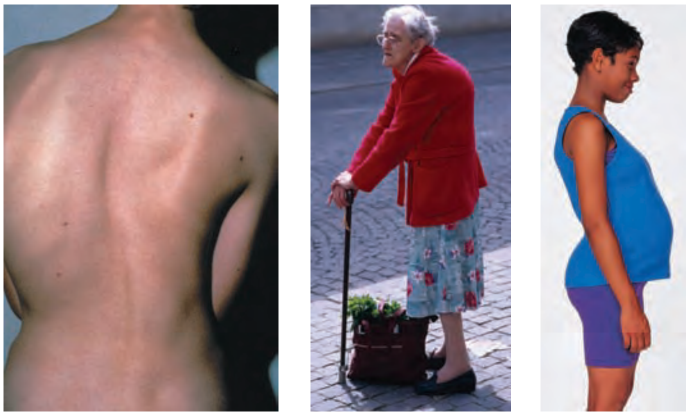


Figure 7.16 The vertebral column. Notice the curvatures in the lateral view. (The terms convex and concave refer to the curvature of the posterior aspect of the vertebral column.) (For a related image, see *A Brief Atlas of the Human Body,* Figure 17.)

Homeostatic Imbalance 7.2

There are several types of abnormal spinal curvatures **(Figure 7.17)**. Some are congenital (present at birth); others result from disease, poor posture, or unequal muscle pull on the spine. *Scoliosis* (sko″le-o′sis), literally, "twisted disease," is an abnormal *lateral* curvature that occurs most often in the thoracic region. It is quite common during late childhood, particularly in girls, for some unknown reason. Other, more severe cases result from abnormal vertebral structure, lower limbs of unequal length, or muscle paralysis. If muscles on one side of the body are nonfunctional, those of the opposite side exert an unopposed pull on the spine and force it out of alignment. Scoliosis is treated (with body braces or surgically) before growth ends to prevent permanent deformity and breathing difficulties due to a compressed lung.

Kyphosis (ki-fo′sis), or hunchback, is a *dorsally* exaggerated *thoracic* curvature. It is particularly common in elderly people because of osteoporosis, but may also reflect tuberculosis of the spine, rickets, or osteomalacia.



(a) Scoliosis (b) Kyphosis (c) Lordosis

Figure 7.17 **Abnormal spinal curvatures.**

Lordosis, or swayback, is an accentuated *lumbar* curvature. It, too, can result from spinal tuberculosis or osteomalacia. Temporary lordosis is common in those carrying a large load up front, such as men with "potbellies" and pregnant women. In an attempt to preserve their center of gravity, these individuals automatically throw back their shoulders, accentuating their lumbar curvature. ✚

Ligaments

Like a tall, tremulous TV transmitting tower, the vertebral column cannot possibly stand upright by itself. It must be held in place by an elaborate system of cable-like supports. In the case of the vertebral column, straplike ligaments and the trunk muscles assume this role.

The major supporting ligaments are the **anterior** and **posterior longitudinal ligaments** **(Figure 7.18)**. These run as continuous bands down the front and back surfaces of the vertebrae from the neck to the sacrum. The broad anterior ligament is strongly attached to both the bony vertebrae and the discs. Along with its supporting role, it prevents hyperextension of the spine (bending too far backward). The posterior ligament, which resists hyperflexion of the spine (bending too sharply forward), is narrow and relatively weak. It attaches only to the discs. However, the **ligamentum flavum**, which connects adjacent vertebrae, contains elastic connective tissue and is especially strong. It stretches as we bend forward and then recoils when we resume an erect posture. Short ligaments connect each vertebra to those immediately above and below.

Intervertebral Discs

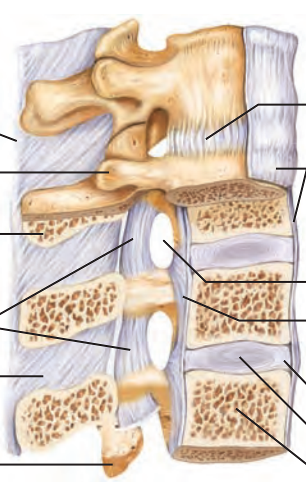
Each **intervertebral disc** is a cushionlike pad composed of two parts. The inner gelatinous **nucleus pulposus** (pul-po′sus; "pulp") acts like a rubber ball, giving the disc its elasticity and compressibility. Surrounding the nucleus pulposus is a strong collar composed of collagen fibers superficially and fibrocartilage internally, the **anulus fibrosus** (an′u-lus fi-bro′sus; "ring of fibers") (Figure 7.18a, c). The anulus fibrosus limits the expansion of the nucleus pulposus when the spine is compressed. It also acts like a woven strap to bind successive vertebrae together, withstands twisting forces, and resists tension in the spine. 7

Sandwiched between the bodies of neighboring vertebrae, the intervertebral discs act as shock absorbers during walking, jumping, and running. They allow the spine to flex and extend, and to a lesser extent to bend laterally. At points of compression, the discs flatten and bulge out a bit between the vertebrae. The discs are thickest in the lumbar and cervical regions, which enhances the flexibility of these regions.

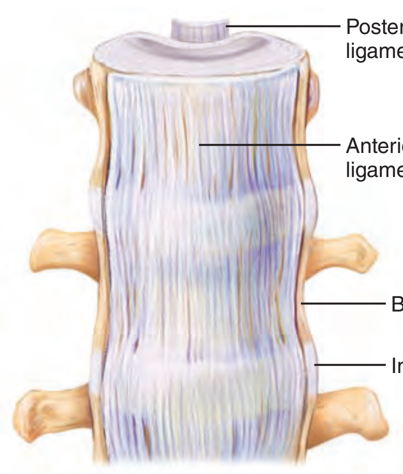
Collectively the discs account for about 25% of the height of the vertebral column. They flatten somewhat during the course of the day, so we are always a few millimeters shorter at night than when we awake in the morning.

Homeostatic Imbalance 7.3

Severe or sudden physical trauma to the spine—for example, from bending forward while lifting a heavy object—may result in herniation of one or more discs. A **herniated** (**prolapsed**)

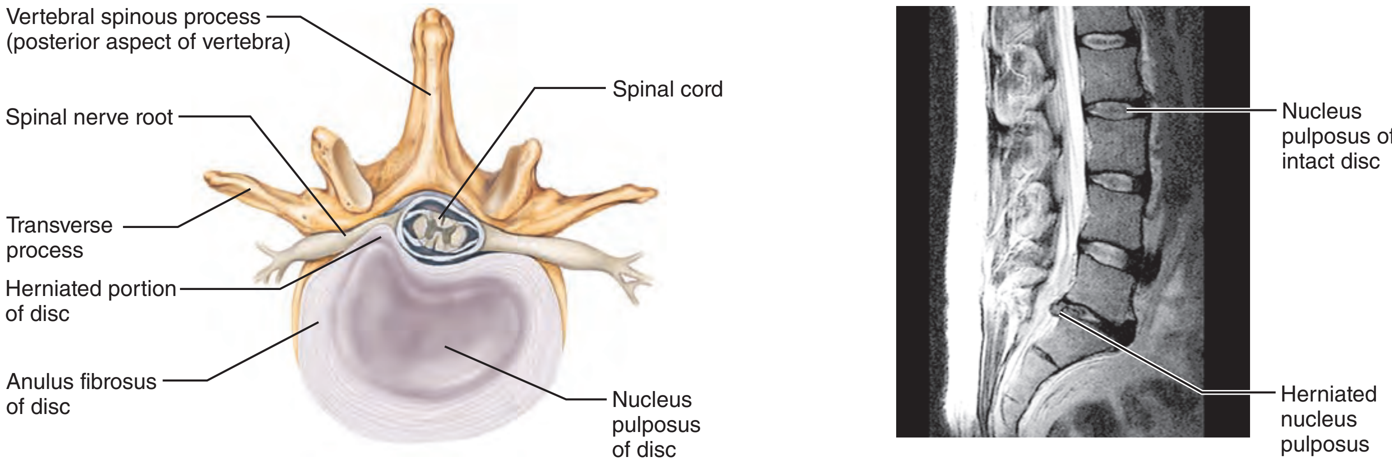


(a) Median section of three vertebrae, illustrating the composition of the discs and the ligaments



(b) Anterior view of part of the spinal column, showing the anterior longitudinal ligament

Figure 7.18 **Ligaments and fibrocartilage discs uniting the vertebrae.**



(c) Superior view of a herniated intervertebral disc

(d) MRI of lumbar region of vertebral column in sagittal section showing herniated disc

Figure 7.18 *(continued)* **Ligaments and fibrocartilage discs uniting the vertebrae.**

disc (commonly called a *slipped disc*) usually involves rupture of the anulus fibrosus followed by protrusion of the spongy nucleus pulposus through the anulus (Figure 7.18c, d). If the protrusion presses on the spinal cord or on spinal nerves exiting from the cord, numbness or excruciating pain may result.

Herniated discs are generally treated with moderate exercise, massage, heat therapy, and painkillers. If this fails, the protruding disc may have to be removed surgically and a bone graft done to fuse the adjoining vertebrae. For those preferring to avoid general anesthesia, part of the disc can be vaporized with a laser in an outpatient procedure called percutaneous laser disc decompression that takes only 30 to 40 minutes. If necessary, tears in the anulus can be sealed by electrothermal means at the same time. The patient leaves with only an adhesive bandage to mark the spot. ✚

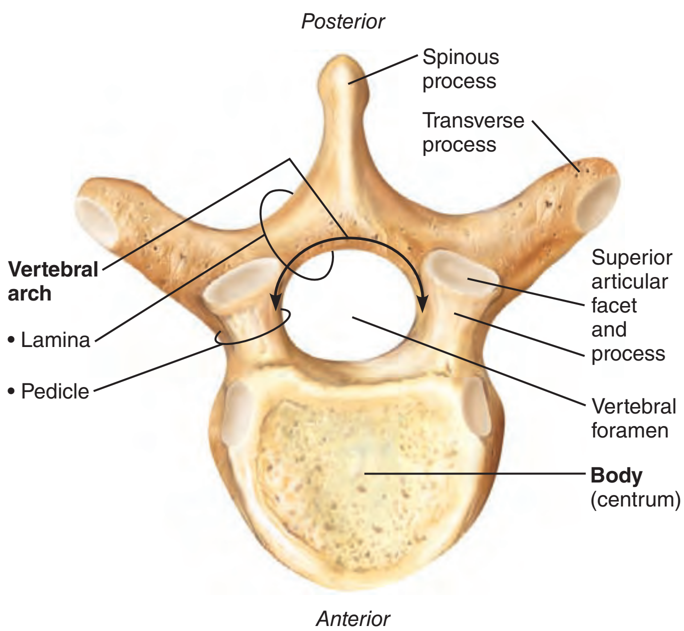


Figure 7.19 Typical vertebral structures. Superior view of a thoracic vertebra. Only bone features are illustrated in this and subsequent bone figures in this chapter. Articular cartilage is not depicted.

☑ Check Your Understanding

13. What are the five major regions of the vertebral column?
14. In which two of these regions is the vertebral column concave posteriorly?
15. Besides the spinal curvatures, which skeletal elements help to make the vertebral column flexible?

For answers, see Appendix H.

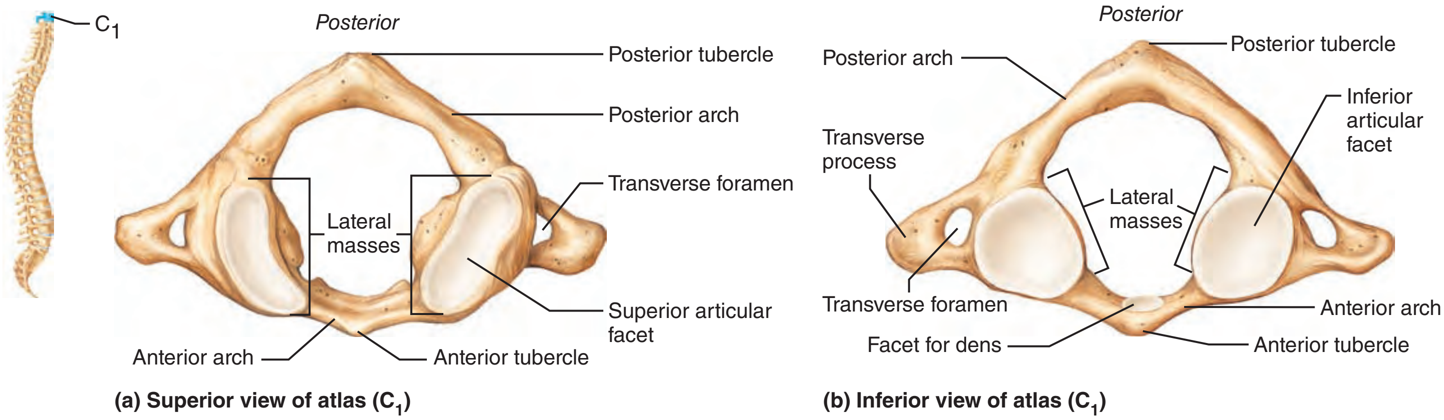
General Structure of Vertebrae

✓ Discuss the structure of a typical vertebra and describe regional features of cervical, thoracic, and lumbar vertebrae.

All vertebrae have a common structural pattern **(Figure 7.19)**. Each vertebra consists of a **body**, or **centrum**, anteriorly and a **vertebral arch** posteriorly. The disc-shaped body is the weight-bearing region. Together, the body and vertebral arch enclose an opening called the **vertebral foramen**. Successive vertebral foramina of the articulated vertebrae form the long **vertebral canal**, through which the spinal cord passes.

The vertebral arch is a composite structure formed by two pedicles and two laminae. The **pedicles** (ped′ĭ-kelz; "little feet"), short bony pillars projecting posteriorly from the vertebral body, form the sides of the arch. The **laminae** (lam′ĭ-ne), flattened plates that fuse in the median plane, complete the arch posteriorly. The pedicles have notches on their superior and inferior borders, providing lateral openings between adjacent vertebrae called **intervertebral foramina** (see Figure 7.16). The spinal nerves issuing from the spinal cord pass through these foramina.

Seven processes project from the vertebral arch. The **spinous process** is a median posterior projection arising at the junction of the two laminae. A **transverse process** extends laterally from each side of the vertebral arch. The spinous and transverse processes are attachment sites for muscles that move the vertebral column and for ligaments that stabilize it. The paired **superior** and **inferior articular processes** protrude superiorly and inferiorly,



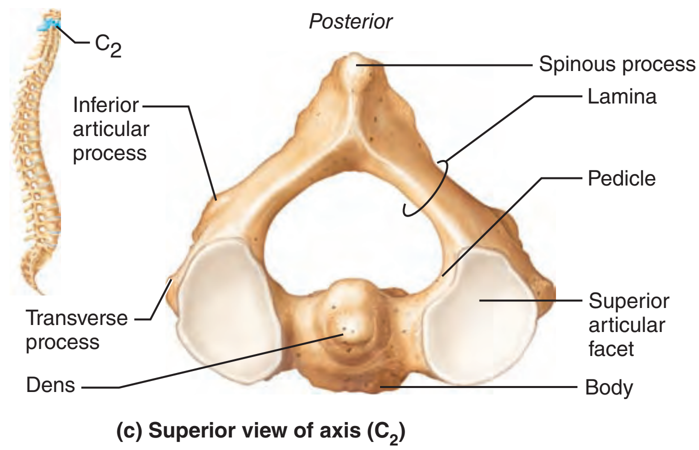


Figure 7.20 The first and second cervical vertebrae. (For a related image, see *A Brief Atlas of the Human Body*, Figure 18.)

respectively, from the pedicle-lamina junctions. The smooth joint surfaces of the articular processes, called *facets* ("little faces"), are covered with hyaline cartilage. The inferior articular processes of each vertebra form movable joints with the superior articular processes of the vertebra immediately below. Thus, successive vertebrae join both at their bodies and at their articular processes.

Regional Vertebral Characteristics

Beyond their common structural features, vertebrae exhibit variations that allow different regions of the spine to perform slightly different functions and movements. In general, movements that can occur between vertebrae are (1) flexion and extension (anterior bending and posterior straightening of the spine), (2) lateral flexion (bending the *upper body* to the right or left), and (3) rotation (in which vertebrae rotate on one another in the longitudinal axis of the spine). The regional vertebral characteristics described in this section are illustrated and summarized in **Table 7.2** on p. 223.

Cervical Vertebrae

The seven cervical vertebrae, identified as C_1–C_7, are the smallest, lightest vertebrae (see Figure 7.16). The first two (C_1 and C_2) are unusual and we will skip them for the moment. The "typical" cervical vertebrae (C_3–C_7) have the following distinguishing features (see Figure 7.21 and Table 7.2):

- The body is oval—wider from side to side than in the anteroposterior dimension.
- Except in C_7, the spinous process is short, projects directly back, and is *bifid* (bi′fid), or split at its tip.
- The vertebral foramen is large and generally triangular.
- Each transverse process contains a **transverse foramen** through which the vertebral arteries pass to service the brain.

The spinous process of C_7 is not bifid and is much larger than those of the other cervical vertebrae (see Figure 7.21a). Because its spinous process is palpable through the skin, C_7 can be used as a landmark for counting the vertebrae and is called the **vertebra prominens** ("prominent vertebra").

The first two cervical vertebrae, the atlas and the axis, are somewhat more robust than the typical cervical vertebra. They have no intervertebral disc between them, and they are highly modified, reflecting their special functions. The **atlas** (C_1) has no body and no spinous process **(Figure 7.20a and b)**. Essentially, it is a ring of bone consisting of *anterior* and *posterior arches* and a *lateral mass* on each side. Each lateral mass has articular facets on both its superior and inferior surfaces. The superior articular facets receive the occipital condyles of the skull—they "carry" the skull, just as Atlas supported the heavens in Greek mythology. These joints allow you to nod "yes." The inferior articular facets form joints with the axis (C_2) below.

The **axis**, which has a body and the other typical vertebral processes, is not as specialized as the atlas. In fact, its only unusual feature is the knoblike **dens** (denz; "tooth") projecting superiorly from its body. The dens is actually the "missing" body of the atlas, which fuses with the axis during embryonic development. Cradled in the anterior arch of the atlas by the transverse ligament **(Figure 7.21a)**, the dens acts as a pivot for the rotation of the atlas. Hence, this joint allows you to rotate your head from side to side to indicate "no."

Thoracic Vertebrae

The 12 thoracic vertebrae (T_1–T_{12}) all articulate with the ribs (see Table 7.2, Figure 7.16, and Figure 7.21b). The first looks much like C_7, and the last four show a progression toward

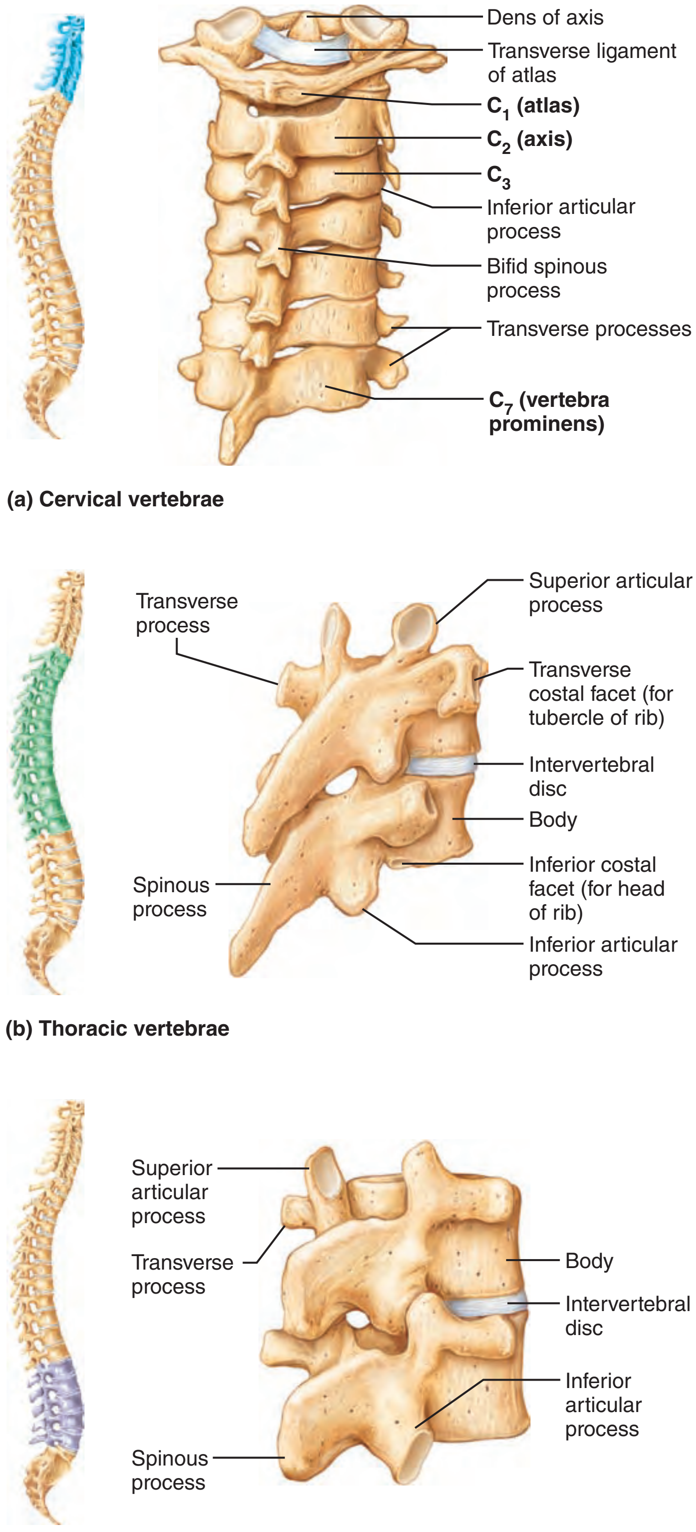


Figure 7.21 Posterolateral views of articulated vertebrae. Notice the bulbous tip on the spinous process of C_7, the vertebra prominens. (For a related image, see *A Brief Atlas of the Human Body*, Figures 19, 20, and 21.)

lumbar vertebral structure. The thoracic vertebrae increase in size from the first to the last. Unique characteristics of these vertebrae include the following:

- The body is roughly heart shaped. It typically bears two small facets, commonly called *demifacets* (half-facets), on each side, one at the superior edge (the *superior costal facet*) and the other at the inferior edge (the *inferior costal facet*). The demifacets receive the heads of the ribs. (The bodies of T_{10}–T_{12} vary from this pattern by having only a single facet to receive their respective ribs.)
- The vertebral foramen is circular.
- The spinous process is long and points sharply downward.
- With the exception of T_{11} and T_{12}, the transverse processes have facets, the *transverse costal facets*, that articulate with the tubercles of the ribs.
- The superior and inferior articular facets lie mainly in the frontal plane, a situation that prevents flexion and extension, but which allows this region of the spine to rotate. Lateral flexion, though possible, is restricted by the ribs.

Lumbar Vertebrae

The lumbar region of the vertebral column, commonly referred to as the small of the back, receives the most stress. The enhanced weight-bearing function of the five lumbar vertebrae (L_1–L_5) is reflected in their sturdier structure. Their bodies are massive and kidney shaped in a superior view (see Table 7.2, Figure 7.16, and Figure 7.21). Other characteristics typical of these vertebrae:

- The pedicles and laminae are shorter and thicker than those of other vertebrae.
- The spinous processes are short, flat, and hatchet shaped and are easily seen when a person bends forward. These processes are robust and project directly backward, adaptations for the attachment of the large back muscles.
- The vertebral foramen is triangular.
- The orientation of the facets of the articular processes of the lumbar vertebrae differs substantially from that of the other vertebra types (see Table 7.2). These modifications lock the lumbar vertebrae together and provide stability by preventing rotation of the lumbar spine. Flexion and extension are possible (as when you do sit-ups), as is lateral flexion.

Sacrum

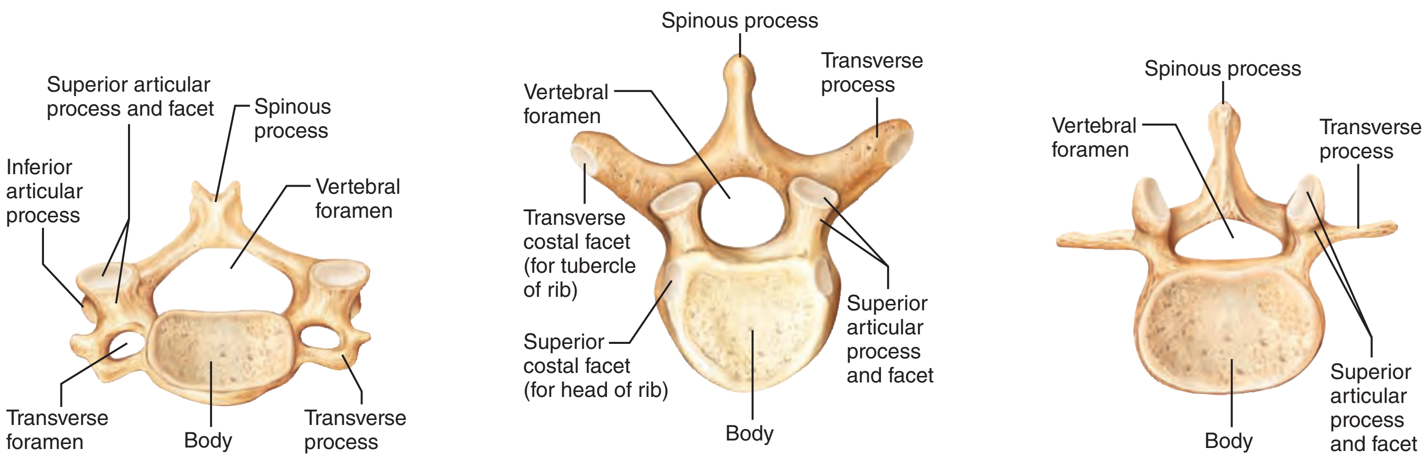
The triangular sacrum, which shapes the posterior wall of the pelvis, is formed by five fused vertebrae (S_1–S_5) in adults (**Figure 7.22**, and see Figure 7.16). It articulates superiorly (via its **superior articular processes**) with L_5 and inferiorly with the coccyx. Laterally, the sacrum articulates, via its **auricular surfaces**, with the two hip bones to form the **sacroiliac joints** (sa″kro-il′e-ak) of the pelvis.

The **sacral promontory** (prom′on-tor″e; “high point of land projecting into the sea”), the anterosuperior margin of the first sacral vertebra, bulges anteriorly into the pelvic cavity. The body’s center of gravity lies about 1 cm posterior to this

Table 7.2 Regional Characteristics of Cervical, Thoracic, and Lumbar Vertebrae

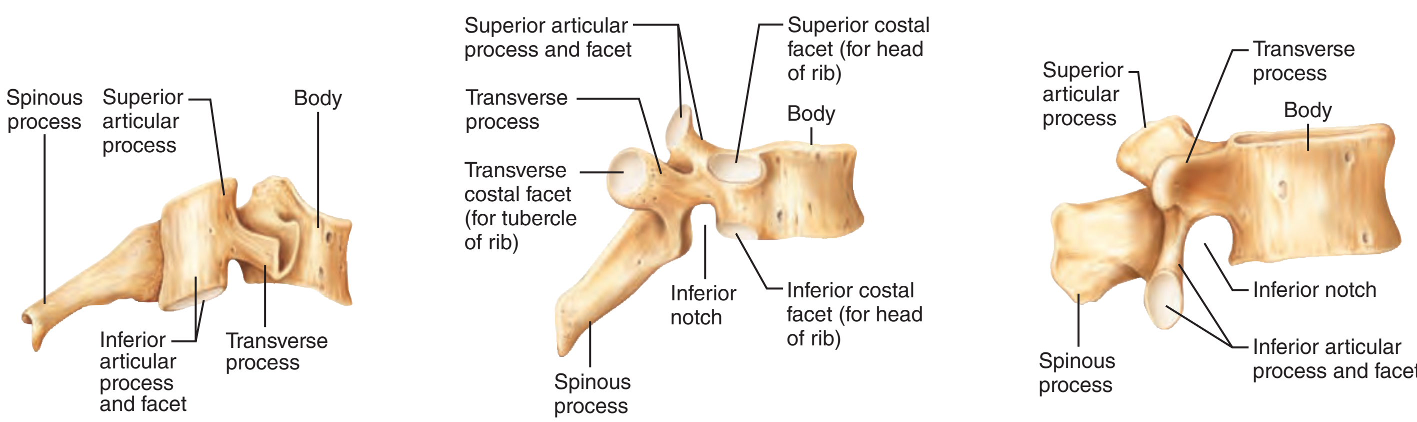
CHARACTERISTIC	CERVICAL (3–7)	THORACIC	LUMBAR
Body	Small, wide side to side	Larger than cervical; heart shaped; bears two costal facets	Massive; kidney shaped
Spinous process	Short; bifid; projects directly posterior	Long; sharp; projects inferiorly	Short; blunt; rectangular; projects directly posteriorly
Vertebral foramen	Triangular	Circular	Triangular
Transverse processes	Contain foramina	Bear facets for ribs (except T_{11} and T_{12})	Thin and tapered
Superior and inferior articular processes	Superior facets directed superoposteriorly	Superior facets directed posteriorly	Superior facets directed posteromedially (or medially)
	Inferior facets directed inferoanteriorly	Inferior facets directed anteriorly	Inferior facets directed anterolaterally (or laterally)
Movements allowed	Flexion and extension; lateral flexion; rotation; the spine region with the greatest range of movement	Rotation; lateral flexion possible but restricted by ribs; flexion and extension limited	Flexion and extension; some lateral flexion; rotation prevented

Superior View



(a) Cervical (b) Thoracic (c) Lumbar

Right Lateral View



(a) Cervical (b) Thoracic (c) Lumbar

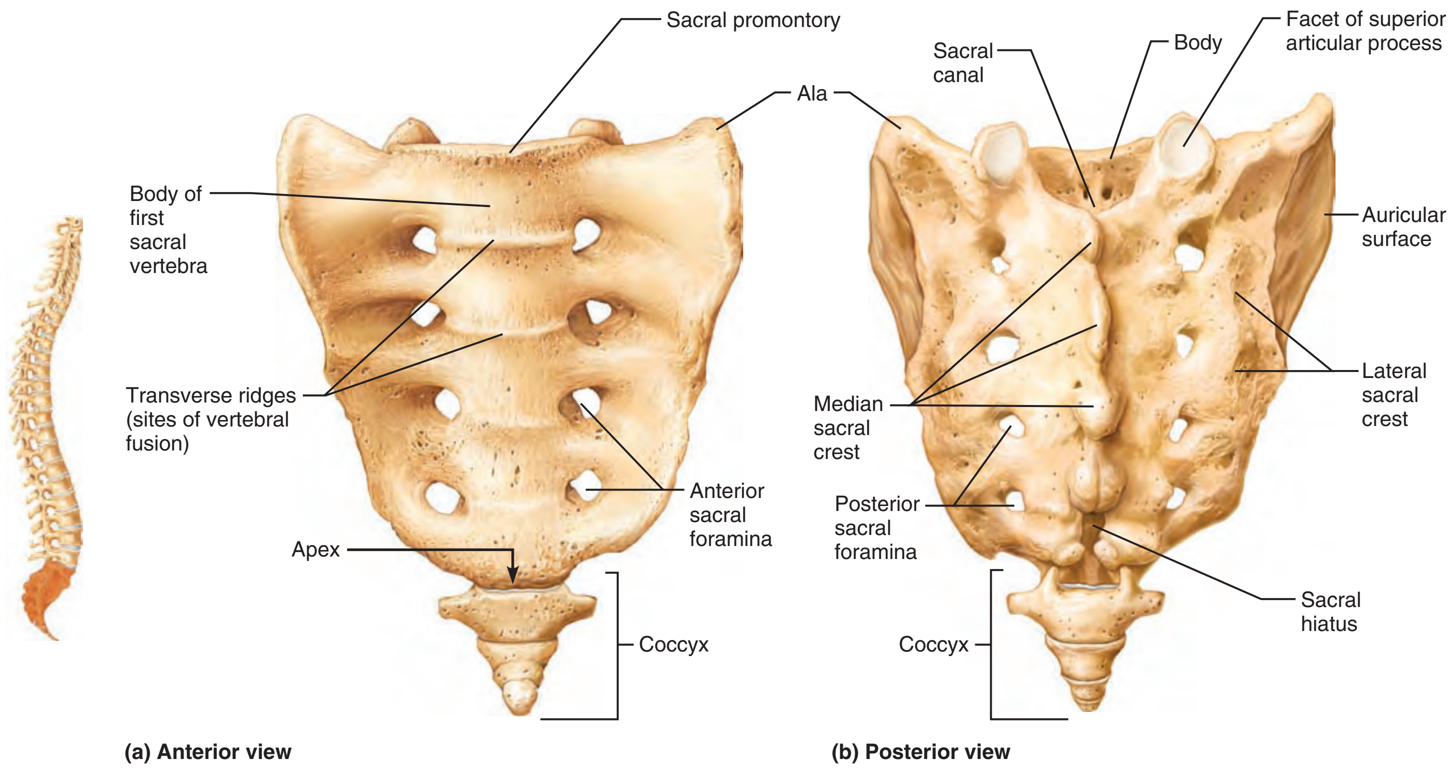


Figure 7.22 The sacrum and coccyx. (For a related image, see *A Brief Atlas of the Human Body*, Figure 22.)

landmark. Four ridges, the **transverse ridges**, cross its concave anterior aspect, marking the lines of fusion of the sacral vertebrae. The **anterior sacral foramina** lie at the lateral ends of these ridges and transmit blood vessels and anterior rami of the sacral spinal nerves. The regions lateral to these foramina expand superiorly as the winglike **alae**.

In its posterior midline the sacral surface is roughened by the **median sacral crest** (the fused spinous processes of the sacral vertebrae). This is flanked laterally by the **posterior sacral foramina**, which transmit the posterior rami of the sacral spinal nerves, and then the **lateral sacral crests** (remnants of the transverse processes of S_1–S_5).

The vertebral canal continues inside the sacrum as the **sacral canal**. Since the laminae of the fifth (and sometimes the fourth) sacral vertebrae fail to fuse medially, an enlarged external opening called the **sacral hiatus** (hi-a′tus; "gap") is obvious at the inferior end of the sacral canal.

Coccyx

The coccyx, our tailbone, is a small triangular bone (Figure 7.22, and see Figure 7.16). It consists of four (or in some cases three or five) vertebrae fused together. The coccyx articulates superiorly with the sacrum. (The name *coccyx* is from the Greek word meaning "cuckoo" and was so named because of its fancied resemblance to a bird's beak.) Except for the slight support the coccyx affords the pelvic organs, it is a nearly useless bone. Occasionally, a baby is born with an unusually long coccyx, which may need to be removed surgically.

The characteristics of the regional vertebrae are summarized in Table 7.2.

Check Your Understanding

16. What is the normal number of cervical vertebrae? Of thoracic vertebrae?
17. How would a complete fracture of the dens affect the mobility of the vertebral column?
18. How can you distinguish a lumbar vertebra from a thoracic vertebra?

For answers, see Appendix H.

The Thoracic Cage

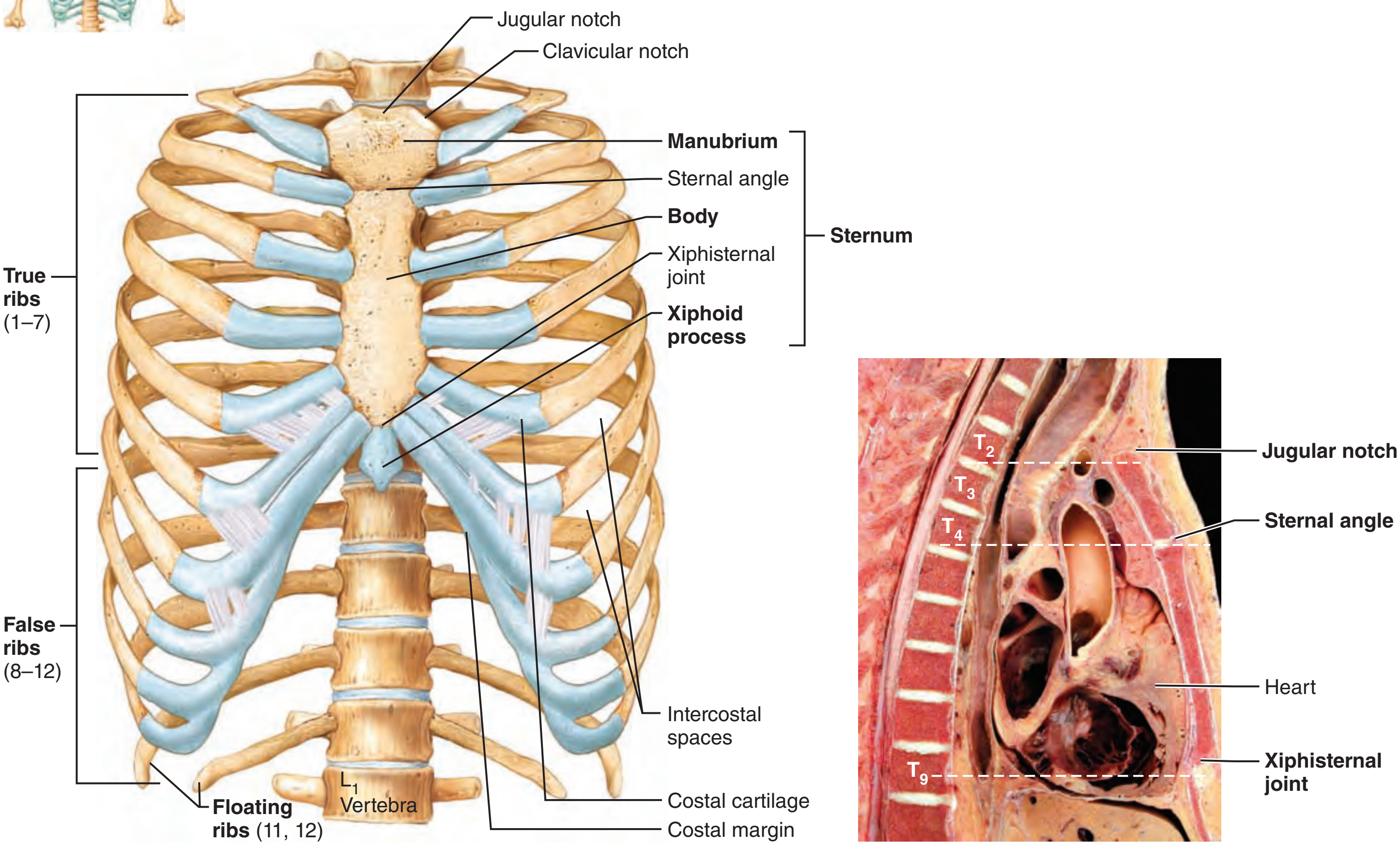
✓ Name and describe the bones of the thoracic cage (bony thorax).

✓ Differentiate true from false ribs.

Anatomically, the thorax is the chest, and its bony underpinnings are called the **thoracic cage** or *bony thorax*. Elements of the thoracic cage include the thoracic vertebrae posteriorly, the ribs laterally, and the sternum and costal cartilages anteriorly. The costal cartilages secure the ribs to the sternum **(Figure 7.23a)**.

Roughly cone shaped with its broad dimension positioned inferiorly, the bony thorax forms a protective cage around the vital organs of the thoracic cavity (heart, lungs, and great blood vessels), supports the shoulder girdles and upper limbs, and provides

Figure 7.23 The thoracic cage. (For a related image, see *A Brief Atlas of the Human Body*, Figure 23a–d.)



(a) Skeleton of the thoracic cage, anterior view

(b) Midsagittal section through the thorax, showing the relationship of surface anatomical landmarks of the thorax to the vertebral column

attachment points for many muscles of the neck, back, chest, and shoulders. The *intercostal spaces* between the ribs are occupied by the intercostal muscles, which lift and then depress the thorax during breathing.

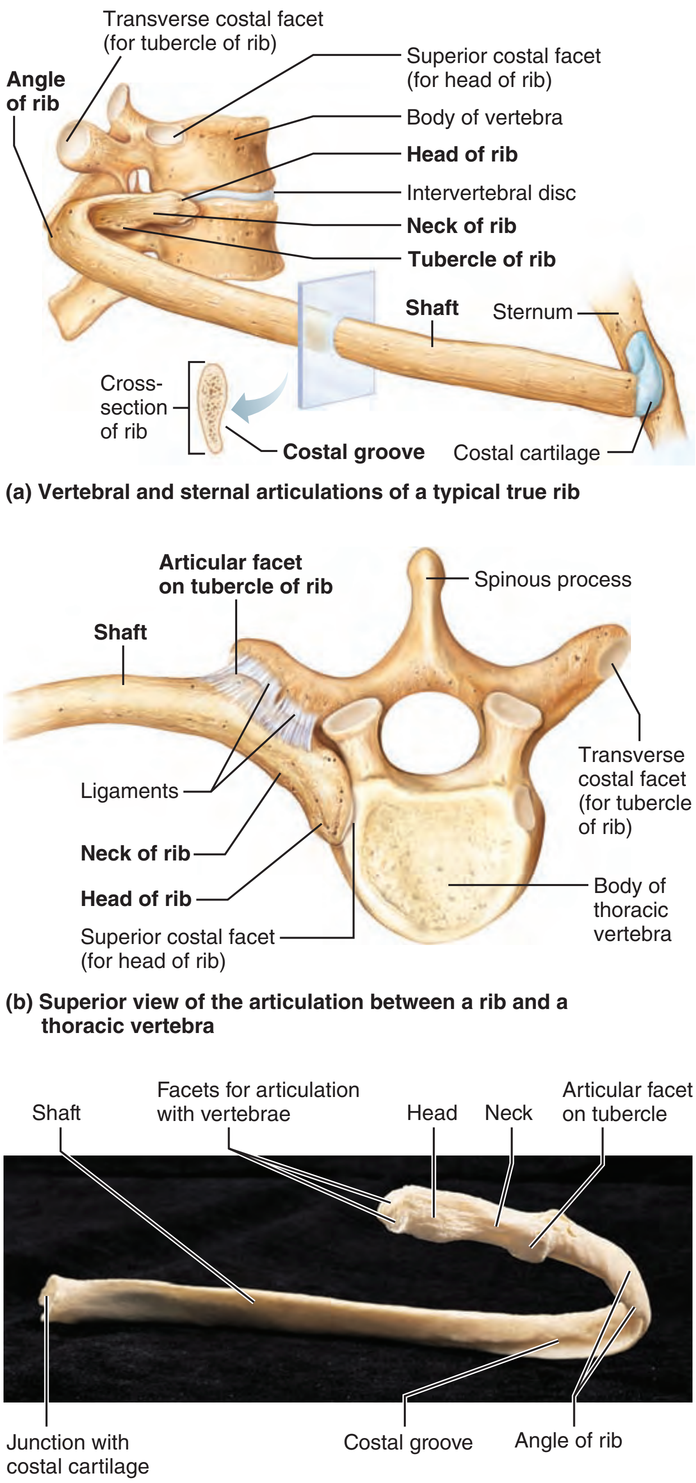
Sternum

The **sternum** (breastbone) lies in the anterior midline of the thorax. Vaguely resembling a dagger, it is a flat bone approximately 15 cm (6 inches) long, resulting from the fusion of three bones: the manubrium, the body, and the xiphoid process. The *manubrium* (mah-nu′bre-um; "knife handle") is the superior portion, which is shaped like the knot in a necktie. The manubrium articulates via its **clavicular notches** (klah-vik′u-lar) with the clavicles (collarbones) laterally, and just below this, it also articulates with the first two pairs of ribs. The *body*, or midportion, forms the bulk of the sternum. The sides of the body are notched where it articulates with the costal cartilages of the second to seventh ribs. The *xiphoid process* (zif′oid; "swordlike") forms the inferior end of the sternum. This small, variably shaped process is a plate of hyaline cartilage in youth, but it is usually ossified in adults over the age of 40. The xiphoid process articulates only with the sternal body and serves as an attachment point for some abdominal muscles.

Homeostatic Imbalance 7.4

In some people, the xiphoid process projects posteriorly. In such cases, blows to the chest can push the xiphoid into the underlying heart or liver, causing massive hemorrhage. ✚

The sternum has three important anatomical landmarks: the jugular notch, the sternal angle, and the xiphisternal joint (Figure 7.23). The easily palpated **jugular** (*suprasternal*) **notch** is the central indentation in the superior border of the manubrium. If you slide your finger down the anterior surface of your neck, it will land in the jugular notch. The jugular notch is generally in line with the disc between the second and third thoracic vertebrae and the point where the left common carotid artery issues from the aorta (Figure 7.23b).



(a) Vertebral and sternal articulations of a typical true rib

(b) Superior view of the articulation between a rib and a thoracic vertebra

(c) A typical rib (rib 6, right), posterior view

Figure 7.24 Ribs. All ribs illustrated in this figure are right ribs. (For a related image, see *A Brief Atlas of the Human Body,* Figure 23e and f.)

The **sternal angle** is felt as a horizontal ridge across the front of the sternum, where the manubrium joins the sternal body. This cartilaginous joint acts like a hinge, allowing the sternal body to swing anteriorly when we inhale. The sternal angle is in line with the disc between the fourth and fifth thoracic vertebrae and at the level of the second pair of ribs. It is a handy reference point for finding the second rib and thus for counting the ribs during a physical examination and for listening to sounds made by specific heart valves.

The **xiphisternal joint** (zif″ĭ-ster′nul) is the point where the sternal body and xiphoid process fuse. It lies at the level of the ninth thoracic vertebra. The heart lies on the diaphragm just deep to this joint.

Ribs

Twelve pairs of **ribs** form the flaring sides of the thoracic cage (Figure 7.23a). All ribs attach posteriorly to the thoracic vertebrae (bodies and transverse processes) and curve inferiorly toward the anterior body surface. The superior seven rib pairs attach directly to the sternum by individual costal cartilages (bars of hyaline cartilage). These are **true** or **vertebrosternal ribs** (ver″tě-bro-ster′nal). (Notice that the anatomical name indicates the two attachment points of a rib—the posterior attachment given first.)

The remaining five pairs of ribs are called **false ribs** because they either attach indirectly to the sternum or entirely lack a sternal attachment. Rib pairs 8–10 attach to the sternum indirectly, each joining the costal cartilage immediately above it. These ribs are also called **vertebrochondral ribs** (ver″tě-bro-kon′dral). The inferior margin of the rib cage, or **costal margin**, is formed by the costal cartilages of ribs 7–10. Rib pairs 11 and 12 are called **vertebral ribs** or **floating ribs** because they have no anterior attachments. Instead, their costal cartilages lie embedded in the muscles of the lateral body wall.

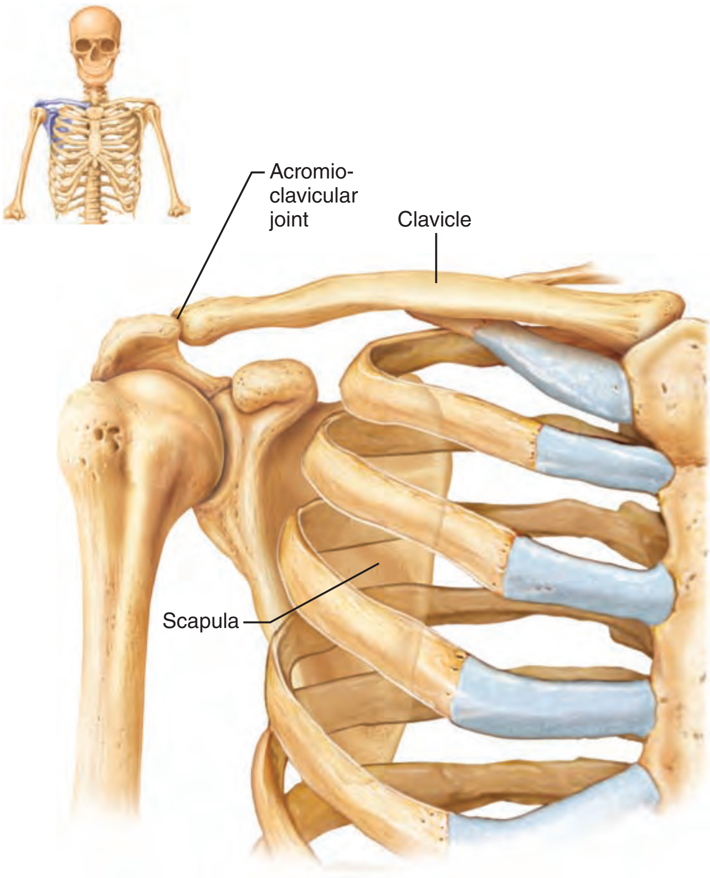
The ribs increase in length from pair 1 to pair 7, then decrease in length from pair 8 to pair 12. Except for the first rib, which lies deep to the clavicle, the ribs are easily felt in people of normal weight.

A typical rib is a bowed flat bone **(Figure 7.24)**. The bulk of a rib is simply called the *shaft*. Its superior border is smooth, but its inferior border is sharp and thin and has a *costal groove* on its inner face that lodges the intercostal nerves and blood vessels.

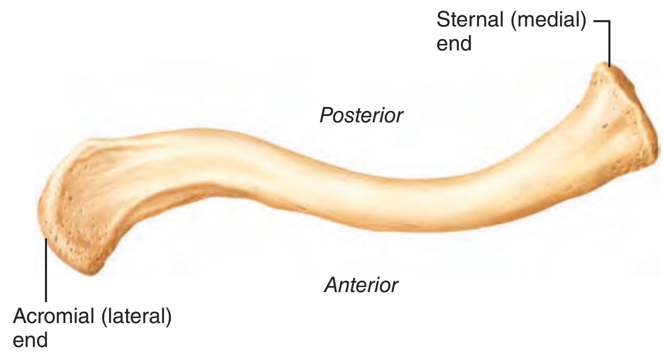
In addition to the shaft, each rib has a head, neck, and tubercle. The wedge-shaped *head*, the posterior end, articulates with the vertebral bodies by two facets: One joins the body of the same-numbered thoracic vertebra, the other articulates with the body of the vertebra immediately superior. The *neck* is the constricted portion of the rib just beyond the head. Lateral to this, the knoblike *tubercle* articulates with the costal facet of the transverse process of the same-numbered thoracic vertebra. Beyond the tubercle, the shaft angles sharply forward (at the angle of the rib) and then extends to attach to its costal cartilage anteriorly. The costal cartilages provide secure but flexible rib attachments to the sternum.

The first pair of ribs is quite atypical. They are flattened superiorly to inferiorly and are quite broad, forming a horizontal table that supports the subclavian blood vessels that serve the upper limbs. There are also other exceptions to the typical rib pattern. Rib 1 and ribs 10–12 articulate with only one vertebral body, and ribs 11 and 12 do not articulate with a vertebral transverse process.

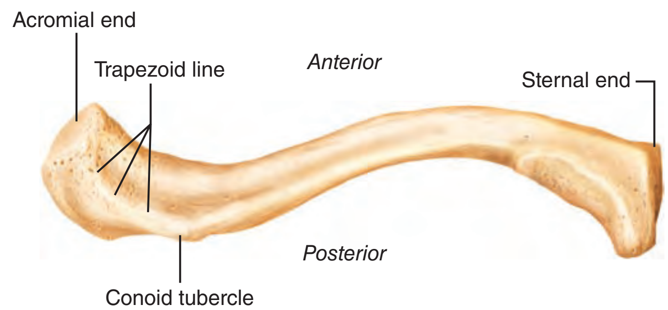
Figure 7.25 The pectoral girdle and clavicle. (For a related image, see *A Brief Atlas of the Human Body*, Figure 24.)



(a) Articulated pectoral girdle



(b) Right clavicle, superior view



(c) Right clavicle, inferior view

Check Your Understanding

19. How does a true rib differ from a false rib?
20. What is the sternal angle and what is its clinical importance?
21. Besides the ribs and sternum, there is a third group of bones making up the thoracic cage. What is it?

For answers, see Appendix H.

PART 2
The Appendicular Skeleton

Bones of the limbs and their girdles are collectively called the **appendicular skeleton** because they are appended to the axial skeleton that forms the longitudinal axis of the body (see Figure 7.1). The yokelike *pectoral girdles* (pek′tor-al; "chest") attach the upper limbs to the body trunk. The more sturdy *pelvic girdle* secures the lower limbs. Although the bones of the upper and lower limbs differ in their functions and mobility, they have the same fundamental plan: Each limb is composed of three major segments connected by movable joints.

The appendicular skeleton enables us to carry out the movements typical of our freewheeling and manipulative lifestyle. Each time we take a step, throw a ball, or pop a caramel into our mouth, we are making good use of our appendicular skeleton.

The Pectoral (Shoulder) Girdle

✓ Identify bones forming the pectoral girdle and relate their structure and arrangement to the function of this girdle.

✓ Identify important bone markings on the pectoral girdle.

The **pectoral girdle**, or **shoulder girdle**, consists of the *clavicle* (klav′ĭ-kl) anteriorly and the *scapula* (skap′u-lah) posteriorly (**Figure 7.25** and Table 7.3 on p. 233). The paired pectoral girdles and their associated muscles form your shoulders. Although the term *girdle* usually signifies a beltlike structure encircling the body, a single pectoral girdle, or even the pair, does not quite satisfy this description. Anteriorly, the medial end of each clavicle joins the sternum; the distal ends of the clavicles meet the scapulae laterally. However, the scapulae fail to complete the ring posteriorly, because their medial borders do not join each other or the axial skeleton. Instead, the scapulae are attached to the thorax and vertebral column only by the muscles that clothe their surfaces.

The pectoral girdles attach the upper limbs to the axial skeleton and provide attachment points for many of the muscles that move the upper limbs. These girdles are very light and allow the upper limbs a degree of mobility not seen anywhere else in the body. This mobility is due to the following factors:

- Because only the clavicle attaches to the axial skeleton, the scapula can move quite freely across the thorax, allowing the arm to move with it.
- The socket of the shoulder joint (the scapula's glenoid cavity) is shallow and poorly reinforced, so it does not restrict the movement of the humerus (arm bone). Although this arrangement is good for flexibility, it is bad for stability: Shoulder dislocations are fairly common.

Clavicles

7

The **clavicles** ("little keys"), or collarbones, are slender, S-shaped bones that can be felt along their entire course as they extend horizontally across the superior thorax (Figure 7.25). Each clavicle is cone shaped at its medial **sternal end**, which attaches to the sternal manubrium, and flattened at its lateral **acromial end** (ah-kro′me-al), which articulates with the scapula. The medial two-thirds of the clavicle is convex anteriorly; its lateral third is concave anteriorly. Its superior surface is fairly smooth, but the inferior surface is ridged and grooved by ligaments and by the action of the muscles that attach to it. The *trapezoid line* and the *conoid tubercle*, for example, are anchoring points for a ligament that connects the clavicle to the scapula.

Besides anchoring many muscles, the clavicles act as braces: They hold the scapulae and arms out laterally, away from the narrower superior part of the thorax. This bracing function becomes obvious when a clavicle is fractured: The entire shoulder region collapses medially. The clavicles also transmit compression forces from the upper limbs to the axial skeleton, for example, when someone pushes a car to a gas station.

The clavicles are not very strong and are likely to fracture, for example, when a person uses outstretched arms to break a fall. The curves in the clavicle ensure that it usually fractures anteriorly (outward). If it were to collapse posteriorly (inward), bone splinters would damage the subclavian artery, which passes just deep to the clavicle to serve the upper limb. The clavicles are exceptionally sensitive to muscle pull and become noticeably larger and stronger in those who perform manual labor or athletics involving the shoulder and arm muscles.

Scapulae

The **scapulae**, or *shoulder blades*, are thin, triangular flat bones (Figure 7.25a and **Figure 7.26**). Interestingly, their name derives from a word meaning "spade" or "shovel," for ancient cultures made spades from the shoulder blades of animals. The scapulae lie on the dorsal surface of the rib cage, between ribs 2 and 7.

Each scapula has three borders. The *superior border* is the shortest, sharpest border. The *medial*, or *vertebral*, *border* parallels the vertebral column. The thick *lateral*, or *axillary*, *border* abuts the armpit and ends superiorly in a small, shallow fossa, the **glenoid cavity** (gle′noid; "pit-shaped"). This cavity articulates with the humerus of the arm, forming the shoulder joint.

Like all triangles, the scapula has three corners or *angles*. The superior scapular border meets the medial border at the *superior angle* and the lateral border at the *lateral angle*. The medial and lateral borders join at the *inferior angle*. The inferior angle moves extensively as the arm is raised and lowered, and is an important landmark for studying scapular movements.

The anterior, or costal, surface of the scapula is concave and relatively featureless. Its posterior surface bears a prominent **spine** that is easily felt through the skin. The spine ends laterally in an enlarged, roughened triangular projection called the **acromion** (ah-kro′me-on; "point of the shoulder"). The acromion articulates with the acromial end of the clavicle, forming the **acromioclavicular joint**.

Projecting anteriorly from the superior scapular border is the **coracoid process** (kor′ah-coid); *corac* means "beaklike," but this process looks more like a bent little finger. The coracoid process helps anchor the biceps muscle of the arm. It is bounded by the **suprascapular notch** (a nerve passage) medially and by the glenoid cavity laterally.

Several large fossae appear on both sides of the scapula and are named according to location. The *infraspinous* and *supraspinous fossae* are inferior and superior, respectively, to the spine. The *subscapular fossa* is the shallow concavity formed by the entire anterior scapular surface. Lying within these fossae are muscles with similar names.

☑ Check Your Understanding

22. What two bones construct each pectoral girdle?
23. Where is the single point of attachment of the pectoral girdle to the axial skeleton?
24. What is the major shortcoming of the flexibility allowed by the shoulder joint?

For answers, see Appendix H.

The Upper Limb

✓ Identify or name the bones of the upper limb and their important markings.

Thirty separate bones form the bony framework of each upper limb (see Figures 7.27 to 7.29, and **Table 7.3** on p. 233). Each of these bones may be described regionally as a bone of the arm, forearm, or hand. (Keep in mind that anatomically the "arm" is only that part of the upper limb between the shoulder and elbow.)

Arm

The **humerus** (hu′mer-us), the sole bone of the arm, is a typical long bone **(Figure 7.27)**. The largest, longest bone of the upper limb, it articulates with the scapula at the shoulder and with the radius and ulna (forearm bones) at the elbow.

At the proximal end of the humerus is its smooth, hemispherical **head**, which fits into the glenoid cavity of the scapula in a manner that allows the arm to hang freely at one's side. Immediately inferior to the head is a slight constriction, the **anatomical neck**. Just inferior to this are the lateral **greater tubercle** and the more medial **lesser tubercle**, separated by the **intertubercular sulcus**, or *bicipital groove* (bi-sip′ĭ-tal). These tubercles are sites of attachment of the rotator cuff muscles. The intertubercular sulcus guides

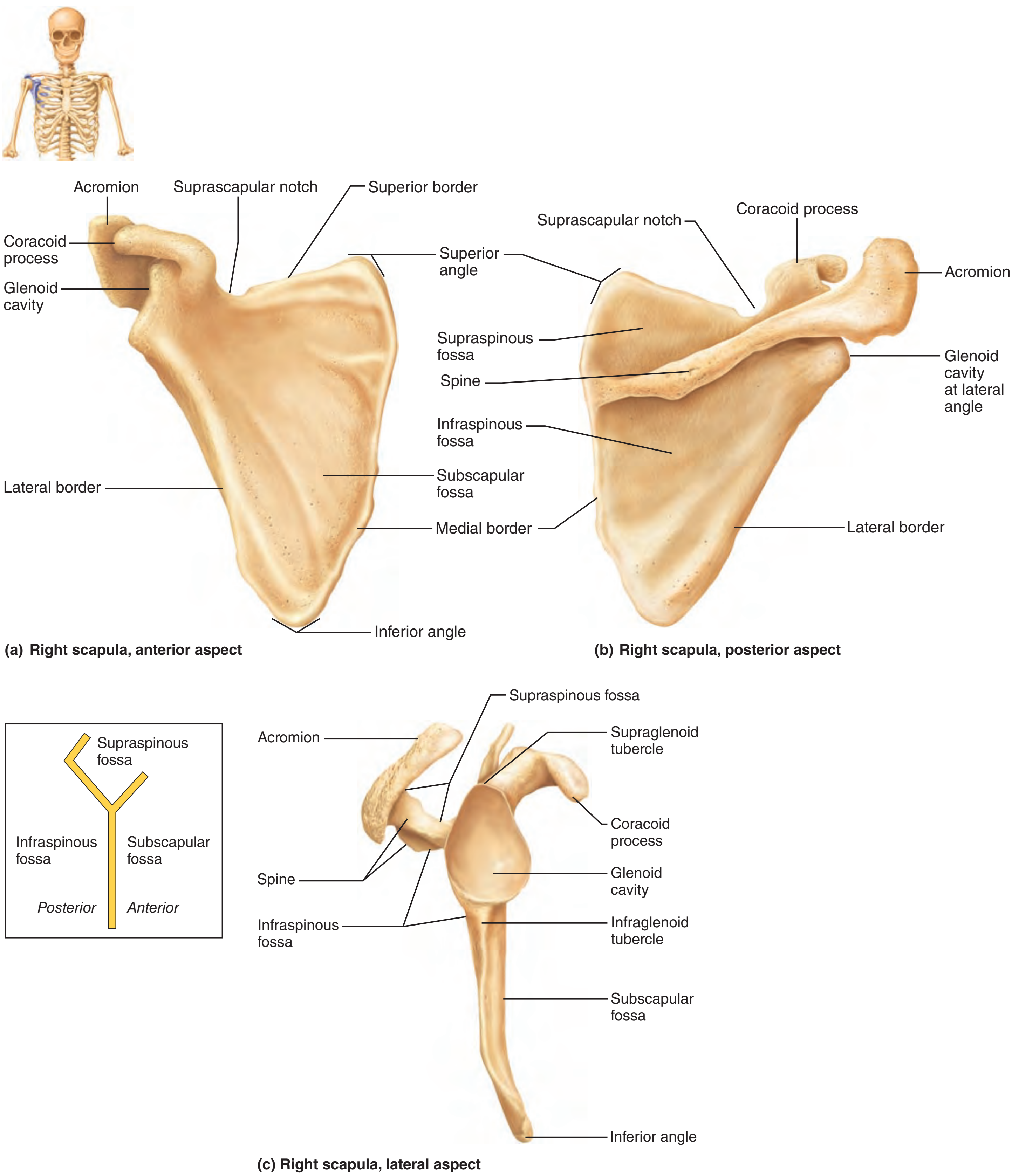
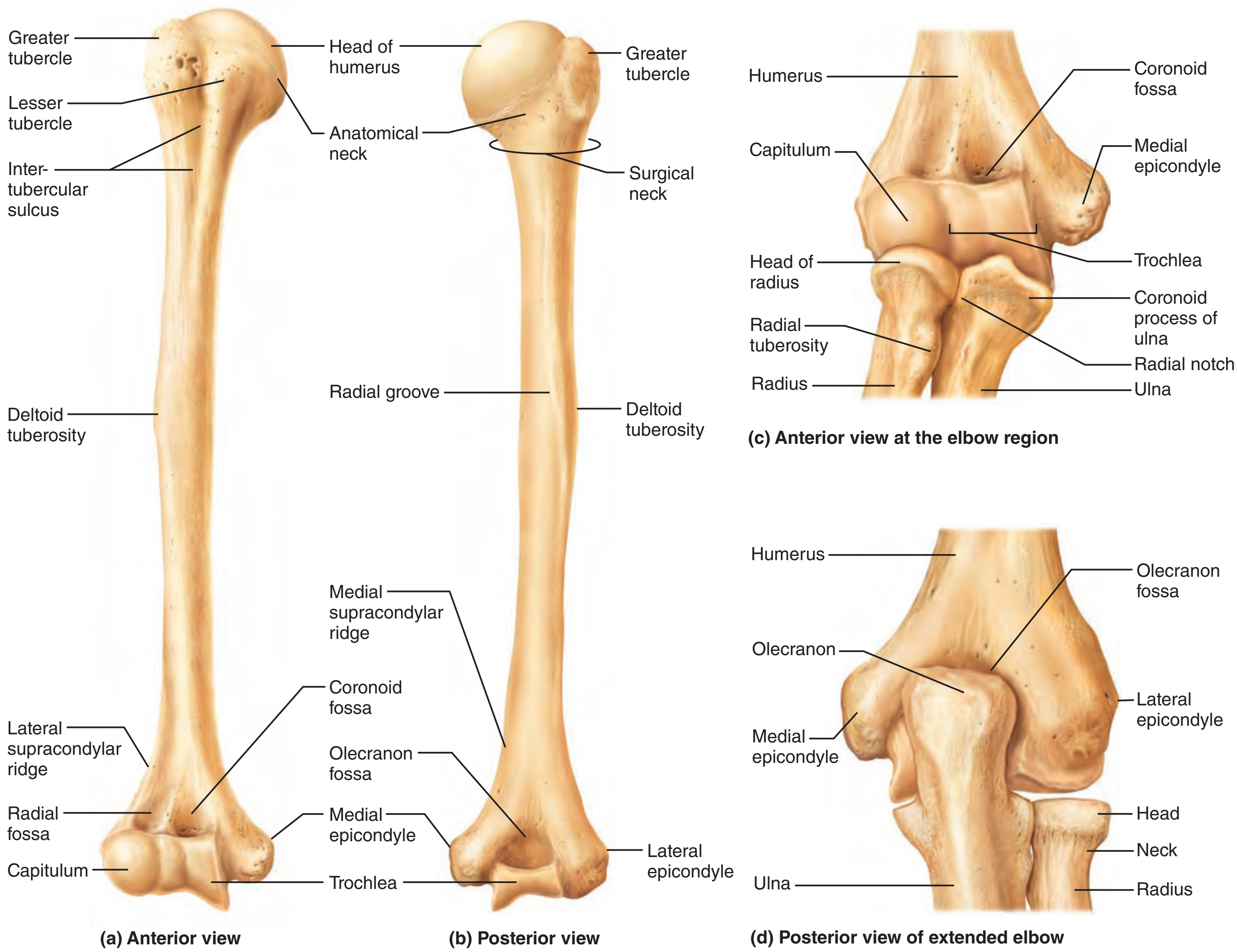


Figure 7.26 The scapula. View (c) is accompanied by a schematic representation of its orientation. (For a related image, see *A Brief Atlas of the Human Body*, Figure 24.)

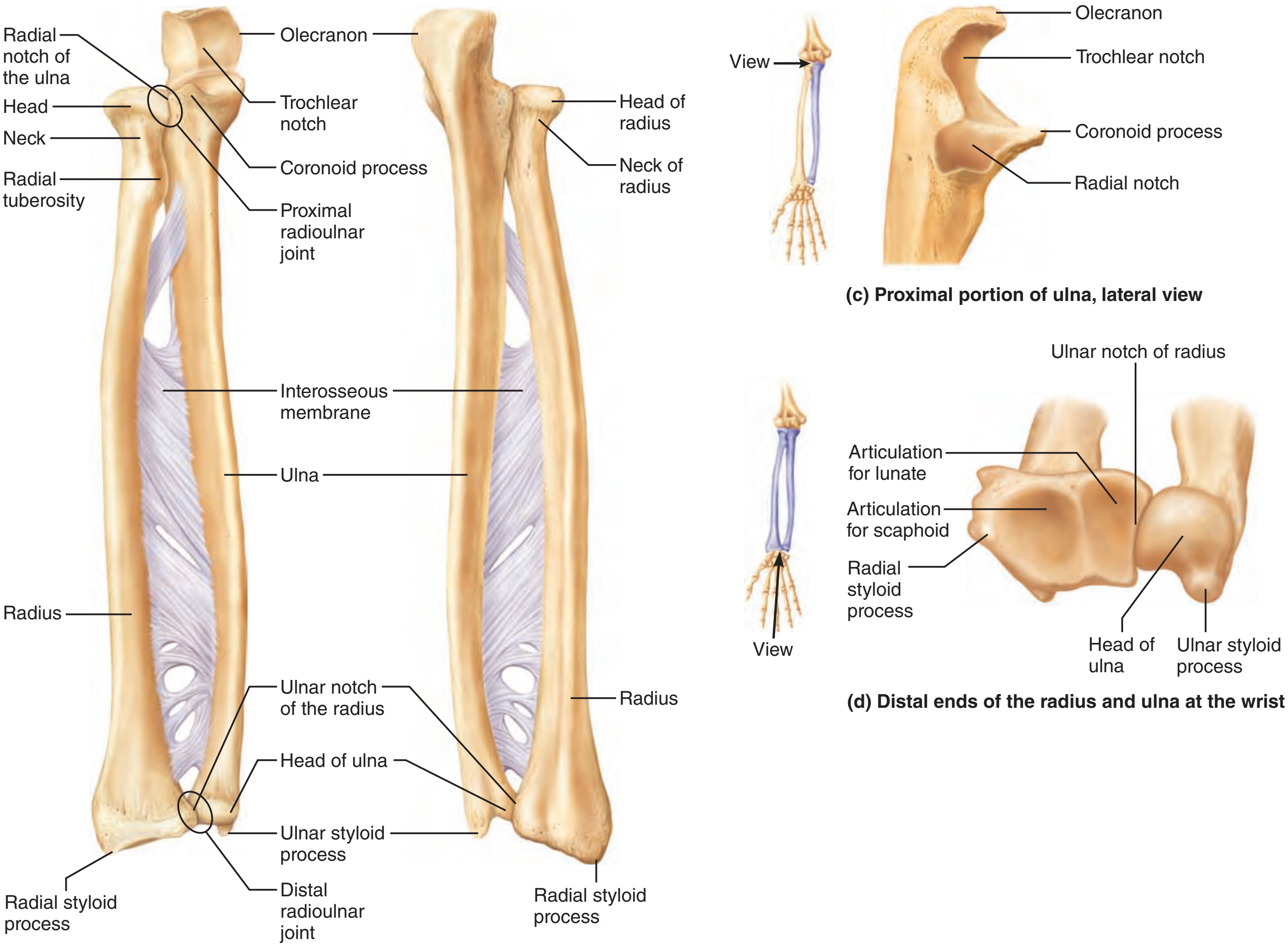
Figure 7.27 The humerus of the right arm and detailed views of articulation at the elbow. (For a related image, see *A Brief Atlas of the Human Body*, Figure 25.)



a tendon of the biceps muscle of the arm to its attachment point at the rim of the glenoid cavity (the supraglenoid tubercle). Just distal to the tubercles is the **surgical neck**, so named because it is the most frequently fractured part of the humerus. About midway down the shaft on its lateral side is the V-shaped **deltoid tuberosity**, the roughened attachment site for the deltoid muscle of the shoulder. Nearby, the **radial groove** runs obliquely down the posterior aspect of the shaft, marking the course of the radial nerve, an important nerve of the upper limb.

At the distal end of the humerus are two condyles: a medial **trochlea** (trok′le-ah; "pulley"), which looks like an hourglass tipped on its side, and the lateral ball-like **capitulum** (kah-pit′u-lum). These condyles articulate with the ulna and the radius, respectively (Figure 7.27c and d). The condyle pair is flanked by the **medial** and **lateral epicondyles** (muscle attachment sites). Directly above these epicondyles are the **medial** and **lateral supracondylar ridges**. The ulnar nerve, which runs behind the medial epicondyle, is responsible for the painful, tingling sensation you experience when you hit your "funny bone."

Superior to the trochlea on the anterior surface is the **coronoid fossa**; on the posterior surface is the deeper **olecranon fossa** (o-lek′rah-non). These two depressions allow the corresponding processes of the ulna to move freely when the elbow is flexed and extended. A small **radial fossa**, lateral to the coronoid fossa, receives the head of the radius when the elbow is flexed.



(a) Anterior view **(b) Posterior view**

(c) Proximal portion of ulna, lateral view

(d) Distal ends of the radius and ulna at the wrist

Figure 7.28 Radius and ulna of the right forearm. Note the structural details of the ulnar head and distal portion of radius and ulna. (For a related image, see *A Brief Atlas of the Human Body*, Figure 26.)

Forearm

Two parallel long bones, the radius and the ulna, form the skeleton of the forearm, or *antebrachium* (an″te-bra′ke-um) **(Figure 7.28)**. Unless a person's forearm muscles are very bulky, these bones are easily palpated along their entire length. Their proximal ends articulate with the humerus; their distal ends form joints with bones of the wrist. The radius and ulna articulate with each other both proximally and distally at small **radioulnar joints** (ra″de-o-ul′nar), and they are connected along their entire length by a flat, flexible ligament, the **interosseous membrane** (in″ter-os′e-us; "between the bones").

In the anatomical position, the radius lies laterally (on the thumb side) and the ulna medially. However, when you rotate your forearm so that the palm faces posteriorly (a movement called pronation), the distal end of the radius crosses over the ulna and the two bones form an X (see Figure 8.6a, p. 259).

Ulna

The **ulna** (ul′nah; "elbow") is slightly longer than the radius. It has the main responsibility for forming the elbow joint with the humerus. Its proximal end looks like the adjustable end of a monkey wrench: It bears two prominent processes, the **olecranon** (elbow)

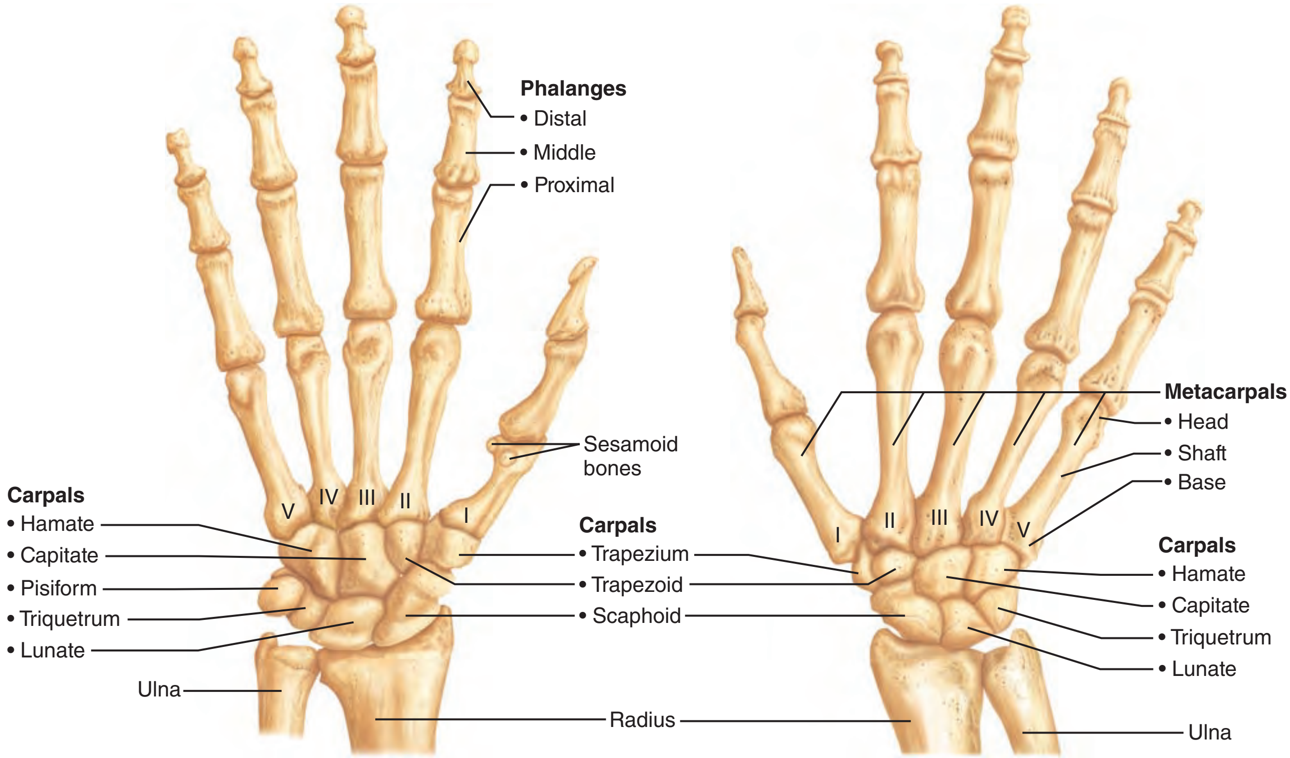


Figure 7.29 Bones of the right hand. (For a related image, see *A Brief Atlas of the Human Body*, Figure 27.)

and the **coronoid process**, separated by a deep concavity, the **trochlear notch** (Figure 7.28c). Together, these two processes grip the trochlea of the humerus, forming a hinge joint that allows the forearm to be bent upon the arm (flexed), then straightened again (extended). When the forearm is fully extended, the olecranon "locks" into the olecranon fossa (Figure 7.27d), keeping the forearm from hyperextending (moving posteriorly beyond the elbow joint). The posterior olecranon forms the angle of the elbow when the forearm is flexed and is the bony part that rests on the table when you lean on your elbows. On the lateral side of the coronoid process is a small depression, the **radial notch**, where the ulna articulates with the head of the radius.

Distally the ulnar shaft narrows and ends in a knoblike **head** (Figure 7.28d). Medial to the head is the **ulnar styloid process**, from which a ligament runs to the wrist. The ulnar head is separated from the bones of the wrist by a disc of fibrocartilage and plays little or no role in hand movements.

Radius

The **radius** ("rod") is thin at its proximal end and wide distally—the opposite of the ulna. The **head** of the radius is shaped somewhat like the head of a nail (Figure 7.28). The superior surface of this head is concave, and it articulates with the capitulum of the humerus. Medially, the head articulates with the radial notch of the ulna (Figure 7.27c). Just inferior to the head is the rough **radial tuberosity**, which anchors the biceps muscle of the arm. Distally, where the radius is expanded, it has a medial **ulnar notch** (Figure 7.28d), which articulates with the ulna, and a lateral **radial styloid process** (an anchoring site for ligaments that run to the wrist). Between these two markings, the radius is concave where it articulates with carpal bones of the wrist.

The ulna contributes more heavily to the elbow joint, and the radius is the major forearm bone contributing to the wrist joint. When the radius moves, the hand moves with it.

Homeostatic Imbalance 7.5

Colles' fracture is a break in the distal end of the radius. It is a common fracture when a falling person attempts to break his or her fall with outstretched hands. ✚

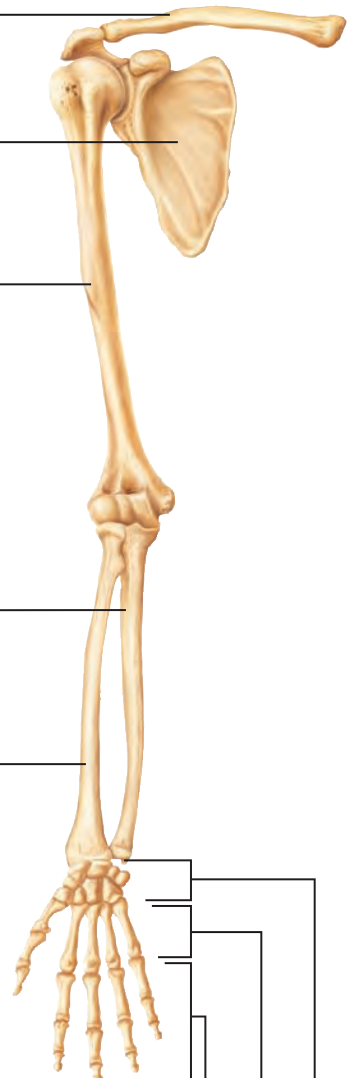
Hand

The skeleton of the hand **(Figure 7.29)** includes the bones of the *carpus* (wrist); the bones of the *metacarpus* (palm); and the *phalanges* (bones of the fingers).

Carpus (Wrist)

A "wrist" watch is actually worn on the distal forearm (over the lower ends of the radius and ulna), not on the wrist at all. The true wrist, or carpus, is the proximal part of the structure we generally call our "hand." The carpus consists of eight marble-size short bones, or **carpals** (kar′palz), closely united by ligaments. Because gliding movements occur between these bones, the carpus as a whole is quite flexible.

Table 7.3 Bones of the Appendicular Skeleton, Part 1: Pectoral Girdle and Upper Limb

BODY REGION	BONES*	ILLUSTRATION	LOCATION	MARKINGS
Pectoral girdle (Figures 7.25, 7.26)	**Clavicle** (2)		Clavicle is in superoanterior thorax; articulates medially with sternum and laterally with scapula	Acromial end; sternal end
	Scapula (2)		Scapula is in posterior thorax; forms part of the shoulder; articulates with humerus and clavicle	Glenoid cavity; spine; acromion; coracoid process; infraspinous, supraspinous, and subscapular fossae
Upper limb Arm (Figure 7.27)	**Humerus** (2)		Humerus is sole bone of arm; between scapula and elbow	Head; greater and lesser tubercles; intertubercular sulcus; radial groove; deltoid tuberosity; trochlea; capitulum; coronoid and olecranon fossae; epicondyles; radial fossa
Forearm (Figure 7.28)	**Ulna** (2)		Ulna is the medial bone of forearm between elbow and wrist; with the humerus forms elbow joint	Coronoid process; olecranon; radial notch; trochlear notch; ulnar styloid process; head
	Radius (2)		Radius is the lateral bone of forearm; articulates with carpals to form part of the wrist joint	Head; radial tuberosity; radial styloid process; ulnar notch
Hand (Figure 7.29)	8 **Carpals** (16): scaphoid, lunate, triquetrum, pisiform, trapezium, trapezoid, capitate, hamate		Carpals form a bony crescent at the wrist; arranged in two rows of four bones each	
	5 **Metacarpals** (10)		Metacarpals form the palm; one in line with each digit	
	14 **Phalanges** (28): distal, middle, proximal		Phalanges form the fingers; three in digits 2–5; two in digit 1 (the thumb)	

Anterior view of pectoral girdle and upper limb

*The number in parentheses ( ) following the bone name denotes the total number of such bones in the body.

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The carpals are arranged in two irregular rows of four bones each (Figure 7.29). In the proximal row (lateral to medial) are the **scaphoid** (skaf′oid; "boat-shaped"), **lunate** (lu′nāt; "moon-like"), **triquetrum** (tri-kwet′rum; "triangular"), and **pisiform** (pi′sĭ-form; "pea-shaped"). Of these, all but the pisiform participate in forming the wrist joint. The carpals of the distal row (lateral to medial) are the **trapezium** (trah-pe′ze-um; "little table"), **trapezoid** (tră′peh-zoid; "four-sided"), **capitate** ("head-shaped"), and **hamate** (ham′āt; "hooked").

There are numerous memory-jogging phrases to help you recall the carpals in the order given above. If you don't have one, try: **S**ally **l**eft **t**he **p**arty **to** **t**ake **C**indy **h**ome. As with all such memory jogs, the first letter of each word is the first letter of the term you need to remember.

7

Homeostatic Imbalance 7.6

The arrangement of its bones is such that the carpus is concave anteriorly and a ligament roofs over this concavity, forming the notorious *carpal tunnel*. Besides the median nerve (which supplies the lateral side of the hand), several long muscle tendons crowd into this tunnel. Overuse and inflammation of the tendons cause them to swell, compressing the median nerve, which causes tingling and numbness of the areas served, and movements of the thumb weaken. Pain is greatest at night. Those who repeatedly flex their wrists and fingers, such as those who work at computer keyboards all day, are particularly susceptible to this nerve impairment, called *carpal tunnel syndrome*. This condition is treated by splinting the wrist during sleep or by surgery. ✚

Metacarpus (Palm)

Five **metacarpals** radiate from the wrist like spokes to form the **metacarpus** or palm of the hand (*meta* = beyond). These small long bones are not named, but instead are numbered I to V from thumb to little finger. The **bases** of the metacarpals articulate with the carpals proximally and each other medially and laterally (Figure 7.29). Their bulbous **heads** articulate with the proximal phalanges of the fingers. When you clench your fist, the heads of the metacarpals become prominent as your *knuckles*.

Metacarpal I, associated with the thumb, is the shortest and most mobile. It occupies a more anterior position than the other metacarpals. Consequently, the joint between metacarpal I and the trapezium is a unique saddle joint that allows *opposition*, the action of touching your thumb to the tips of your other fingers.

Phalanges (Fingers)

The **fingers**, or **digits** of the upper limb, are numbered 1 to 5 beginning with the thumb, or **pollex** (pol′eks). In most people, the third finger is the longest. Each hand contains 14 miniature long bones called **phalanges** (fah-lan′jēz). Except for the thumb, each finger has three phalanges: *distal*, *middle*, and *proximal*. The thumb has no middle phalanx. [Phalanx (fa′langks; "a closely knit row of soldiers") is the singular term for phalanges.]

☑ Check Your Understanding

25. Which bones play the major role in forming the elbow joint?
26. Which bones of the upper limb have a styloid process?
27. Where are carpals found and what type of bone (short, irregular, long, or flat) are they?

For answers, see Appendix H.

The Pelvic (Hip) Girdle

✓ Name the bones contributing to the os coxae, and relate the pelvic girdle's strength to its function.

✓ Describe differences in the male and female pelves and relate these to functional differences.

The **pelvic girdle**, or **hip girdle**, attaches the lower limbs to the axial skeleton, transmits the full weight of the upper body to the lower limbs, and supports the visceral organs of the pelvis (Figures 7.30 and 7.31 and **Table 7.4**, p. 237). Unlike the pectoral girdle, which is sparingly attached to the thoracic cage, the pelvic girdle is secured to the axial skeleton by some of the strongest ligaments in the body. And unlike the shallow glenoid cavity of the scapula, the corresponding sockets of the pelvic girdle are deep and cuplike and firmly secure the head of the femur in place. Thus, even though both the shoulder and hip joints are ball-and-socket joints, very few of us can wheel or swing our legs about with the same degree of freedom as our arms. The pelvic girdle lacks the mobility of the pectoral girdle but is far more stable.

The pelvic girdle is formed by the sacrum* (a part of the axial skeleton) and a pair of **hip bones**, each also called an **os coxae** (ahs kok′se), or **coxal bone** (*coxa* = hip). Each hip bone unites with its partner anteriorly and with the sacrum posteriorly **(Figure 7.30)**.

Each large, irregularly shaped hip bone consists of three separate bones during childhood: the ilium, ischium, and pubis **(Figure 7.31)**. In adults, these bones are firmly fused and their boundaries are indistinguishable. Their names are retained, however, to refer to different regions of the composite hip bone.

At the point of fusion of the ilium, ischium, and pubis is a deep hemispherical socket called the **acetabulum** (as″ĕ-tab′u-lum; "vinegar cup") on the lateral surface of the pelvis (Figure 7.31). The acetabulum receives the head of the femur, or thigh bone, at this *hip joint*.

Ilium

The **ilium** (il′e-um; "flank") is a large flaring bone that forms the superior region of a coxal bone. It consists of a **body** and a superior winglike portion called the **ala** (a′lah). When you rest your hands on your hips, you are resting them on the thickened superior margins of the alae, the **iliac crests**, to which many muscles attach. Each iliac crest ends anteriorly in the blunt **anterior superior iliac spine** and posteriorly in the sharp **posterior superior iliac spine**.

Located below these are the less prominent *anterior* and *posterior inferior iliac spines*. All of these spines are attachment points for the muscles of the trunk, hip, and thigh. The anterior

*Some authorities do not consider the sacrum part of the pelvic girdle, but here we follow the convention in *Terminologia Anatomica*.

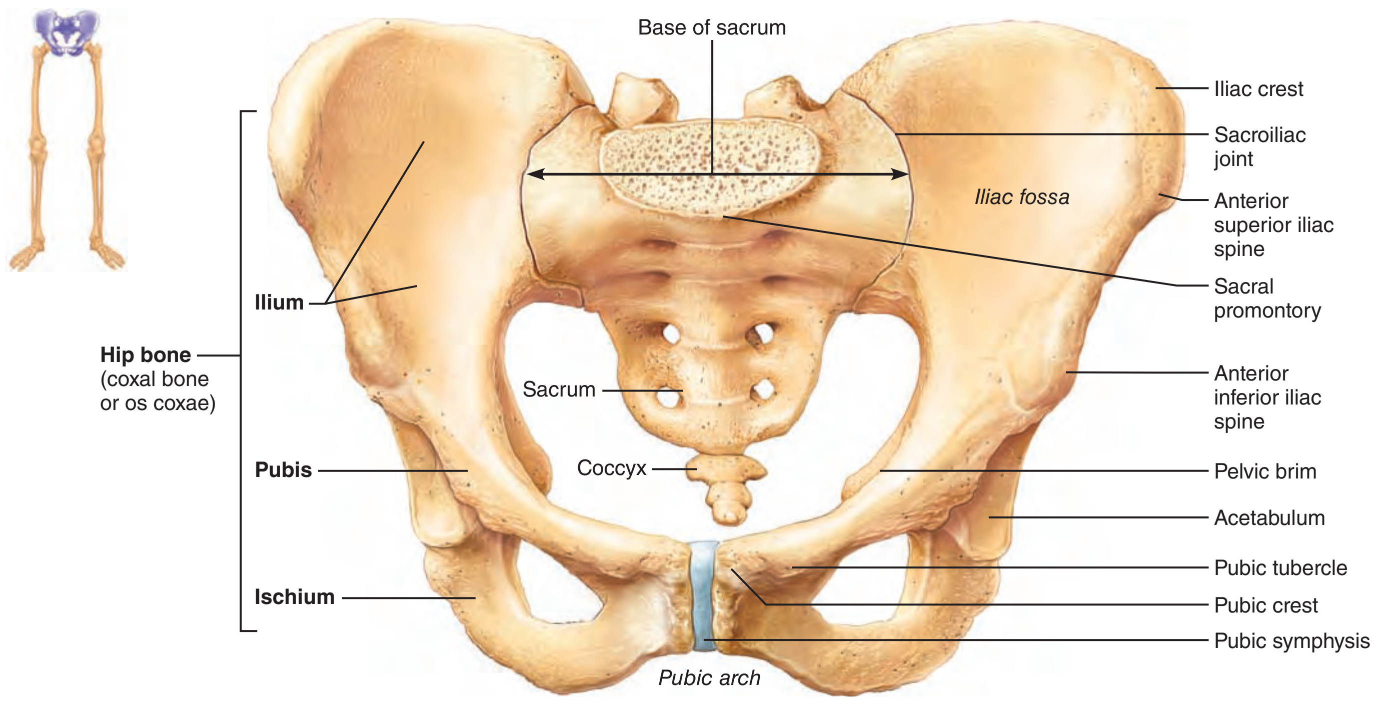


Figure 7.30 Pelvis. The pelvis consists of the two hip (coxal) bones, the sacrum, and the coccyx.

superior iliac spine is an especially important anatomical landmark. It is easily felt through the skin and is visible in thin people. The posterior superior iliac spine is difficult to palpate, but its position is revealed by a skin dimple in the sacral region.

Just inferior to the posterior inferior iliac spine, the ilium indents deeply to form the **greater sciatic notch** (si-at′ik), through which the thick cordlike sciatic nerve passes to enter the thigh. The broad posterolateral surface of the ilium, the **gluteal surface** (gloo′te-al), is crossed by three ridges, the **posterior**, **anterior**, and **inferior gluteal lines**, to which the gluteal (buttock) muscles attach.

The medial surface of the iliac ala exhibits a concavity called the **iliac fossa**. Posterior to this, the roughened **auricular surface** (aw-rik′u-lar; "ear-shaped") articulates with the same-named surface of the sacrum, forming the *sacroiliac joint* (Figure 7.30). The weight of the body is transmitted from the spine to the pelvis through the sacroiliac joints. Running inferiorly and anteriorly from the auricular surface is a robust ridge called the **arcuate line** (ar′ku-at; "bowed"). The arcuate line helps define the *pelvic brim*, the superior margin of the *true pelvis*, which we will discuss shortly. Anteriorly, the body of the ilium joins the pubis; inferiorly it joins the ischium.

Ischium

The **ischium** (is′ke-um; "hip") forms the posteroinferior part of the hip bone (Figures 7.30 and 7.31). Roughly L- or arc-shaped, it has a thicker, superior **body** adjoining the ilium and a thinner, inferior **ramus** (*ramus* = branch). The ramus joins the pubis anteriorly. The ischium has three important markings. Its **ischial spine** projects medially into the pelvic cavity and serves as a point of attachment of the *sacrospinous ligament* running from the sacrum. Just inferior to the ischial spine is the **lesser sciatic notch**. A number of nerves and blood vessels pass through this notch to supply the anogenital area. The inferior surface of the ischial body is rough and grossly thickened as the **ischial tuberosity**. When we sit, our weight is borne entirely by the ischial tuberosities, which are the strongest parts of the hip bones.

A massive ligament runs from the sacrum to each ischial tuberosity. This *sacrotuberous ligament* (not illustrated) helps hold the pelvis together. The ischial tuberosity is also a site of attachment of the large hamstring muscles of the posterior thigh.

Pubis

The **pubis** (pu′bis; "sexually mature"), or *pubic bone*, forms the anterior portion of the hip bone (Figures 7.30 and 7.31). In the anatomical position, it lies nearly horizontally and the urinary bladder rests upon it. Essentially, the pubis is V shaped with **superior** and **inferior pubic rami** issuing from its flattened medial **body**. The anterior border of the pubis is thickened to form the **pubic crest**. At the lateral end of the pubic crest is the **pubic tubercle**, one of the attachments for the *inguinal ligament*. As the two rami of the pubis run laterally to join with the body and ramus of the ischium, they define a large opening in the hip bone, the **obturator foramen** (ob″tu-ra′tor), through which a few blood vessels and nerves pass. Although the obturator foramen is large, it is nearly closed by a fibrous membrane in life (*obturator* = closed up).

The bodies of the two pubic bones are joined by a fibrocartilage disc, forming the midline **pubic symphysis** joint. Inferior to this joint, the inferior pubic rami angle laterally, forming an inverted V-shaped arch called the **pubic arch** or **subpubic angle**. The acuteness of this arch helps to differentiate the male and female pelves.

(Text continues on p. 238.)

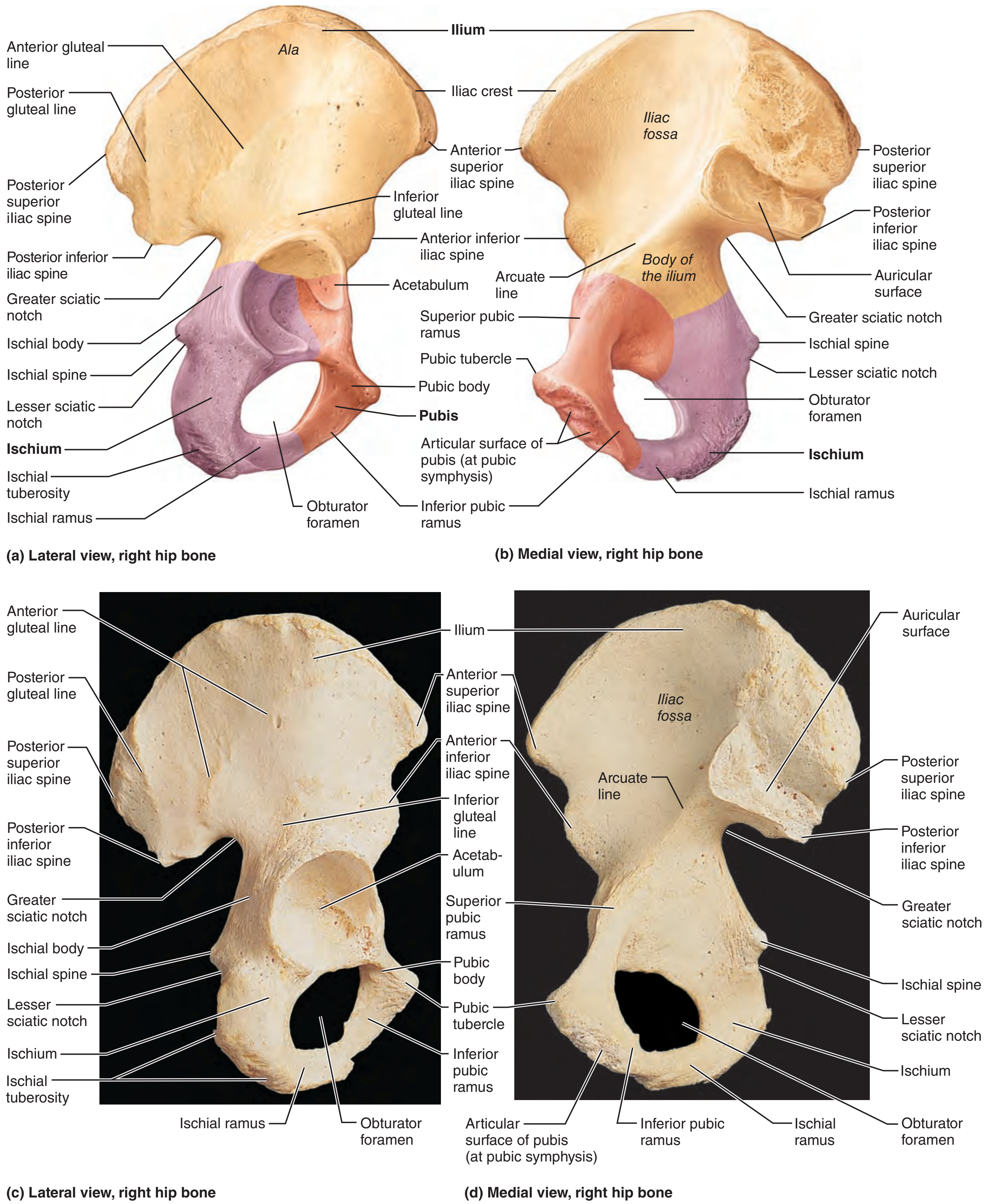
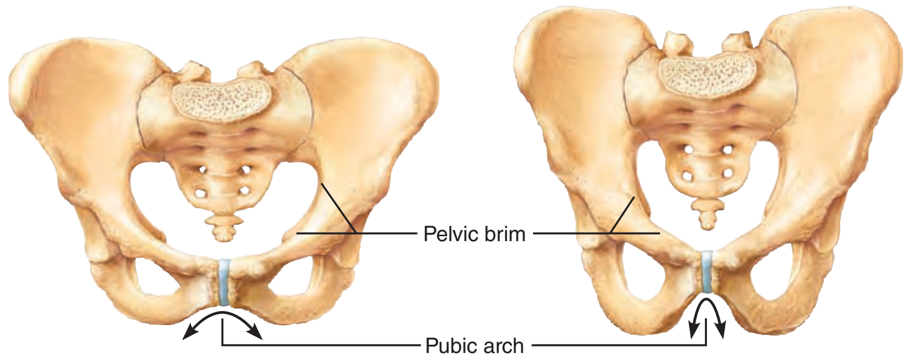
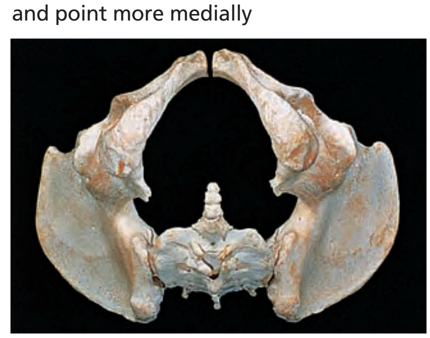


Figure 7.31 The hip (coxal) bones. Lateral and medial views of the right hip bone. The point of fusion of the ilium (gold), ischium (violet), and pubic (red) bones at the acetabulum is indicated in the diagrams (a, b). (For a related image, see *A Brief Atlas of the Human Body*, Figure 28.)

Table 7.4 Comparison of the Male and Female Pelves

CHARACTERISTIC	FEMALE	MALE
General structure and functional modifications	Tilted forward; adapted for childbearing; true pelvis defines the birth canal; cavity of the true pelvis is broad, shallow, and has a greater capacity	Tilted less far forward; adapted for support of a male's heavier build and stronger muscles; cavity of the true pelvis is narrow and deep
Bone thickness	Less; bones lighter, thinner, and smoother	Greater; bones heavier and thicker, and markings are more prominent
Acetabula	Smaller; farther apart	Larger; closer
Pubic angle/arch	Broader (80° to 90°); more rounded	Angle is more acute (50° to 60°)
Anterior view		



CHARACTERISTIC	FEMALE	MALE
Sacrum	Wider; shorter; sacral curvature is accentuated	Narrow; longer; sacral promontory more ventral
Coccyx	More movable; projects inferiorly	Less movable; projects anteriorly
Greater sciatic notch	Wide and shallow	Narrow and deep
Left lateral view		
Pelvic inlet (brim)	Wider; oval from side to side	Narrow; basically heart shaped
Pelvic outlet	Wider; ischial tuberosities shorter, farther apart and everted	Narrower; ischial tuberosities longer, sharper, and point more medially
Posteroinferior view		

Pelvic Structure and Childbearing

The deep, basinlike structure formed by the hip bones, sacrum, and coccyx is called the **pelvis** or the *bony pelvis*. The differences between the male and female pelves are striking. The female pelvis is modified for childbearing: It tends to be wider, shallower, lighter, and rounder than that of a male. The female pelvis not only accommodates a growing fetus, but it must be large enough to allow the infant's relatively large head to exit at birth. The major differences between the typical male and female pelves are summarized and illustrated in Table 7.4.

The pelvis is said to consist of a false (greater) pelvis and a true (lesser) pelvis separated by the **pelvic brim**, a continuous oval ridge that runs from the pubic crest through the arcuate line and sacral promontory (Figure 7.30). The **false pelvis**, that portion superior to the pelvic brim, is bounded by the alae of the ilia laterally and the lumbar vertebrae posteriorly. The false pelvis is really part of the abdomen and helps support the abdominal viscera. It does not restrict childbirth in any way.

The **true pelvis** is the region inferior to the pelvic brim that is almost entirely surrounded by bone. It forms a deep bowl containing the pelvic organs. Its dimensions, particularly those of its *inlet* and *outlet*, are critical to the uncomplicated delivery of a baby, and they are carefully measured by an obstetrician.

The **pelvic inlet** *is* the pelvic brim, and its widest dimension is from right to left along the frontal plane. As labor begins, an infant's head typically enters the inlet with its forehead facing one ilium and its occiput facing the other. A sacral promontory that is particularly large can impair the infant's entry into the true pelvis.

The **pelvic outlet**, illustrated in the photos at the bottom of Table 7.4, is the inferior margin of the true pelvis. It is bounded anteriorly by the pubic arch, laterally by the ischia, and posteriorly by the sacrum and coccyx. Both the coccyx and the ischial spines protrude into the outlet opening, so a sharply angled coccyx or unusually large spines can interfere with delivery. The largest dimension of the outlet is the anteroposterior diameter.

Generally, after the baby's head passes through the inlet, it rotates so that the forehead faces posteriorly and the occiput anteriorly, and this is the usual position of the baby's head as it leaves the mother's body (see Figure 28.18 (2)). Thus, during birth, the infant's head makes a quarter turn to follow the widest dimensions of the true pelvis.

☑ Check Your Understanding

28. The ilium and pubis help to form the os coxae. What other bone is involved in forming the os coxae?

29. The pelvic girdle is a heavy, strong girdle. How does its structure reflect its function?

30. Which of the following terms or phrases refer to the female pelvis? Wider, shorter sacrum; cavity narrow and deep; narrow heart-shaped inlet; more movable coccyx; long ischial spines.

For answers, see Appendix H.

The Lower Limb

✓ Identify the lower limb bones and their important markings.

The lower limbs carry the entire weight of the erect body and are subjected to exceptional forces when we jump or run. Thus, it is not surprising that the bones of the lower limbs are thicker and stronger than comparable bones of the upper limbs. The three segments of each lower limb are the thigh, the leg, and the foot (see **Table 7.5** on p. 243).

Thigh

The **femur** (fe′mur; "thigh"), the single bone of the thigh **(Figure 7.32)**, is the largest, longest, strongest bone in the body. Its durable structure reflects the fact that the stress on the femur during vigorous jumping can reach 280 kg/cm^2 (about 2 tons per square inch)! The femur is clothed by bulky muscles that prevent us from palpating its course down the length of the thigh. Its length is roughly one-quarter of a person's height.

Proximally, the femur articulates with the hip bone and then courses medially as it descends toward the knee. This arrangement allows the knee joints to be closer to the body's center of gravity and provides for better balance. The medial course of the two femurs is more pronounced in women because of their wider pelvis, a situation that may contribute to the greater incidence of knee problems in female athletes.

The ball-like **head** of the femur has a small central pit called the **fovea capitis** (fo′ve-ah kă′pĭ-tis; "pit of the head"). The short *ligament of the head of the femur* runs from this pit to the acetabulum, where it helps secure the femur. The head is carried on a *neck* that angles *laterally* to join the shaft. This arrangement reflects the fact that the femur articulates with the lateral aspect (rather than the inferior region) of the pelvis. The neck is the weakest part of the femur and is often fractured, an injury commonly called a broken hip.

At the junction of the shaft and neck are the lateral **greater trochanter** (tro-kan′ter) and posteromedial **lesser trochanter**. These projections serve as sites of attachment for thigh and buttock muscles. The two trochanters are connected by the **intertrochanteric line** anteriorly and by the prominent **intertrochanteric crest** posteriorly.

Inferior to the intertrochanteric crest on the posterior shaft is the **gluteal tuberosity**, which blends into a long vertical ridge, the **linea aspera** (lin′e-ah as′per-ah; "rough line"), inferiorly. Distally, the linea aspera diverges, forming the **medial** and **lateral supracondylar lines**. All of these markings are sites of muscle attachment. Except for the linea aspera, the femur shaft is smooth and rounded.

Distally, the femur broadens and ends in the wheel-like **lateral** and **medial condyles**, which articulate with the tibia of the leg. The **medial** and **lateral epicondyles** (sites of muscle attachment) flank the condyles superiorly. On the superior part of the medial epicondyle is a bump, the **adductor tubercle**. The smooth **patellar surface**, between the condyles on the anterior femoral surface, articulates with the *patella* (pah-tel′ah), or kneecap (see Figure 7.32 and Table 7.5). Between the condyles on the posterior aspect of the femur is the deep, U-shaped

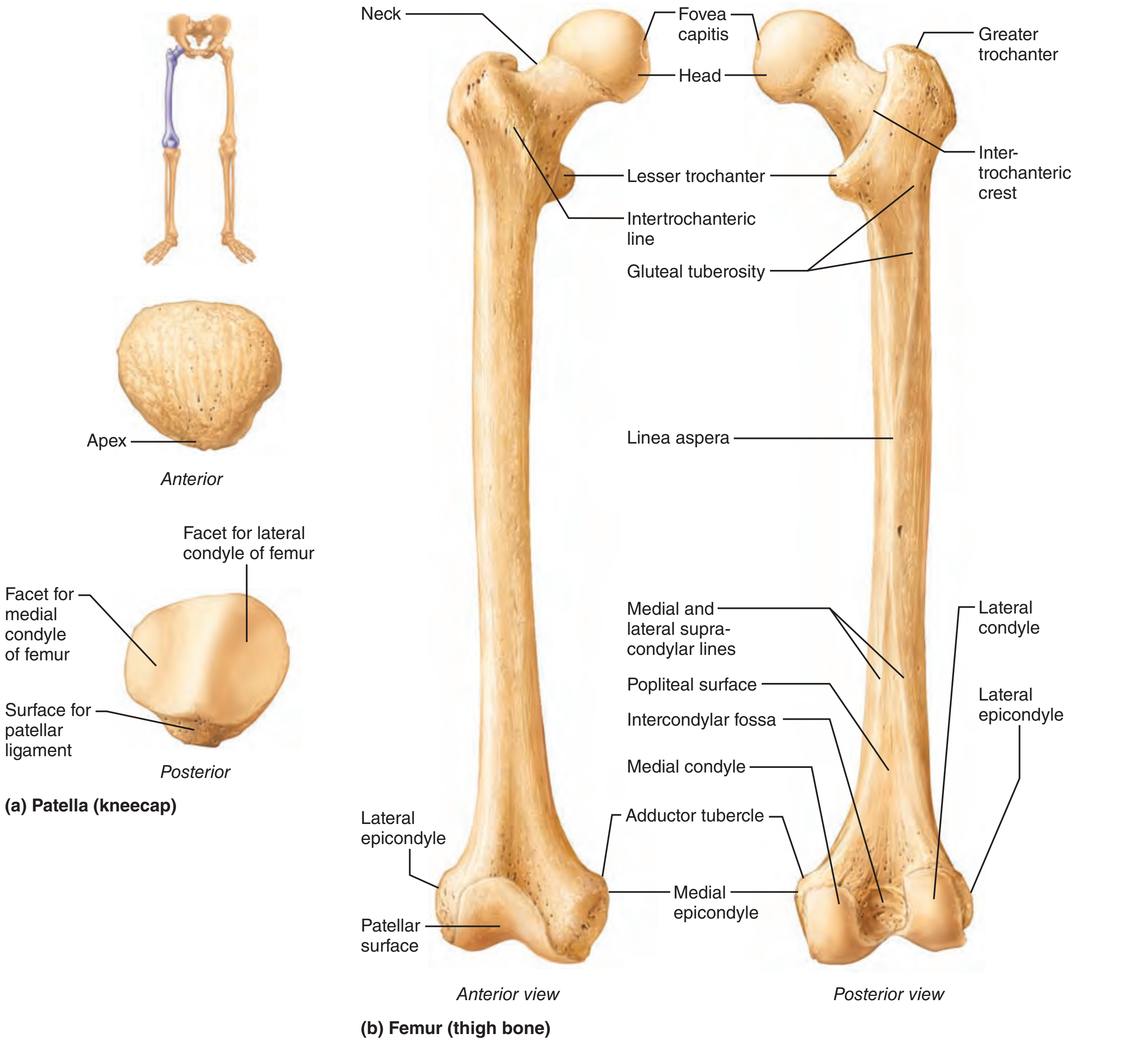


Figure 7.32 Bones of the right knee and thigh. (For a related image, see *A Brief Atlas of the Human Body*, Figure 29.)

intercondylar fossa, and superior to that on the shaft is the smooth *popliteal surface*.

The **patella** ("small pan") is a triangular sesamoid bone enclosed in the (quadriceps) tendon that secures the anterior thigh muscles to the tibia. It protects the knee joint anteriorly and improves the leverage of the thigh muscles acting across the knee.

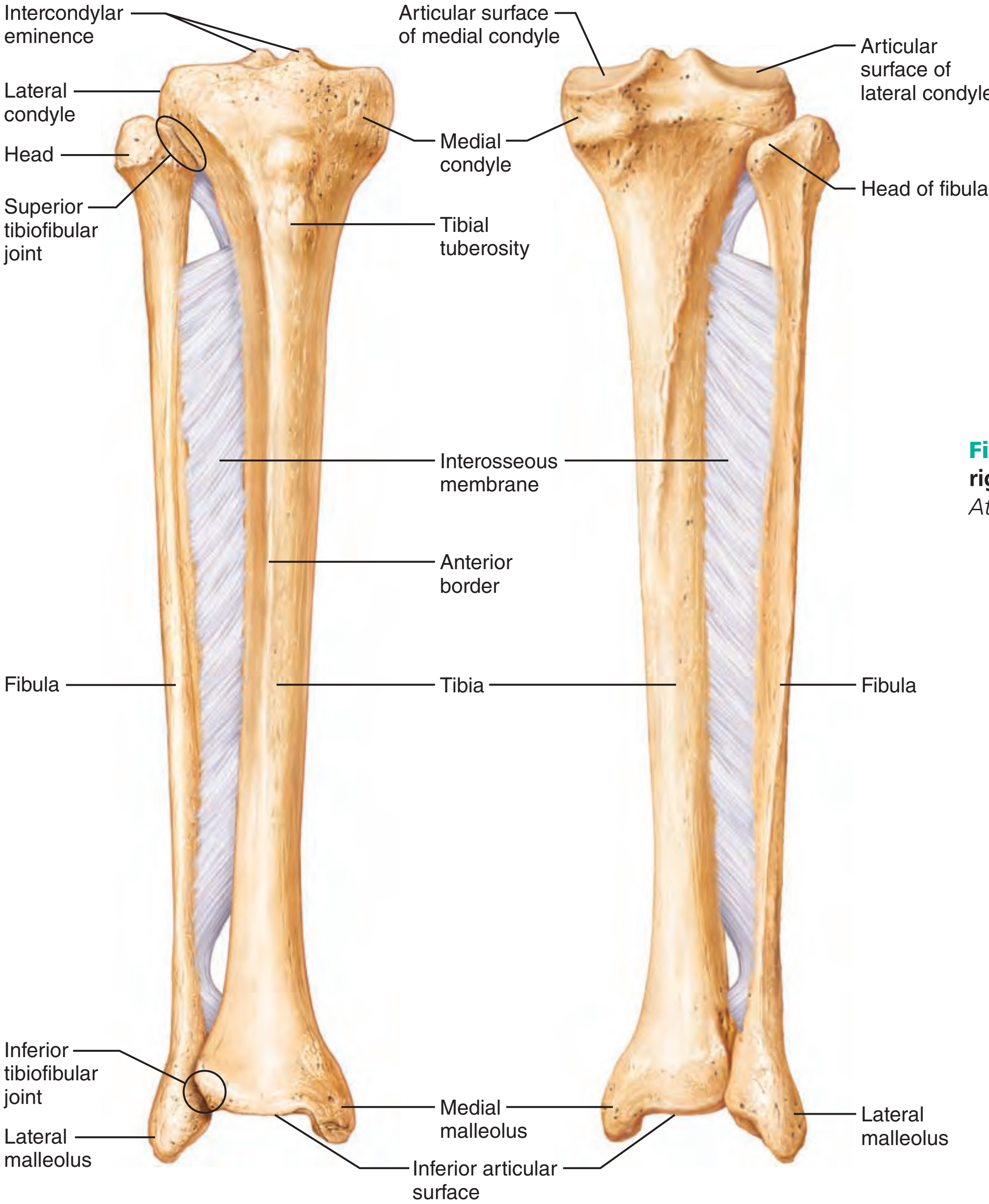
Leg

Two parallel bones, the tibia and fibula, form the skeleton of the leg, the region of the lower limb between the knee and the ankle **(Figure 7.33)**. These two bones are connected by an *interosseous membrane* and articulate with each other both proximally and distally. Unlike the joints between the radius and ulna of the forearm, the *tibiofibular joints* (tib″e-o-fib′u-lar) of the leg allow essentially no movement. The bones of the leg thus form a less flexible but stronger and more stable limb than those of the forearm. The medial tibia articulates proximally with the femur to form the modified hinge joint of the knee and distally with the talus bone of the foot at the ankle. The fibula, by contrast, does not contribute to the knee joint and merely helps stabilize the ankle joint.

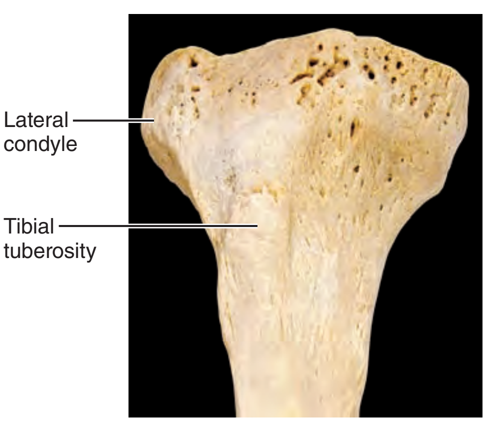
Tibia

The **tibia** (tib′e-ah; "shinbone") receives the weight of the body from the femur and transmits it to the foot. It is second only to the femur in size and strength. At its broad proximal end are the concave **medial** and **lateral condyles**, which look

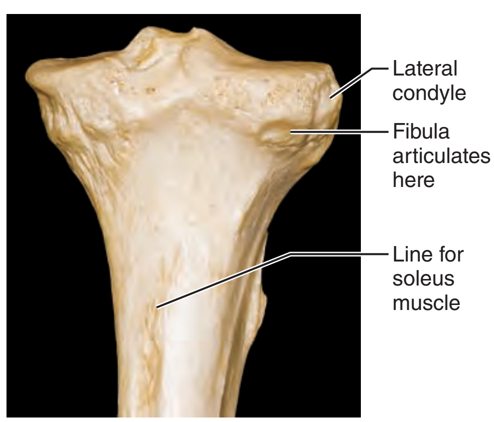
Figure 7.33 The tibia and fibula of the right leg. (For a related image, see *A Brief Atlas of the Human Body,* Figure 30.)



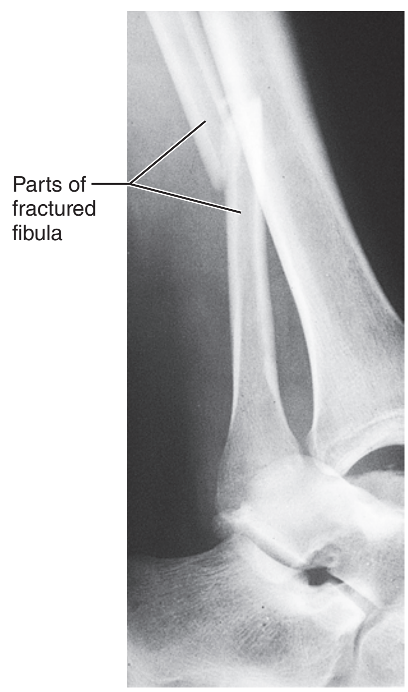
(a) Anterior view **(b) Posterior view**



(c) Anterior view, proximal tibia



(d) Posterior view, proximal tibia



(e) X ray of Pott's fracture of the fibula

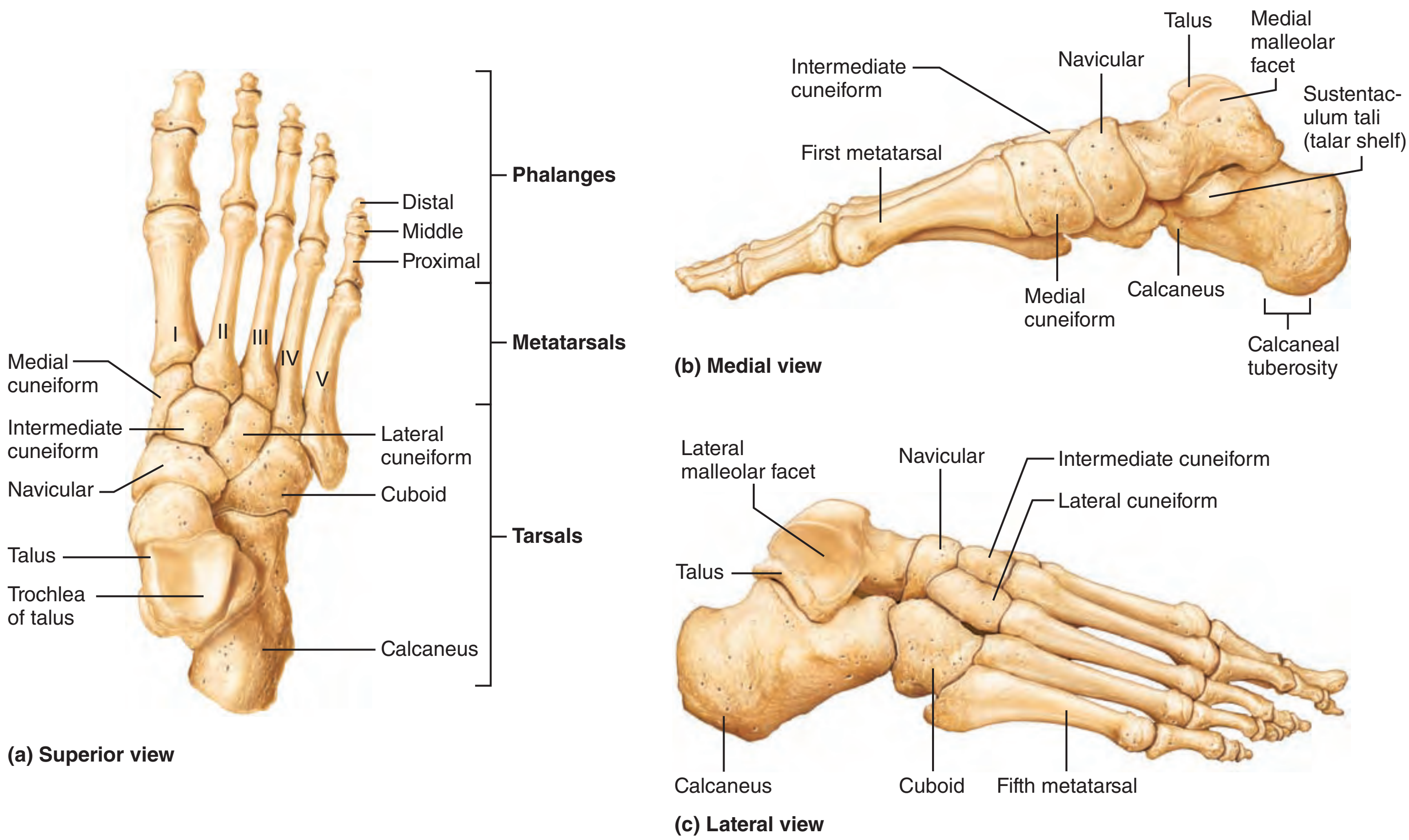


Figure 7.34 Bones of the right foot. (For a related image, see *A Brief Atlas of the Human Body*, Figure 31a, c, and d.)

like two huge checkers lying side by side. These are separated by an irregular projection, the **intercondylar eminence**. The tibial condyles articulate with the corresponding condyles of the femur. The inferior region of the lateral tibial condyle bears a facet that indicates the site of the *superior tibiofibular joint*. Just inferior to the condyles, the tibia's anterior surface displays the rough **tibial tuberosity**, to which the patellar ligament attaches.

The tibial shaft is triangular in cross section. Neither the tibia's sharp **anterior border** nor its medial surface is covered by muscles, so they can be felt just deep to the skin along their entire length. The anguish of a "bumped" shin is an experience familiar to nearly everyone. Distally the tibia is flat where it articulates with the talus bone of the foot. Medial to that joint surface is an inferior projection, the **medial malleolus** (mah-le′o-lus; "little hammer"), which forms the medial bulge of the ankle. The **fibular notch**, on the lateral surface of the tibia, participates in the *inferior tibiofibular joint*.

Fibula

The **fibula** (fib′u-lah; "pin") is a sticklike bone with slightly expanded ends. It articulates proximally and distally with the lateral aspects of the tibia. Its proximal end is its **head**; its distal end is the **lateral malleolus**. The lateral malleolus forms the conspicuous lateral ankle bulge and articulates with the talus. The fibular shaft is heavily ridged and appears to have been twisted a quarter turn. The fibula does not bear weight, but several muscles originate from it.

Homeostatic Imbalance 7.7

A *Pott's fracture* occurs at the distal end of the fibula, the tibia, or both. It is a common sports injury. (See Figure 7.33e.) ✚

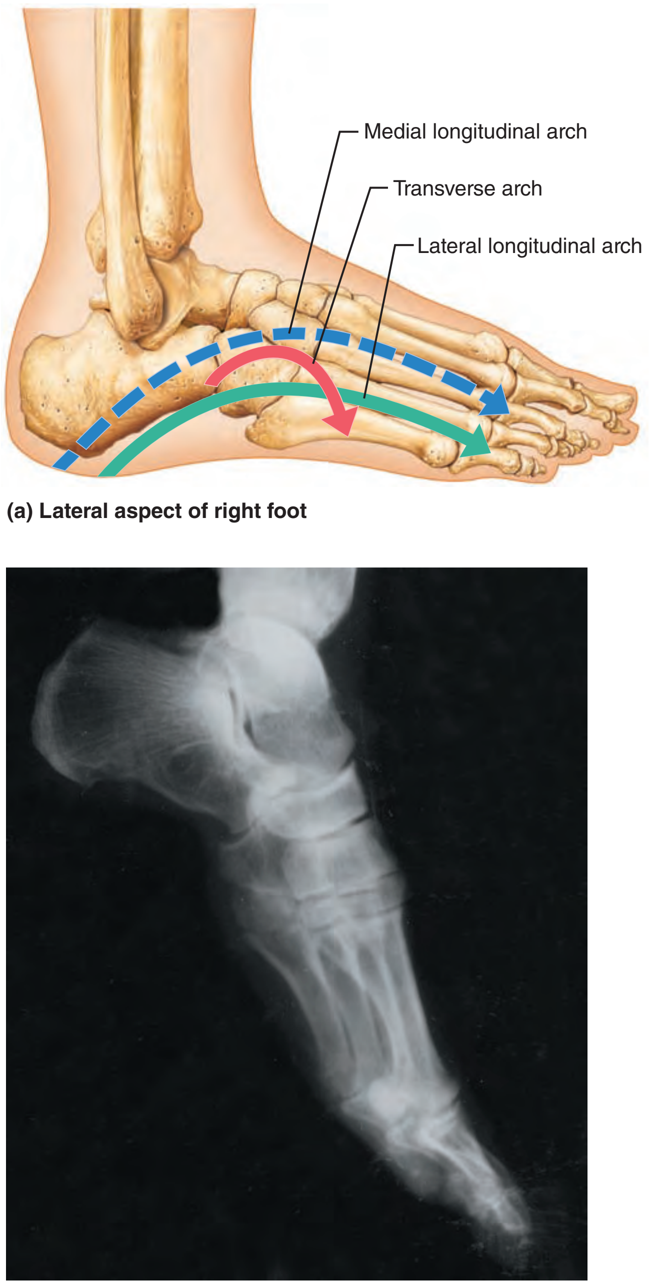
☑ Check Your Understanding

31. What lower limb bone is the second largest bone in the body?
32. Where is the medial malleolus located?
33. Which of the following sites is not a site of muscle attachment? Greater trochanter, lesser trochanter, gluteal tuberosity, lateral condyle.

For answers, see Appendix H.

Foot

The skeleton of the foot includes the bones of the *tarsus*, the bones of the *metatarsus*, and the *phalanges*, or toe bones **(Figure 7.34)**. The foot has two important functions: It supports our body weight, and it acts as a lever to propel the body forward when we walk and run. A single bone could serve both purposes, but it would adapt poorly to uneven ground. Segmentation makes the foot pliable, avoiding this problem.



(a) Lateral aspect of right foot

(b) X ray, medial aspect of right foot

Figure 7.35 Arches of the foot.

Tarsus

The **tarsus** is made up of seven bones called **tarsals** (tar′salz) that form the posterior half of the foot. It corresponds to the carpus of the hand. Body weight is carried primarily by the two largest, most posterior tarsals: the **talus** (ta′lus; "ankle"), which articulates with the tibia and fibula superiorly, and the strong **calcaneus** (kal-ka′ne-us; "heel bone"), which forms the heel of the foot and carries the talus on its superior surface. The thick *calcaneal*, or *Achilles*, *tendon* of the calf muscles attaches to the posterior surface of the calcaneus. The part of the calcaneus that touches the ground is the **calcaneal tuberosity**, and its shelflike projection that supports part of the talus is the **sustentaculum tali** (sus″ten-tak′u-lum ta′le; "supporter of the talus") or **talar shelf**. The tibia articulates with the talus at the *trochlea* of the talus. The remaining tarsals are the lateral **cuboid**, the medial **navicular** (nah-vik′u-lar), and the anterior **medial**, **intermediate**, and **lateral cuneiform bones** (ku-ne′i-form; "wedge-shaped"). The cuboid and cuneiform bones articulate with the metatarsal bones anteriorly.

Metatarsus

The **metatarsus** consists of five small, long bones called **metatarsals**. These are numbered I to V beginning on the medial (great toe) side of the foot. The first metatarsal, which plays an important role in supporting body weight, is short and thick. The arrangement of the metatarsals is more parallel than that of the metacarpals of the hands. Distally, where the metatarsals articulate with the proximal phalanges of the toes, the enlarged head of the first metatarsal forms the "ball" of the foot.

Phalanges (Toes)

The 14 phalanges of the toes are a good deal smaller than those of the fingers and so are less nimble. But their general structure and arrangement are the same. There are three phalanges in each digit except for the great toe, the **hallux**. The hallux has only two, proximal and distal.

Arches of the Foot

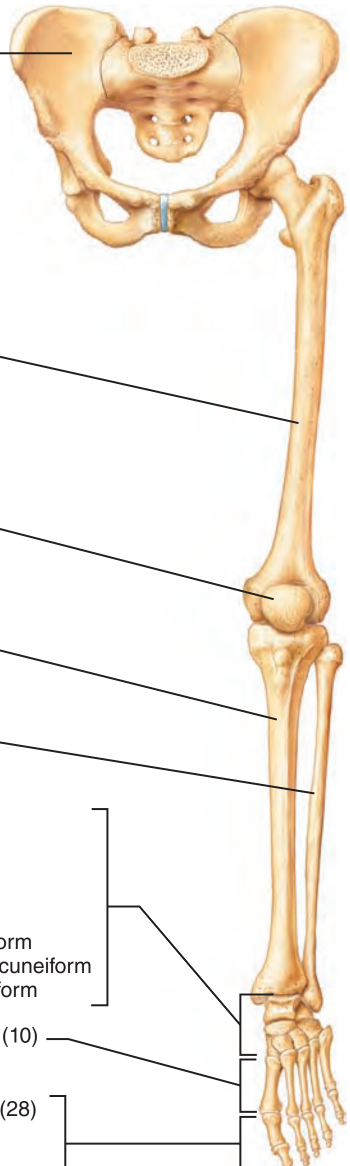
A segmented structure can hold up weight only if it is arched. The foot has three arches: two *longitudinal arches* (*medial* and *lateral*) and one *transverse arch* **(Figure 7.35)**, which account for its awesome strength. These arches are maintained by the interlocking shapes of the foot bones, by strong ligaments, and by the pull of some tendons during muscle activity. The ligaments and muscle tendons provide a certain amount of springiness. In general, the arches "give," or stretch slightly, when weight is applied to the foot and spring back when the weight is removed, which makes walking and running more economical in terms of energy use than would otherwise be the case.

If you examine your wet footprints, you will see that the medial margin from the heel to the head of the first metatarsal leaves no print. This is because the **medial longitudinal arch** curves well above the ground. The talus is the keystone of this arch, which originates at the calcaneus, rises toward the talus, and then descends to the three medial metatarsals.

The **lateral longitudinal arch** is very low. It elevates the lateral part of the foot just enough to redistribute some of the weight to the calcaneus and the head of the fifth metatarsal (to the ends of the arch). The cuboid is the keystone bone of this arch.

The two longitudinal arches serve as pillars for the **transverse arch**, which runs obliquely from one side of the foot to the other, following the line of the joints between the tarsals and metatarsals. Together, the arches of the foot form a half-dome that distributes about half of a person's standing and walking weight to the heel bones and half to the heads of the metatarsals.

Table 7.5 Bones of the Appendicular Skeleton, Part 2: Pelvic Girdle and Lower Limb

BODY REGION	BONES*	ILLUSTRATION	LOCATION	MARKINGS
Pelvic girdle (Figures 7.30, 7.31)	**Coxal** (2) (hip)		Each coxal (hip) bone is formed by the fusion of an ilium, ischium, and pubis; the coxal bones articulate anteriorly at the pubic symphysis and form sacroiliac joints with the sacrum posteriorly; girdle consisting of both coxal bones and the sacrum is basinlike	Iliac crest; anterior and posterior iliac spines; auricular surface; greater and lesser sciatic notches; obturator foramen; ischial tuberosity and spine; acetabulum; pubic arch; pubic crest; pubic tubercle
Lower limb Thigh (Figure 7.32)	**Femur** (2)		Femur is the sole bone of thigh; between hip joint and knee; largest bone of the body	Head; greater and lesser trochanters; neck; lateral and medial condyles and epicondyles; gluteal tuberosity; linea aspera
Kneecap (Figure 7.32)	**Patella** (2)		Patella is a sesamoid bone formed within the tendon of the quadriceps (anterior thigh) muscles	
Leg (Figure 7.33)	**Tibia** (2)		Tibia is the larger and more medial bone of leg; between knee and foot	Medial and lateral condyles; tibial tuberosity; anterior border; medial malleolus
	Fibula (2)		Fibula is the lateral bone of leg; sticklike	Head; lateral malleolus
Foot (Figure 7.34)	7 **Tarsals** (14) talus, calcaneus, navicular, cuboid, lateral cuneiform, intermediate cuneiform, medial cuneiform		Tarsals are seven bones forming the proximal part of the foot; the talus articulates with the leg bones at the ankle joint; the calcaneus, the largest tarsal, forms the heel	
	5 **Metatarsals** (10)		Metatarsals are five bones numbered I–V	
	14 **Phalanges** (28) distal, middle, proximal		Phalanges form the toes; three in digits 2–5, two in digit 1 (the great toe)	

* The number in parentheses ( ) following the bone name denotes the total number of such bones in the body.

Homeostatic Imbalance 7.8

Standing immobile for extended periods places excessive strain on the tendons and ligaments of the feet (because the muscles are inactive) and can result in fallen arches, or "flat feet," particularly if a person is overweight. Running on hard surfaces can also cause arches to fall unless the runner wears shoes that give proper arch support. ✚

The bones of the thigh, leg, and foot are summarized in Table 7.5.

Check Your Understanding

34. Besides supporting our weight, what is a major function of the arches of the foot?
35. What are the two largest tarsal bones in each foot, and which one forms the heel of the foot?

For answers, see Appendix H.

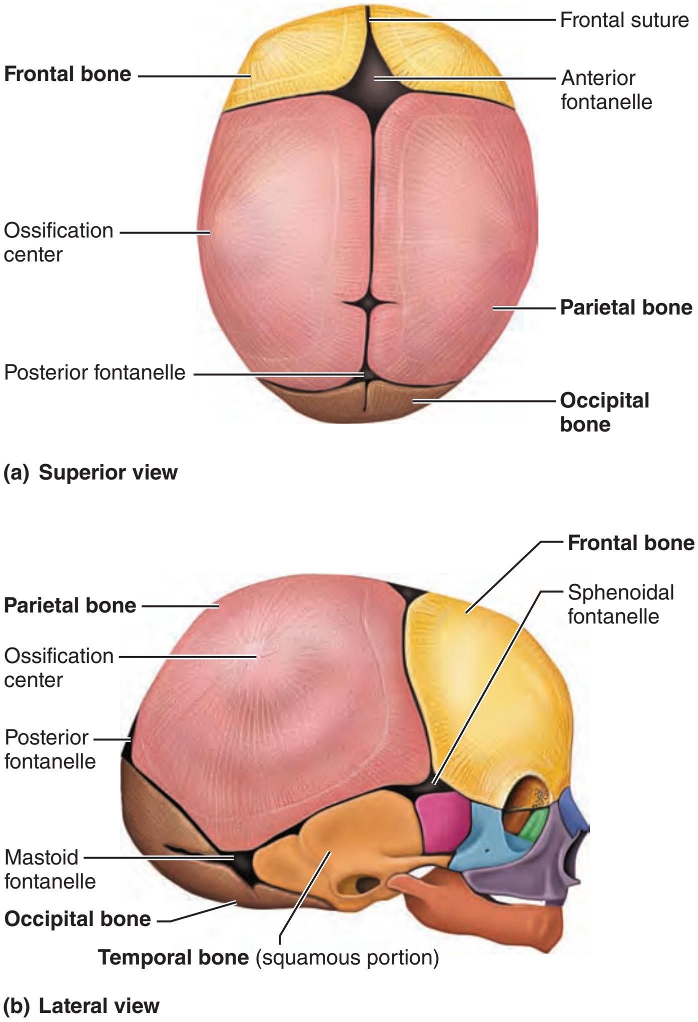


Figure 7.36 Skull of a newborn. Notice that the infant's skull has more bones than that of an adult. (For a related image, see *A Brief Atlas of the Human Body*, Figure 16.)

Developmental Aspects of the Skeleton

- ✓ Define fontanelles and indicate their significance.
- ✓ Describe how skeletal proportions change through life.
- ✓ Discuss how age-related skeletal changes may affect health.

The membrane bones of the skull start to ossify late in the second month of development. The rapid deposit of bone matrix at the ossification centers produces cone-shaped protrusions in the developing bones. At birth, the skull bones are still incomplete and are connected by as yet unossified remnants of fibrous membranes called **fontanelles** (fon″tah-nelz′) **(Figure 7.36)**. The fontanelles allow the infant's head to be compressed slightly during birth, and they accommodate brain growth in the fetus and infant. A baby's pulse can be felt surging in these "soft spots"; hence their name (*fontanelle* = little fountain). The large, diamond-shaped *anterior fontanelle* is palpable for 1½ to 2 years after birth. The others are replaced by bone by the end of the first year.

Figure 7.37 A baby born with a cleft lip and palate.

Homeostatic Imbalance 7.9

Several congenital abnormalities may distort the skull. Most common is *cleft palate*, a condition in which the right and left halves of the palate fail to fuse medially **(Figure 7.37)**. The persistent opening between the oral and nasal cavities interferes with sucking and can lead to aspiration (inhalation) of food into the lungs and *aspiration pneumonia*.✚

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, and several bones are still unfused (e.g., the mandible and frontal bones). The maxillae and mandible are foreshortened, and the contours of the face are flat (Figure 7.39). By 9 months after birth, the cranium is already half of its adult size (volume) because of the rapid growth of the brain. By 8 to 9 years, the cranium has almost reached adult proportions.

Between the ages of 6 and 13, the head appears to enlarge substantially as the face literally grows out from the skull. The jaws, cheekbones, and nose become more prominent. These facial changes are correlated with the expansion of the nose and paranasal sinuses, and development of the permanent teeth. Figure 7.39 tracks how differential bone growth alters body proportions throughout life.

Only the thoracic and sacral curvatures are well developed at birth. These so-called **primary curvatures** are convex posteriorly, and an infant's spine arches, like that of a four-legged animal **(Figure 7.38)**.

The **secondary curvatures**—cervical and lumbar—are convex anteriorly and are associated with a child's development. They result from reshaping of the intervertebral discs rather than from modifications of the vertebrae. The cervical curvature is present before birth but is not pronounced until the baby starts to lift its head (at about 3 months). The lumbar curvature develops when the baby begins to walk (at about 12 months). The lumbar curvature positions the weight of the trunk over the body's center of gravity, providing optimal balance when standing.

Vertebral problems (scoliosis or lordosis; see Figure 7.17a and c) may appear during the early school years, when rapid growth of the limb bones stretches many muscles. During the

Figure 7.38 The C-shaped spine of a newborn infant.

preschool years, lordosis is often present, but this is usually rectified as the abdominal muscles become stronger and the pelvis tilts forward. The thorax grows wider, but a true "military posture" (head erect, shoulders back, abdomen in, and chest out) does not develop until adolescence.

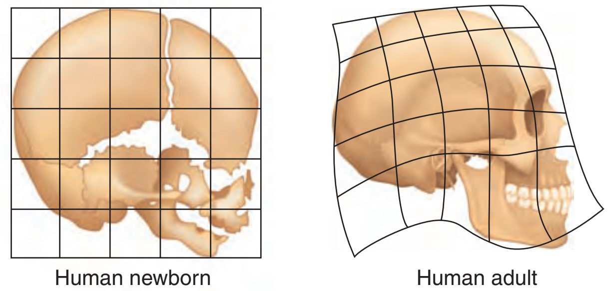
Homeostatic Imbalance 7.10

The appendicular skeleton can also suffer from a number of congenital abnormalities. One that occurs in just over 1% of infants and is quite severe is *dysplasia of the hip* (dis-pla′ze-ah; "bad formation"). The acetabulum forms incompletely or the ligaments of the hip joint are loose, so the head of the femur slips out of its socket. Early treatment (a splint or harness to hold the femur in place or surgery to tighten hip ligaments) is essential to prevent permanent crippling. +

During youth, growth of the skeleton not only increases overall body height but also changes body proportions **(Figure 7.39)**. 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, a condition that persists 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.

Old age affects many parts of the skeleton, especially the spine. As the discs become thinner, less hydrated, and less elastic, the risk of disc herniation increases. By 55 years, a loss of several centimeters in stature is common. Further shortening can be produced by osteoporosis of the spine or by kyphosis (called "dowager's hump" in the elderly; see Figure 7.17b). What was done during youth may be undone in old age as the vertebral column gradually resumes its initial arc shape.

The thorax becomes more rigid with age, largely because the costal cartilages ossify. This loss of rib cage elasticity causes shallow breathing, which leads to less efficient gas exchange.



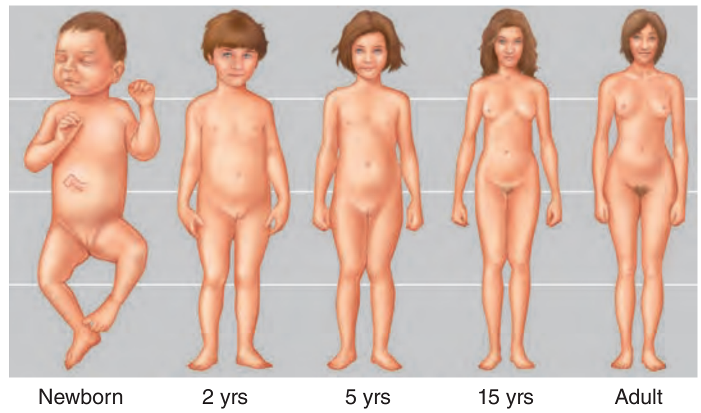


Figure 7.39 Different growth rates of body parts determine body proportions. (a) Differential growth transforms the rounded, foreshortened skull of a newborn to the sloping skull of an adult. **(b)** During growth of a human, the arms and legs grow faster than the head and trunk, as seen in this conceptualization of different-aged individuals all drawn at the same height.

All bones, you will recall, lose mass with age. Cranial bones lose less mass than most, but changes in facial contours with age are common. As the bony tissue of the jaws declines, the jaws look small and childlike once again. If the elderly person loses his or her teeth, this loss of bone from the jaws is accelerated, because the alveolar region bone is resorbed. As bones become more porous, they are more likely to fracture, especially the vertebrae and the neck of the femur.

Check Your Understanding

36. What developmental events result in a dramatic enlargement of the facial skeleton between the ages of 6 and 13?
37. Under what conditions does the lumbar curvature of the spine develop?

For answers, see Appendix H.

Our skeleton is a marvelous substructure, to be sure, but it is much more than that. It is a protector and supporter of other body systems, and without it (and the joints considered in Chapter 8), our muscles would be almost useless. The homeostatic relationships between the skeletal system and other body systems are illustrated in *System Connections* in Chapter 6 (p. 195).

7

Chapter Summary

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7

1. The axial skeleton forms the longitudinal axis of the body. Its principal subdivisions are the skull, vertebral column, and thoracic cage. It provides support and protection (by enclosure).
2. The appendicular skeleton consists of the bones of the pectoral and pelvic girdles and the limbs. It allows mobility for manipulation and locomotion.

PART 1 The Axial Skeleton

The Skull (pp. 201–217)

1. The skull is formed by 22 bones. The cranium forms the vault and base of the skull, which protect the brain. The facial skeleton provides openings for the respiratory and digestive passages and attachment points for facial muscles.
2. Except for the temporomandibular joints, all bones of the adult skull are joined by immovable sutures.
3. **Cranium.** The eight bones of the cranium include the paired parietal and temporal bones and the single frontal, occipital, ethmoid, and sphenoid bones (see Table 7.1, pp. 216–217).
4. **Facial bones.** The 14 bones of the face include the paired maxillae, zygomatics, nasals, lacrimals, palatines, and inferior nasal conchae and the single mandible and vomer bones (Table 7.1).
5. **Orbits and nasal cavity.** Both the orbits and the nasal cavities are complicated bony regions formed of several bones.
6. **Paranasal sinuses.** Paranasal sinuses occur in the frontal, ethmoid, sphenoid, and maxillary bones.
7. **Hyoid bone.** The hyoid bone, supported in the neck by ligaments, serves as an attachment point for tongue and neck muscles.

The Vertebral Column (pp. 218–224)

1. **General characteristics.** The vertebral column includes 24 movable vertebrae (7 cervical, 12 thoracic, and 5 lumbar) and the sacrum and coccyx.
2. The fibrocartilage intervertebral discs act as shock absorbers and provide flexibility to the vertebral column.
3. The primary curvatures of the vertebral column are the thoracic and sacral; the secondary curvatures are the cervical and lumbar. Curvatures increase spine flexibility.
4. **General structure of vertebrae.** With the exception of C_1 and C_2, all vertebrae have a body, two transverse processes, two superior and two inferior articular processes, a spinous process, and a vertebral arch.
5. **Regional vertebral characteristics.** Special features distinguish the regional vertebrae (see Table 7.2, p. 223).

The Thoracic Cage (pp. 224–227)

1. The bones of the thoracic cage include the 12 rib pairs, the sternum, and the thoracic vertebrae. The thoracic cage protects the organs of the thoracic cavity.
2. **Sternum.** The sternum consists of the fused manubrium, body, and xiphoid process.
3. **Ribs.** The first seven rib pairs are called true ribs; the rest are called false ribs. Ribs 11 and 12 are floating ribs.

PART 2 The Appendicular Skeleton

The Pectoral (Shoulder) Girdle* (pp. 227–228)

1. Each pectoral girdle consists of one clavicle and one scapula. The pectoral girdles attach the upper limbs to the axial skeleton.
2. **Clavicles.** The clavicles hold the scapulae laterally away from the thorax. The sternoclavicular joints are the only attachment points of the pectoral girdle to the axial skeleton.
3. **Scapulae.** The scapulae articulate with the clavicles and with the humerus bones of the arms.

The Upper Limb* (pp. 228–234)

1. Each upper limb consists of 30 bones and is specialized for mobility.
2. **Arm/forearm/hand.** The skeleton of the arm is composed solely of the humerus; the skeleton of the forearm is composed of the radius and ulna; and the skeleton of the hand consists of the carpals, metacarpals, and phalanges.

The Pelvic (Hip) Girdle* (pp. 234–238)

1. The pelvic girdle, a heavy structure specialized for weight bearing, is composed of two hip bones and the sacrum. It secures the lower limbs to the axial skeleton.
2. Each hip bone consists of three fused bones: ilium, ischium, and pubis. The acetabulum occurs at the point of fusion.
3. **Ilium/ischium/pubis.** The ilium is the superior flaring portion of the hip bone. Each ilium forms a secure joint with the sacrum posteriorly. The ischium is a curved bar of bone; we sit on the ischial tuberosities. The V-shaped pubic bones articulate anteriorly at the pubic symphysis.
4. **Pelvic structure and childbearing.** The pelvis is the deep, basinlike structure formed by the hip bones, sacrum, and coccyx. The male pelvis is deep and narrow with larger, heavier bones than those of the female. The female pelvis, which forms the birth canal, is shallow and wide.

The Lower Limb* (pp. 238–243)

1. Each lower limb consists of the thigh, leg, and foot and is specialized for weight bearing and locomotion.
2. **Thigh.** The femur is the only bone of the thigh. Its ball-shaped head articulates with the acetabulum.
3. **Leg.** The bones of the leg are the tibia, which participates in forming both the knee and ankle joints, and the fibula.
4. **Foot.** The bones of the foot include the tarsals, metatarsals, and phalanges. The most important tarsals are the calcaneus (heel bone) and the talus, which articulates with the tibia superiorly.
5. The foot is supported by three arches (lateral, medial, and transverse) that distribute body weight to the heel and ball of the foot.

Developmental Aspects of the Skeleton (pp. 244–245)

1. Fontanelles, 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. Increase in size of the facial skeleton follows tooth development and enlargement of nose and sinus cavities.
2. The vertebral column is C shaped at birth (thoracic and sacral curvatures are present); the secondary curvatures form when the baby begins to lift its head and walk.
3. Long bones continue to grow in length until late adolescence. The head and torso, initially 1½ times the length of the lower limbs, equal their length by the age of 10.
4. Changes in the female pelvis (preparatory for childbirth) occur during puberty.
5. Once at adult height, the skeleton changes little until late middle age. With old age, the intervertebral discs thin; this, along with osteoporosis, leads to a gradual loss in height and increased risk of disc herniation. Loss of bone mass increases the risk of fractures, and thoracic cage rigidity promotes breathing difficulties.

***For associated bone markings, see the pages indicated in the section heads.**

Review Questions

Multiple Choice/Matching

(Some questions have more than one correct answer. Select the best answer or answers from the choices given.)

1. Match the bones in column B with their description in column A. (Note that some descriptions require more than a single choice.)

Column A	Column B
____ (1) connected by the coronal suture	(a) ethmoid
	(b) frontal
____ (2) keystone bone of cranium	(c) mandible
	(d) maxillary
____ (3) keystone bone of the face	(e) occipital
	(f) palatine
____ (4) form the hard palate	(g) parietal
____ (5) allows the spinal cord to pass	(h) sphenoid
	(i) temporal
____ (6) forms the chin	
____ (7) contain paranasal sinuses	
____ (8) contains mastoid sinuses	

2. Match the key terms with the bone descriptions that follow.

Key:

(a) clavicle (b) ilium (c) ischium
(d) pubis (e) sacrum (f) scapula
(g) sternum

____ (1) bone of the axial skeleton to which the pectoral girdle attaches
____ (2) markings include glenoid cavity and acromion
____ (3) features include the ala, crest, and greater sciatic notch
____ (4) doubly curved; acts as a shoulder strut
____ (5) hip bone that articulates with the axial skeleton
____ (6) the "sit-down" bone
____ (7) anteriormost bone of the pelvic girdle
____ (8) part of the vertebral column

3. Use key choices to identify the bone descriptions that follow.

Key:

(a) carpals (b) femur (c) fibula
(d) humerus (e) radius (f) tarsals
(g) tibia (h) ulna

____ (1) articulates with the acetabulum and the tibia
____ (2) forms the lateral aspect of the ankle
____ (3) bone that "carries" the hand
____ (4) the wrist bones
____ (5) end shaped like a monkey wrench
____ (6) articulates with the capitulum of the humerus
____ (7) largest bone of this "group" is the calcaneus

Short Answer Essay Questions

4. Name the cranial and facial bones and compare and contrast the functions of the cranial and facial skeletons.
5. How do the relative proportions of the cranium and face of a fetus compare with those of an adult skull?
6. Name and diagram the normal vertebral curvatures. Which are primary and which are secondary curvatures?
7. List at least two specific anatomical characteristics each for typical cervical, thoracic, and lumbar vertebrae that would allow anyone to identify each type correctly.
8. What is the function of the intervertebral discs?
9. Distinguish between the anulus fibrosus and nucleus pulposus regions of a disc. Which provides durability and strength? Which provides resilience? Which part is involved in a "slipped" disc?
10. What is a true rib? A false rib?
11. The major function of the shoulder girdle is flexibility. What is the major function of the pelvic girdle? Relate these functional differences to anatomical differences seen in these girdles.
12. List three important differences between the male and female pelves.
13. Briefly describe the anatomical characteristics and impairment of function seen in cleft palate and hip dysplasia.
14. Compare a young adult skeleton to that of an extremely aged person relative to bone mass in general and the bony structure of the skull, thorax, and vertebral column in particular.
15. Peter Howell, a teaching assistant in the anatomy class, picked up a hip bone and pretended it was a telephone. He held the big hole in this bone right up to his ear and said, "Hello, obturator, obturator (operator, operator)." Name the structure he was helping the students to learn.

Critical Thinking and Clinical Application Questions

1. Justiniano worked in a poultry-packing plant where his job was cutting open chickens and stripping out their visceral organs. After work, he typed for long hours on his computer keyboard, writing a book about his work in the plant. Soon, his wrist

and hand began to hurt whenever he flexed it, and he began to awaken at night with pain and tingling on the thumb-half of his hand. What condition did he probably have?

2. Ralph had polio as a boy and was partially paralyzed in one lower limb for over a year. Although no longer paralyzed, he now has a severe lateral curvature of the lumbar spine. Explain what has happened and identify his condition.
3. Mary's grandmother slipped on a scatter rug and fell heavily to the floor. Her left lower limb was laterally rotated and noticeably shorter than the right, and when she attempted to get up, she winced with pain. Mary surmised that her grandmother might have "fractured her hip," which later proved to be true. What bone was probably fractured and at what site? Why is a "fractured hip" a common type of fracture in the elderly?
4. Mrs. Shea came up with what she considered to be a clever idea to bypass the long lines at Disney World. She had her husband rent a wheelchair and he wheeled her around from one exhibit to another for the better part of three days. As they sat on the plane, waiting to take off for Chicago, she complained to him that she had two sore spots on her buttocks. Why? What do you suppose would happen (to her buttocks) if she was wheeled around for a few more days?

AT THE CLINIC

7

Related Clinical Terms

Chiropractic (ki″ro-prak′tik) A system of treating disease by manipulating the vertebral column based on the idea that most diseases are due to pressure on nerves caused by faulty bone alignment; a specialist in this field is a chiropractor.

Clubfoot A relatively common congenital defect (one in 700 births) in which the soles of the feet face medially and the toes point inferiorly; may be genetically induced or reflect an abnormal position of the foot during fetal development.

Laminectomy Surgical removal of a vertebral lamina; most often done to relieve the symptoms of a ruptured disc.

Orthopedist (or″tho-pe′dist) or **orthopedic surgeon** A physician who specializes in restoring lost skeletal system function or repairing damage to bones and joints.

Pelvimetry Measurement of the dimensions of the inlet and outlet of the pelvis, usually to determine whether the pelvis is of adequate size to allow normal delivery of a baby.

Spina bifida (spi′nah bĭ′fĭ-dah; "cleft spine") Congenital defect of the vertebral column in which one or more of the vertebral arches are incomplete; ranges in severity from inconsequential to severe conditions that impair neural functioning and encourage nervous system infections.

Spinal fusion Surgical procedure involving insertion of bone chips (or crushed bone) to immobilize and stabilize a specific region of the vertebral column, particularly in cases of vertebral fracture and herniated discs.

Case Study Skeleton

Kayla Tanner, a 45-year-old mother of four, was a passenger on the bus involved in an accident on Route 91. When paramedics arrived on the scene, they found Mrs. Tanner lying on her side in the aisle. Upon examination, they found that her right thigh appeared shorter than her left thigh. They also noticed that even slight hip movement caused considerable pain. Suspecting a hip dislocation, they stabilized and transported her.

In the emergency department, doctors discovered a decreased ability to sense light touch in her right foot, and she was unable to move her toes or ankle. Dislocation of her right hip was confirmed by X ray. Mrs. Tanner was sedated to relax the muscles around the hip, and then doctors placed her in the supine position and performed a closed reduction ("popped" the femur back in place).

1. Mrs. Tanner's pelvic girdle contains a hemispherical socket at the point where her femur attaches. Name this structure.
2. Name the structure on the femur that forms the "ball" that fits into the "socket" you named in question 1.
3. There are three bones in the pelvic girdle that fuse together at a point within the structure that you named in question 1. Name those three bones.
4. Mrs. Tanner suffered an injury to the hip joint, but if you were asked to rest your hands on your hips, you would not actually touch this joint. What structure in the pelvic girdle would your hands be resting on?
5. The sedation that Mrs. Tanner was given was to relax the large muscles of the thigh and buttocks that attach to the proximal end of the femur. Name the structures on the femur where these muscles attach.
6. Mrs. Tanner's injury caused damage to the sciatic nerve that passes across the hip and down into the thigh, lower leg, and foot. Name the pelvic structure that this nerve passes through as it travels into the upper thigh.

(Answers in Appendix H)

8

Joints

The graceful movements of ballet dancers and the rough-and-tumble grapplings of football players demonstrate the great variety of motion allowed by **joints**, or **articulations**—the sites where two or more bones meet. Our joints have two fundamental functions: They give our skeleton mobility, and they hold it together, sometimes playing a protective role in the process.

Joints are the weakest parts of the skeleton. Nonetheless, their structure resists various forces, such as crushing or tearing, that threaten to force them out of alignment.

Classification of Joints

- ✓ Define joint or articulation.
- ✓ Classify joints by structure and by function.

Joints are classified by structure and by function. The *structural classification* focuses on the material binding the bones together and whether or not a joint cavity is present. Structurally, there are *fibrous*, *cartilaginous*, and *synovial joints* (**Table 8.1** on p. 253).

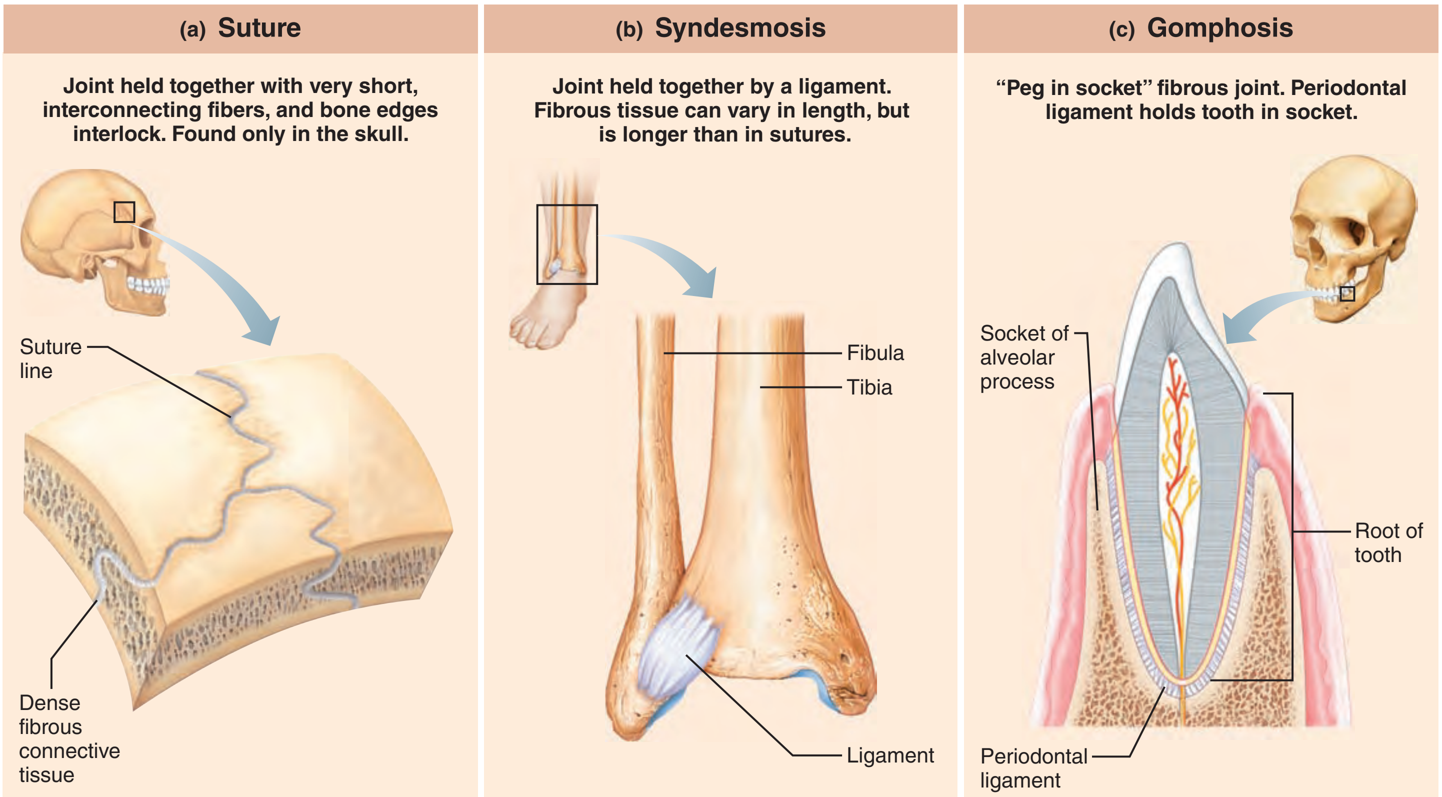


Figure 8.1 **Fibrous joints.**

The *functional classification* is based on the amount of movement allowed at the joint. On this basis, there are **synarthroses** (sin″ar-thro′sēz; *syn* =together, *arthro* =joint), which are immovable joints; **amphiarthroses** (am″fe-ar-thro′sēz; *amphi* =on both sides), slightly movable joints; and **diarthroses** (di″ar-thro′sēz; *dia* =through, apart), or freely movable joints. Freely movable joints predominate in the limbs. Immovable and slightly movable joints are largely restricted to the axial skeleton. This localization of functional joint types is understandable because the less movable the joint, the more stable it is likely to be.

In general, fibrous joints are immovable, and synovial joints are freely movable. However, cartilaginous joints have both rigid and slightly movable examples. Since the structural categories are more clear-cut, we will use the structural classification in this discussion, indicating functional properties where appropriate.

Fibrous Joints

✓ Describe the general structure of fibrous joints. Name and give an example of each of the three common types of fibrous joints.

In **fibrous joints**, the bones are joined by fibrous tissue, namely dense fibrous connective tissue, and no joint cavity is present. The amount of movement allowed depends on the length of the connective tissue fibers uniting the bones. Most fibrous joints are immovable, although a few are slightly movable. The three types of fibrous joints are *sutures*, *syndesmoses*, and *gomphoses*.

Sutures

Sutures, literally "seams," occur only between bones of the skull **(Figure 8.1a)**. The wavy articulating bone edges interlock, and the junction is completely filled by a minimal amount of very short connective tissue fibers that are continuous with the periosteum. The result is nearly rigid splices that knit the bones together, yet allow the skull to expand as the brain grows during youth. During middle age, the fibrous tissue ossifies and the skull bones fuse into a single unit. At this stage, the closed sutures are more precisely called **synostoses** (sin″os-to′sēz), literally, "bony junctions." Because movement of the cranial bones would damage the brain, the immovable nature of sutures is a protective adaptation.

Syndesmoses

In **syndesmoses** (sin″des-mo′sēz), the bones are connected exclusively by *ligaments* (*syndesmos* =ligament), cords or bands of fibrous tissue. Although the connecting fibers are always longer than those in sutures, they vary quite a bit in length.

The amount of movement allowed at a syndesmosis depends on the length of the connecting fibers. If the fibers are short (as in the ligament connecting the distal ends of the tibia and fibula, Figure 8.1b), little or no movement is allowed, a characteristic best described as "give." If the fibers are long (as in the ligament-like interosseous membrane connecting the radius and ulna, Figure 7.28, p. 231), a large amount of movement is possible.

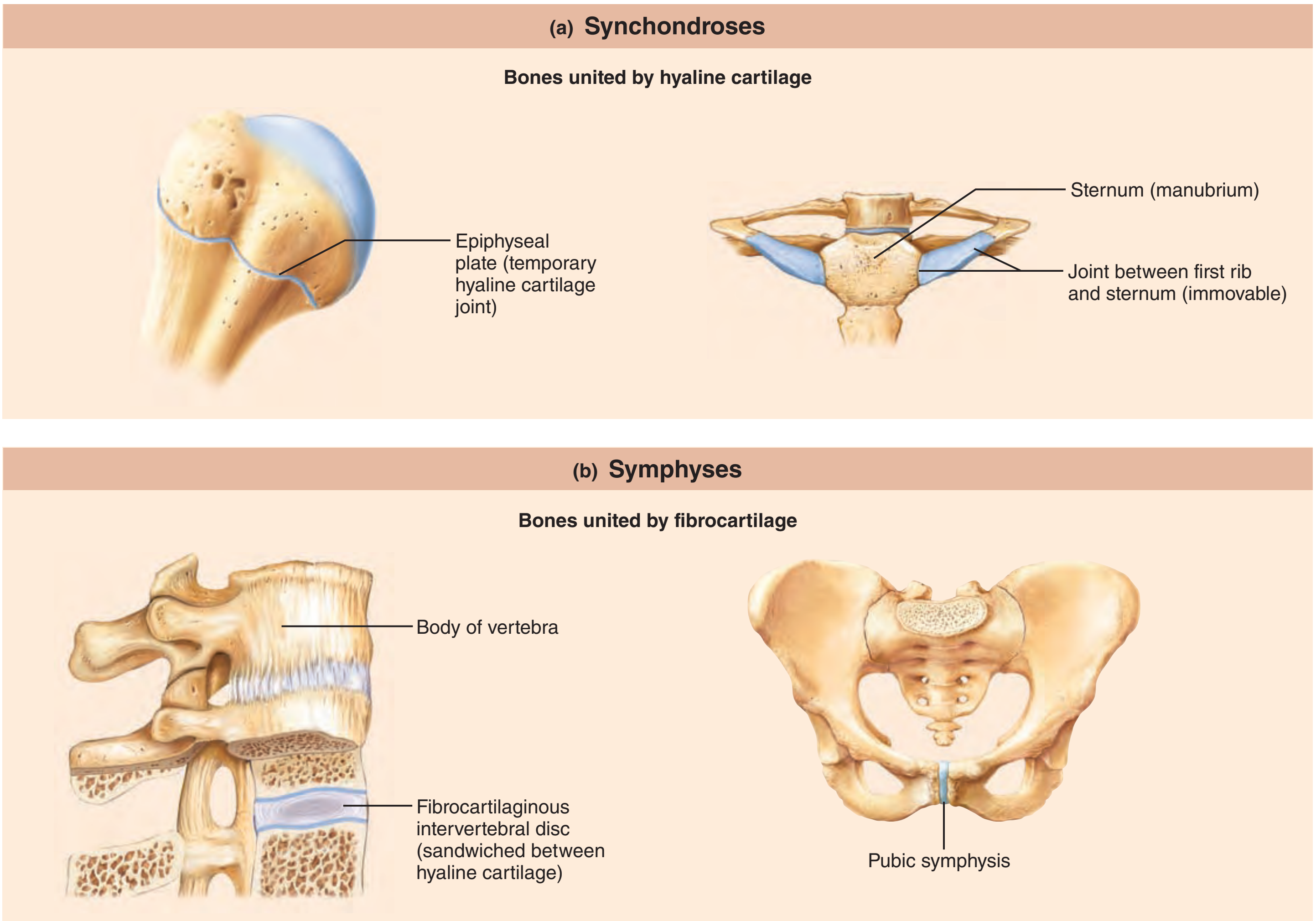


Figure 8.2 **Cartilaginous joints.**

Gomphoses

A **gomphosis** (gom-fo′sis) is a peg-in-socket fibrous joint (Figure 8.1c). The only example is the articulation of a tooth with its bony alveolar socket. The term *gomphosis* comes from the Greek *gompho*, meaning "nail" or "bolt," and refers to the way teeth are embedded in their sockets (as if hammered in). The fibrous connection in this case is the short **periodontal ligament** (Figure 23.11, p. 860).

Cartilaginous Joints

✓ Describe the general structure of cartilaginous joints. Name and give an example of each of the two common types of cartilaginous joints.

In **cartilaginous joints** (kar″tĭ-laj′ĭ-nus), the articulating bones are united by cartilage. Like fibrous joints, they lack a joint cavity and are not highly movable. The two types of cartilaginous joints are *synchondroses* and *symphyses*.

Synchondroses

A bar or plate of *hyaline cartilage* unites the bones at a **synchondrosis** (sin″kon-dro′sis; "junction of cartilage"). Virtually all synchondroses are synarthrotic.

The most common examples of synchondroses are the epiphyseal plates in long bones of children **(Figure 8.2a)**. Epiphyseal plates are temporary joints and eventually become synostoses. Another example of a synchondrosis is the immovable joint between the costal cartilage of the first rib and the manubrium of the sternum (Figure 8.2a).

Symphyses

A joint where *fibrocartilage* unites the bone is a **symphysis** (sim′fih-sis; "growing together"). Since fibrocartilage is compressible and resilient, it acts as a shock absorber and permits a limited amount of movement at the joint. Even though fibrocartilage is the main element of a symphysis, hyaline cartilage is also present in the form of articular cartilages on the bony surfaces. Symphyses are amphiarthrotic joints designed for strength with flexibility.

Examples include the intervertebral joints and the pubic symphysis of the pelvis (Figure 8.2b, and see **Table 8.2** on p. 254).

Check Your Understanding

1. What term is a synonym for "joint"?
2. What functional joint class contains the least-mobile joints?
3. Of sutures, symphyses, and synchondroses, which are cartilaginous joints?
4. How are joint mobility and stability related?

For answers, see Appendix H.

Synovial Joints

✓ Describe the structural characteristics of synovial joints.

✓ Compare the structures and functions of bursae and tendon sheaths.

✓ List three natural factors that stabilize synovial joints.

8

Synovial joints (si-no′ve-al; "joint eggs") are those in which the articulating bones are separated by a fluid-containing joint cavity. This arrangement permits substantial freedom of movement, and all synovial joints are freely movable diarthroses. Nearly all joints of the limbs—indeed, most joints of the body—fall into this class.

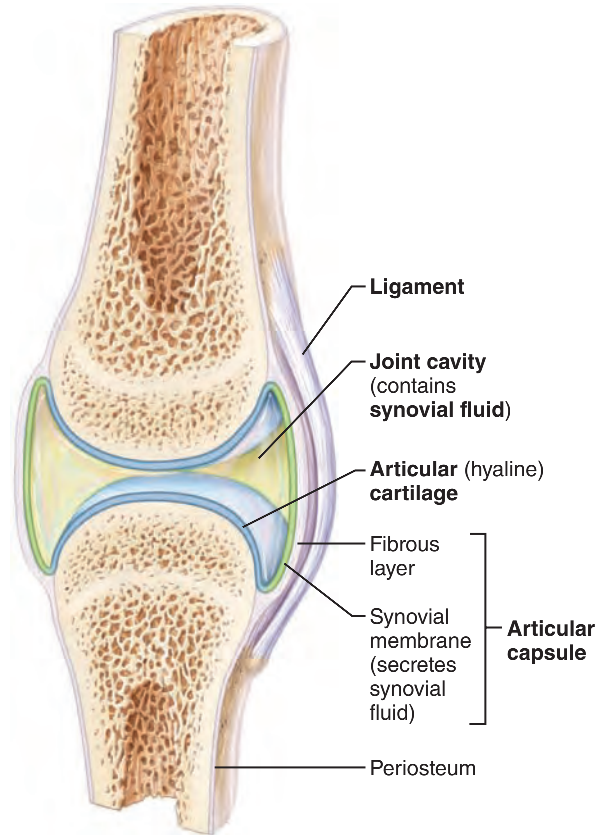


Figure 8.3 General structure of a synovial joint.

General Structure

Synovial joints have six distinguishing features **(Figure 8.3)**:

- **Articular cartilage.** Glassy-smooth hyaline cartilage covers the opposing bone surfaces as **articular cartilage**. These thin (1 mm or less) but spongy cushions absorb compression placed on the joint and thereby keep the bone ends from being crushed.
- **Joint (articular) cavity.** A feature unique to synovial joints, the joint cavity is really just a potential space that contains a small amount of synovial fluid.
- **Articular capsule.** The joint cavity is enclosed by a two-layered **articular capsule**, or *joint capsule*. The tough external **fibrous layer** is composed of dense irregular connective tissue that is continuous with the periostea of the articulating bones. It strengthens the joint so that the bones are not pulled apart. The inner layer of the joint capsule is a **synovial membrane** composed of loose connective tissue. Besides lining the fibrous layer internally, it covers all internal joint surfaces that are not hyaline cartilage. The synovial membrane's function is to make synovial fluid.
- **Synovial fluid.** A small amount of slippery **synovial fluid** occupies all free spaces within the joint capsule. This fluid is derived largely by filtration from blood flowing through the capillaries in the synovial membrane. Synovial fluid has a viscous, egg-white consistency (*ovum* =egg) due to hyaluronic acid secreted by cells in the synovial membrane, but it thins and becomes less viscous during joint activity.

  Synovial fluid, which is also found *within* the articular cartilages, provides a slippery, weight-bearing film that reduces friction between the cartilages. Without this lubricant, rubbing would wear away joint surfaces and excessive friction could overheat and destroy the joint tissues, essentially "cooking" them. The synovial fluid is forced from the cartilages when a joint is compressed; then as pressure on the joint is relieved, synovial fluid seeps back into the articular cartilages like water into a sponge, ready to be squeezed out again the next time the joint is loaded (put under pressure). This process, called *weeping lubrication*, lubricates the free surfaces of the cartilages and nourishes their cells. (Remember, cartilage is avascular.) Synovial fluid also contains phagocytic cells that rid the joint cavity of microbes and cellular debris.
- **Reinforcing ligaments.** Synovial joints are reinforced and strengthened by a number of bandlike **ligaments**. Most often, these are **capsular ligaments**, which are thickened parts of the fibrous layer. In other cases, they remain distinct and are found outside the capsule (as **extracapsular ligaments**) or deep to it (as **intracapsular ligaments**). Since intracapsular ligaments are covered with synovial membrane, they do not actually lie *within* the joint cavity.

  People said to be double-jointed amaze the rest of us by placing both heels behind their neck. However, they have the normal number of joints. It's just that their joint capsules and ligaments are more stretchy and loose than average.
- **Nerves and blood vessels.** Synovial joints are richly supplied with sensory nerve fibers that innervate the capsule. Some of

Table 8.1 Summary of Joint Classes

STRUCTURAL CLASS	STRUCTURAL CHARACTERISTICS	TYPES	MOBILITY
Fibrous	Bone ends/parts united by collagen 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	1. Plane 2. Hinge 3. Pivot 4. Condylar 5. Saddle 6. Ball and socket	Freely movable (diarthrosis; movements depend on design of joint)

these fibers detect pain, as anyone who has suffered joint injury is aware, but most monitor joint position and stretch. Monitoring joint stretch is one of several ways the nervous system senses our posture and body movements (see p. 487). Synovial joints are also richly supplied with blood vessels, most of which supply the synovial membrane. There, extensive capillary beds produce the blood filtrate that is the basis of synovial fluid.

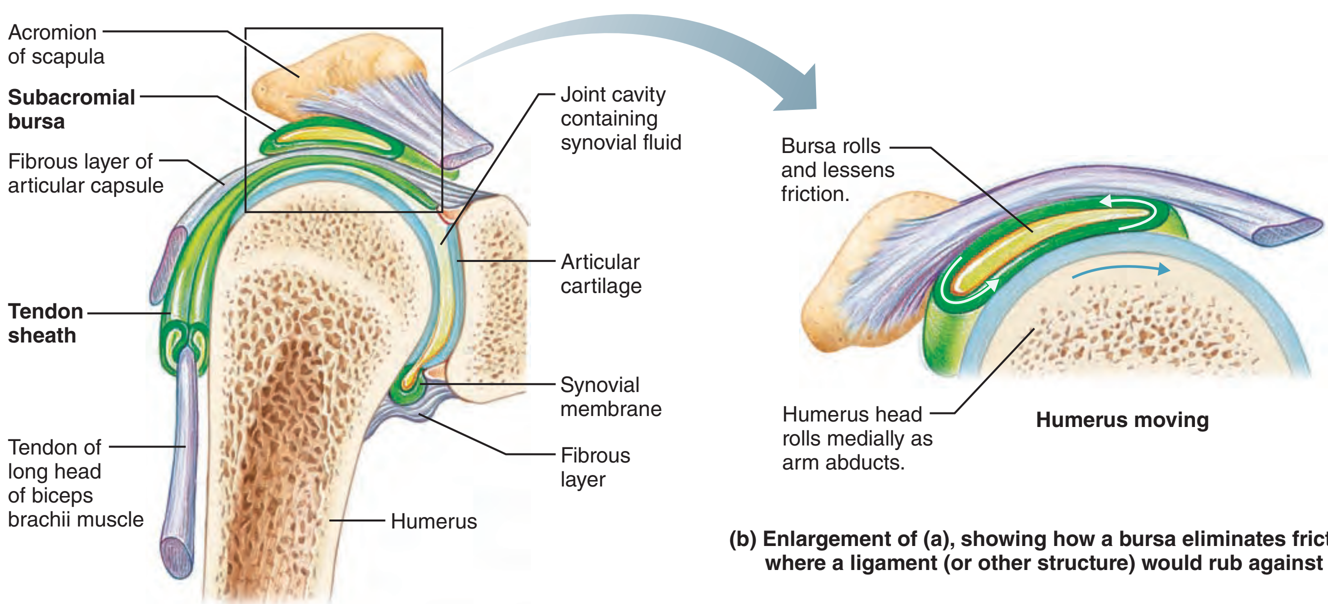
Besides the basic components described above, certain synovial joints have other structural features. Some, such as the hip and knee joints, have cushioning **fatty pads** between the fibrous layer and the synovial membrane or bone. Others have discs or wedges of fibrocartilage separating the articular surfaces. Where present, these **articular discs**, or **menisci** (mĕ-nis′ki; "crescents"), extend inward from the articular capsule and partially or completely divide the synovial cavity in two (see the menisci of the knee in Figure 8.8a, b, e, and f). Articular discs improve the fit between articulating bone ends, making the joint more stable and minimizing wear and tear on the joint surfaces. Besides the knees, articular discs occur in the jaw and a few other joints (see notations in the Structural Type column in Table 8.2).

8

Bursae and Tendon Sheaths

Bursae and tendon sheaths are not strictly part of synovial joints, but they are often found closely associated with them **(Figure 8.4)**. Essentially bags of lubricant, they act as "ball bearings" to reduce friction between adjacent structures during joint activity. **Bursae** (ber′se; "purse") are flattened fibrous sacs lined with synovial membrane and containing a thin film of synovial fluid. They occur where ligaments, muscles, skin, tendons, or bones rub together.

A **tendon sheath** is essentially an elongated bursa that wraps completely around a tendon subjected to friction, like a bun around a hot dog. They are common where several tendons are crowded together within narrow canals (in the wrist region, for example).



(a) Frontal section through the right shoulder joint

(b) Enlargement of (a), showing how a bursa eliminates friction where a ligament (or other structure) would rub against a bone

Figure 8.4 **Bursae and tendon sheaths.**

Table 8.2 Structural and Functional Characteristics of Body Joints

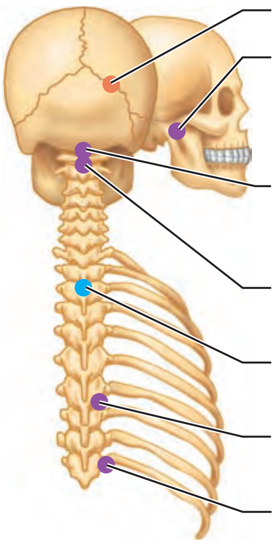
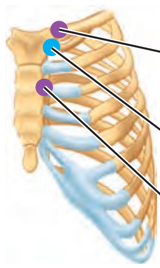
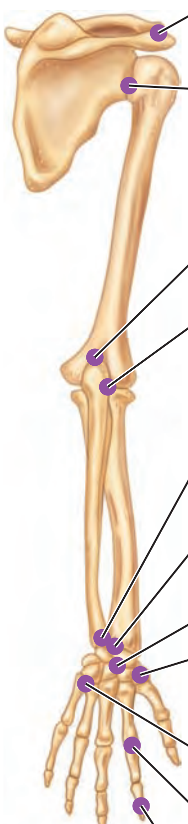
ILLUSTRATION	JOINT	ARTICULATING BONES	STRUCTURAL TYPE*	FUNCTIONAL TYPE; MOVEMENTS ALLOWED
	Skull	Cranial and facial bones	Fibrous; suture	Synarthrotic; no movement
	Temporo-mandibular	Temporal bone of skull and mandible	Synovial; modified hinge† (contains articular disc)	Diarthrotic; gliding and uniaxial rotation; slight lateral movement, elevation, depression, protraction, and retraction of mandible
	Atlanto-occipital	Occipital bone of skull and atlas	Synovial; condylar	Diarthrotic; biaxial; flexion, extension, lateral flexion, circumduction of head on neck
	Atlantoaxial	Atlas (C_1) and axis (C_2)	Synovial; pivot	Diarthrotic; uniaxial; rotation of the head
	Intervertebral	Between adjacent vertebral bodies	Cartilaginous; symphysis	Amphiarthrotic; slight movement
	Intervertebral	Between articular processes	Synovial; plane	Diarthrotic; gliding
	Costovertebral	Vertebrae (transverse processes or bodies) and ribs	Synovial; plane	Diarthrotic; gliding of ribs
	Sternoclavicular	Sternum and clavicle	Synovial; shallow saddle (contains articular disc)	Diarthrotic; multiaxial (allows clavicle to move in all axes)
	Sternocostal (first)	Sternum and rib 1	Cartilaginous; synchondrosis	Synarthrotic; no movement
	Sternocostal	Sternum and ribs 2–7	Synovial; double plane	Diarthrotic; gliding
	Acromio-clavicular	Acromion of scapula and clavicle	Synovial; plane (contains articular disc)	Diarthrotic; gliding and rotation of scapula on clavicle
	Shoulder (glenohumeral)	Scapula and humerus	Synovial; ball-and-socket	Diarthrotic; multiaxial; flexion, extension, abduction, adduction, circumduction, rotation of humerus
	Elbow	Ulna (and radius) with humerus	Synovial; hinge	Diarthrotic; uniaxial; flexion, extension of forearm
	Proximal radioulnar	Radius and ulna	Synovial; pivot	Diarthrotic; uniaxial; pivot (convex head of radius rotates in radial notch of ulna)
	Distal radioulnar	Radius and ulna	Synovial; pivot (contains articular disc)	Diarthrotic; uniaxial; rotation of radius around long axis of forearm to allow pronation and supination
	Wrist	Radius and proximal carpals	Synovial; condylar	Diarthrotic; biaxial; flexion, extension, abduction, adduction, circumduction of hand
	Intercarpal	Adjacent carpals	Synovial; plane	Diarthrotic; gliding
	Carpometacarpal of digit 1 (thumb)	Carpal (trapezium) and metacarpal 1	Synovial; saddle	Diarthrotic; biaxial; flexion, extension, abduction, adduction, circumduction, opposition of metacarpal I
	Carpometacarpal of digits 2–5	Carpal(s) and metacarpal(s)	Synovial; plane	Diarthrotic; gliding of metacarpals
	Metacarpo-phalangeal (knuckle)	Metacarpal and proximal phalanx	Synovial; condylar	Diarthrotic; biaxial; flexion, extension, abduction, adduction, circumduction of fingers
	Interphalangeal (finger)	Adjacent phalanges	Synovial; hinge	Diarthrotic; uniaxial; flexion, extension of fingers

Table 8.2 *(continued)*

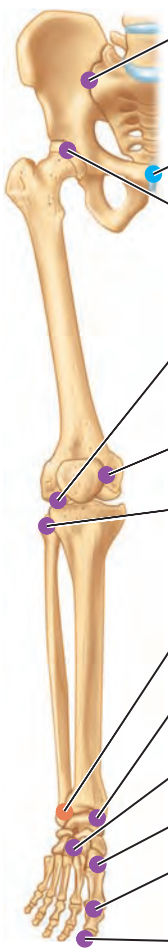


ILLUSTRATION	JOINT	ARTICULATING BONES	STRUCTURAL TYPE*	FUNCTIONAL TYPE; MOVEMENTS ALLOWED
	Sacroiliac	Sacrum and coxal bone	Synovial; plane in childhood, increasingly fibrous in adult	Diarthrotic in child; amphiarthrotic in adult; (more movement during pregnancy)
	Pubic symphysis	Pubic bones	Cartilaginous; symphysis	Amphiarthrotic; slight movement (enhanced during pregnancy)
	Hip (coxal)	Hip bone and femur	Synovial; ball-and-socket	Diarthrotic; multiaxial; flexion, extension, abduction, adduction, rotation, circumduction of thigh
	Knee (tibiofemoral)	Femur and tibia	Synovial; modified hinge† (contains articular discs)	Diarthrotic; biaxial; flexion, extension of leg, some rotation allowed in flexed position
	Knee (femoropatellar)	Femur and patella	Synovial; plane	Diarthrotic; gliding of patella
	Superior tibiofibular	Tibia and fibula (proximally)	Synovial; plane	Diarthrotic; gliding of fibula
	Inferior tibiofibular	Tibia and fibula (distally)	Fibrous; syndesmosis	Synarthrotic; slight "give" during dorsiflexion
	Ankle	Tibia and fibula with talus	Synovial; hinge	Diarthrotic; uniaxial; dorsiflexion, and plantar flexion of foot
	Intertarsal	Adjacent tarsals	Synovial; plane	Diarthrotic; gliding; inversion and eversion of foot
	Tarsometatarsal	Tarsal(s) and metatarsal(s)	Synovial; plane	Diarthrotic; gliding of metatarsals
	Metatarso-phalangeal	Metatarsal and proximal phalanx	Synovial; condylar	Diarthrotic; biaxial; flexion, extension, abduction, adduction, circumduction of great toe
	Interpha-langeal (toe)	Adjacent phalanges	Synovial; hinge	Diarthrotic; uniaxial; flexion; extension of toes

***Fibrous joints** indicated by orange circles; **cartilaginous joints** by blue circles; **synovial joints** by purple circles.
† These modified hinge joints are structurally bicondylar.

Factors Influencing the Stability of Synovial Joints

Because joints are constantly stretched and compressed, they must be stabilized so that they do not dislocate (come out of alignment). The stability of a synovial joint depends chiefly on three factors: the shapes of the articular surfaces; the number and positioning of ligaments; and muscle tone.

Articular Surfaces

The shapes of articular surfaces determine what movements are possible at a joint, but surprisingly, articular surfaces play only a minor role in joint stability. Many joints have shallow sockets or noncomplementary articulating surfaces ("misfits") that actually hinder joint stability. But when articular surfaces are large and fit snugly together, or when the socket is deep, stability is vastly improved. The ball and deep socket of the hip joint provide the best example of a joint made extremely stable by the shape of its articular surfaces.

Ligaments

The capsules and ligaments of synovial joints unite the bones and prevent excessive or undesirable motion. As a rule, the more ligaments a joint has, the stronger it is. However, when other stabilizing factors are inadequate, undue tension is placed on the ligaments and they stretch. Stretched ligaments stay stretched, like taffy, and a ligament can stretch only about 6% of its length before it snaps. Thus, when ligaments are the major means of bracing a joint, the joint is not very stable.

Muscle Tone

For most joints, the muscle tendons that cross the joint are the most important stabilizing factor. These tendons are kept taut at all times by the tone of their muscles. (*Muscle tone* is defined as low levels of contractile activity in relaxed muscles that keep the muscles healthy and ready to react to stimulation.) Muscle tone is extremely important in reinforcing the shoulder and knee joints and the arches of the foot.

☑ Check Your Understanding

5. What are the two layers of the articular capsule?
6. How do bursae and tendon sheaths improve joint function?
7. Generally speaking, what factor is most important in stabilizing synovial joints?
8. What is the importance of weeping lubrication?

For answers, see Appendix H.

Movements Allowed by Synovial Joints

✓ Name and describe (or perform) the common body movements.

✓ Name and provide examples of the six types of synovial joints based on the movement(s) allowed.

Every skeletal muscle of the body is attached to bone or other connective tissue structures at no fewer than two points. The muscle's **origin** is attached to the immovable (or less movable) bone. Its other end, the **insertion**, is attached to the movable bone. Body movement occurs when muscles contract across joints and their insertion moves toward their origin. The movements can be described in directional terms relative to the lines, or axes, around which the body part moves and the planes of space along which the movement occurs, that is, along the transverse, frontal, or sagittal plane. (See Chapter 1 to review these planes.)

Range of motion allowed by synovial joints varies from **nonaxial movement** (slipping movements only, since there is no axis around which movement can occur) to **uniaxial movement** (movement in one plane) to **biaxial movement** (movement in two planes) to **multiaxial movement** (movement in or around all three planes of space and axes). Range of motion varies greatly in different people. In some, such as trained gymnasts or acrobats, range of joint movement may be extraordinary. The ranges of motion at the major joints are given in the far right column of Table 8.2.

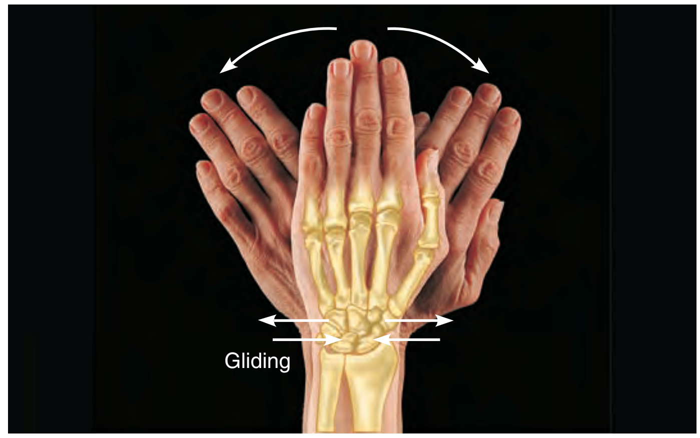
There are three general types of movements: *gliding*, *angular movements*, and *rotation*. The most common body movements allowed by synovial joints are described next and illustrated in **Figure 8.5**.

Gliding Movements

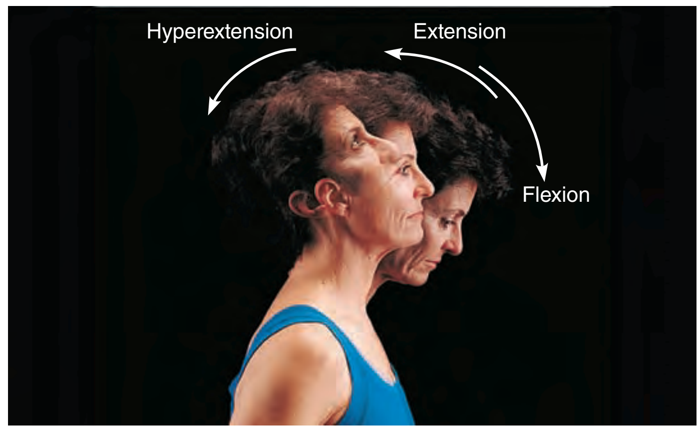
Gliding occurs when one flat, or nearly flat, bone surface glides or slips over another (back-and-forth and side-to-side; Figure 8.5a) without appreciable angulation or rotation. Gliding occurs at the intercarpal and intertarsal joints, and between the flat articular processes of the vertebrae (Table 8.2).

Angular Movements

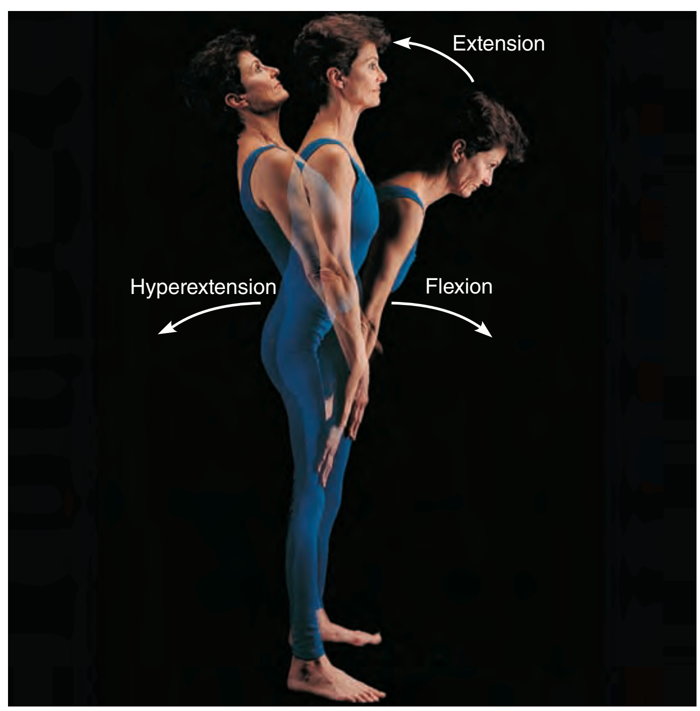
Angular movements (Figure 8.5b–e) increase or decrease the angle between two bones. These movements may occur in any plane of the body and include flexion, extension, hyperextension, abduction, adduction, and circumduction.



(a) Gliding movements at the wrist

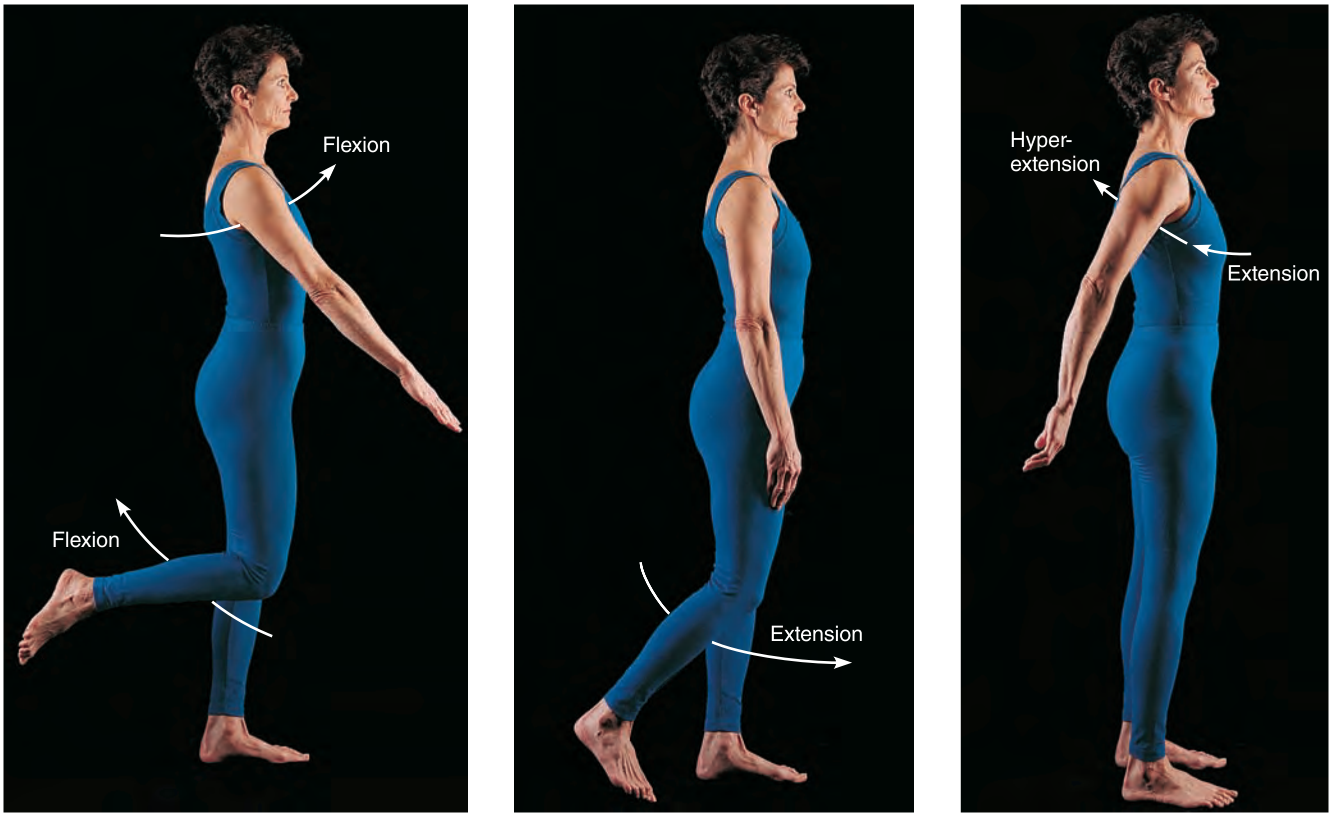


(b) Angular movements: flexion, extension, and hyperextension of the neck



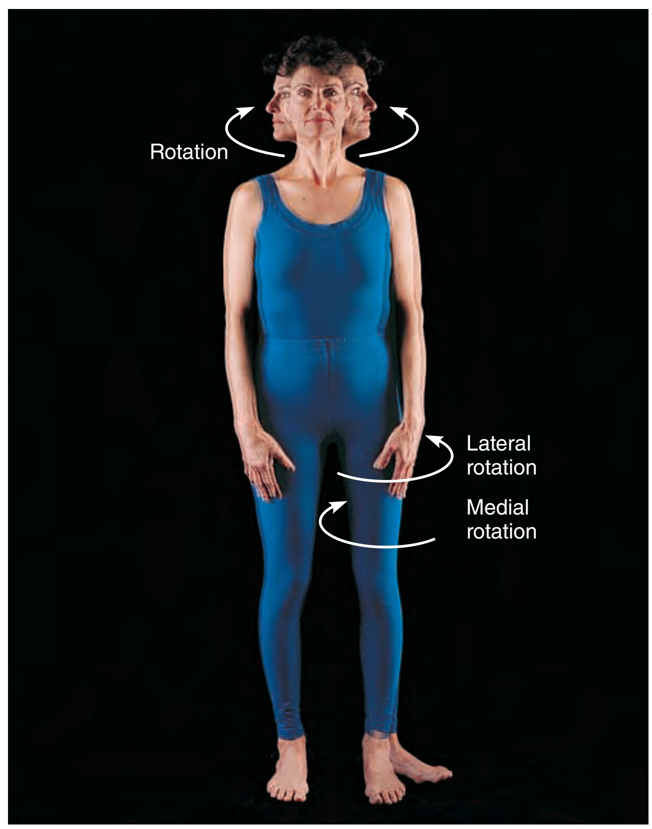
(c) Angular movements: flexion, extension, and hyperextension of the vertebral column

Figure 8.5 **Movements allowed by synovial joints.**



(d) Angular movements: flexion, extension, and hyperextension at the shoulder and knee

(e) Angular movements: abduction, adduction, and circumduction of the upper limb at the shoulder



(f) Rotation of the head, neck, and lower limb

Figure 8.5 *(continued)*

Flexion **Flexion** (flek′shun) is a bending movement, usually along the sagittal plane, that *decreases the angle* of the joint and brings the articulating bones closer together. Examples include bending the head forward on the chest (Figure 8.5b) and bending the body trunk or the knee from a straight to an angled position (Figure 8.5c and d). As a less obvious example, the arm is flexed at the shoulder when the arm is lifted in an anterior direction (Figure 8.5d).

Extension **Extension** is the reverse of flexion and occurs at the same joints. It involves movement along the sagittal plane that *increases the angle* between the articulating bones and typically straightens a flexed limb or body part. Examples include straightening a flexed neck, body trunk, elbow, or knee (Figure 8.5b–d). Continuing such movements beyond the anatomical position is called **hyperextension** (literally, "superextension") (Figure 8.5b–d).

8

Abduction **Abduction** ("moving away") is movement of a limb *away* from the midline or median plane of the body, along the frontal plane. Raising the arm or thigh laterally is an example of abduction (Figure 8.5e). For the fingers or toes, abduction means spreading them apart. In this case "midline" is the longest digit: the third finger or second toe. Notice, however, that lateral bending of the trunk away from the body midline in the frontal plane is called lateral flexion, not abduction.

Adduction **Adduction** ("moving toward") is the opposite of abduction, so it is the movement of a limb *toward* the body midline or, in the case of the digits, toward the midline of the hand or foot (Figure 8.5e).

Circumduction **Circumduction** (Figure 8.5e) is moving a limb so that it describes a cone in space (*circum* = around; *duco* = to draw). The distal end of the limb moves in a circle, while the point of the cone (the shoulder or hip joint) is more or less stationary. A pitcher winding up to throw a ball is actually circumducting his or her pitching arm. Because circumduction consists of flexion, abduction, extension, and adduction performed in succession, it is the quickest way to exercise the many muscles that move the hip and shoulder ball-and-socket joints.

Rotation

Rotation is the turning of a bone around its own long axis. It is the only movement allowed between the first two cervical vertebrae and is common at the hip (Figure 8.5f) and shoulder joints. Rotation may be directed toward the midline or away from it. For example, in *medial rotation* of the thigh, the femur's anterior surface moves toward the median plane of the body; *lateral rotation* is the opposite movement.

Special Movements

Certain movements do not fit into any of the above categories and occur at only a few joints. Some of these special movements are illustrated in **Figure 8.6**.

Supination and Pronation The terms **supination** (soo″pĭ-na′shun; "turning backward") and **pronation** (pro-na′shun; "turning forward") refer to the movements of the radius around the ulna (Figure 8.6a). Rotating the forearm laterally so that the palm faces anteriorly or superiorly is supination. In the anatomical position, the hand is supinated and the radius and ulna are parallel.

In pronation, the forearm rotates medially and the palm faces posteriorly or inferiorly. Pronation moves the distal end of the radius across the ulna so that the two bones form an X. This is the forearm's position when we are standing in a relaxed manner. Pronation is a much weaker movement than supination.

A trick to help you keep these terms straight: A *pro* basketball player pronates his or her forearm to dribble the ball.

Dorsiflexion and Plantar Flexion of the Foot The up-and-down movements of the foot at the ankle are given more specific names (Figure 8.6b). Lifting the foot so that its superior surface approaches the shin is **dorsiflexion** (corresponds to wrist extension), whereas depressing the foot (pointing the toes) is **plantar flexion** (corresponds to wrist flexion).

Inversion and Eversion **Inversion** and **eversion** are special movements of the foot (Figure 8.6c). In inversion, the sole of the foot turns medially. In eversion, the sole faces laterally.

Protraction and Retraction Nonangular anterior and posterior movements in a transverse plane are called **protraction** and **retraction**, respectively (Figure 8.6d). The mandible is protracted when you jut out your jaw and retracted when you bring it back.

Elevation and Depression **Elevation** means lifting a body part superiorly (Figure 8.6e). For example, the scapulae are elevated when you shrug your shoulders. Moving the elevated part inferiorly is **depression**. During chewing, the mandible is alternately elevated and depressed.

Opposition The saddle joint between metacarpal I and the trapezium allows a movement called **opposition** of the thumb (Figure 8.6f). This movement is the action taken when you touch your thumb to the tips of the other fingers on the same hand. It is opposition that makes the human hand such a fine tool for grasping and manipulating objects.

Types of Synovial Joints

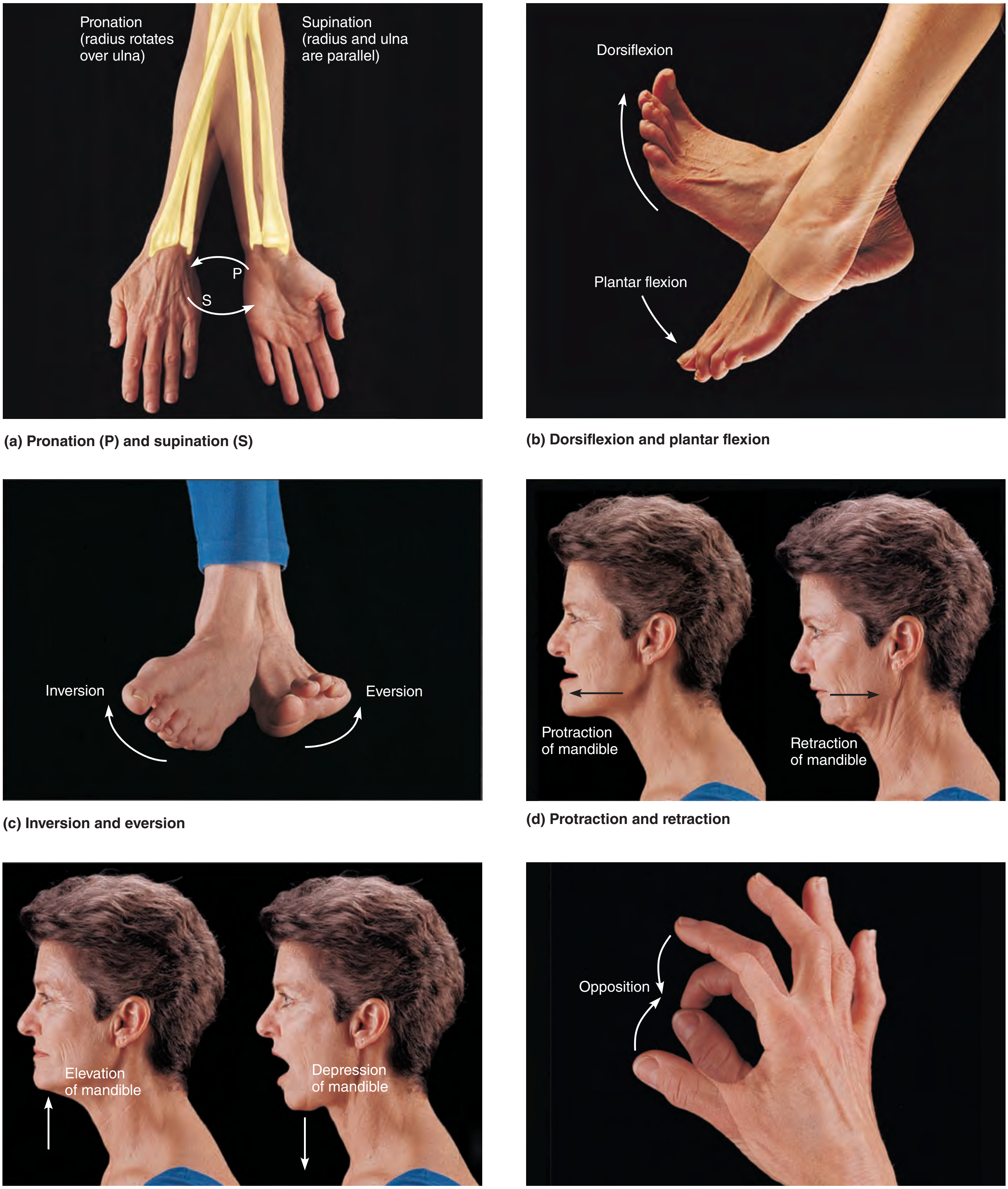
Although all synovial joints have structural features in common, they do not have a common structural plan. Based on the shape of their articular surfaces, which in turn determine the movements allowed, synovial joints can be classified further into six major categories—plane, hinge, pivot, condylar (or ellipsoid), saddle, and ball-and-socket joints. The properties of these joints are summarized in *Focus on Types of Synovial Joints* **(Figure 8.7)** on pp. 260–261.

☑ Check Your Understanding

9. John bent over to pick up a dime. What movement was occurring at his hip joint, at his knees, and between his index finger and thumb?
10. On the basis of movement allowed, which of the following joints are uniaxial? Hinge, condylar, saddle, pivot.

For answers, see Appendix H.

(Text continues on p. 262.)



(a) Pronation (P) and supination (S)

(b) Dorsiflexion and plantar flexion

(c) Inversion and eversion

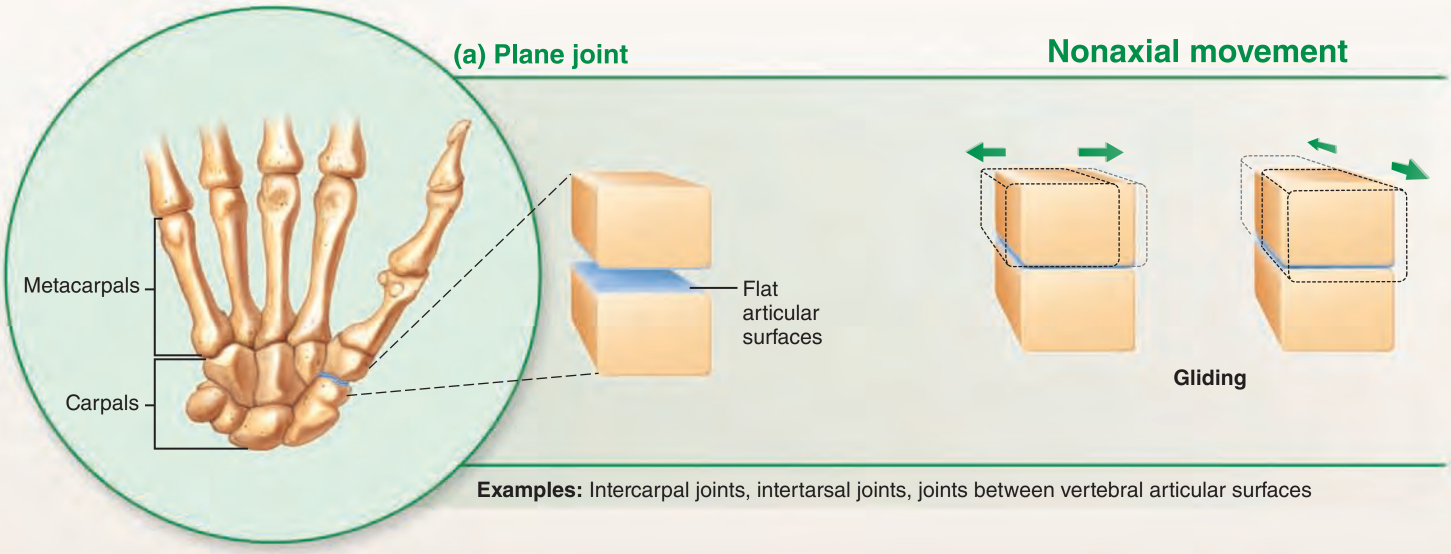
(d) Protraction and retraction

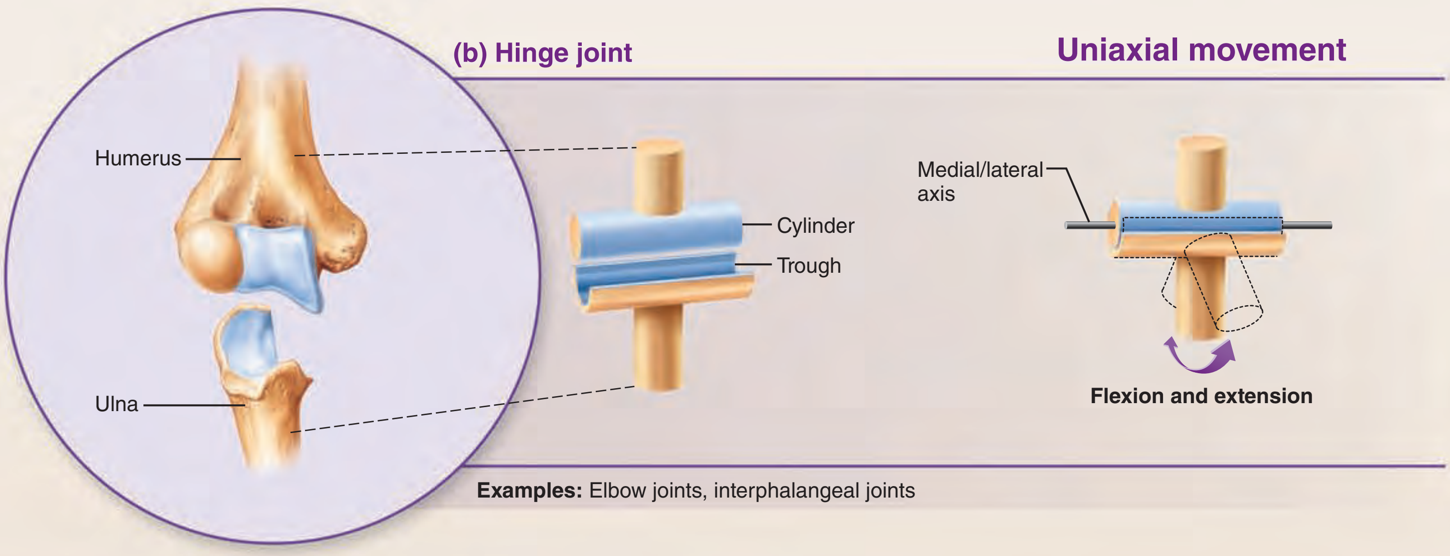
(e) Elevation and depression

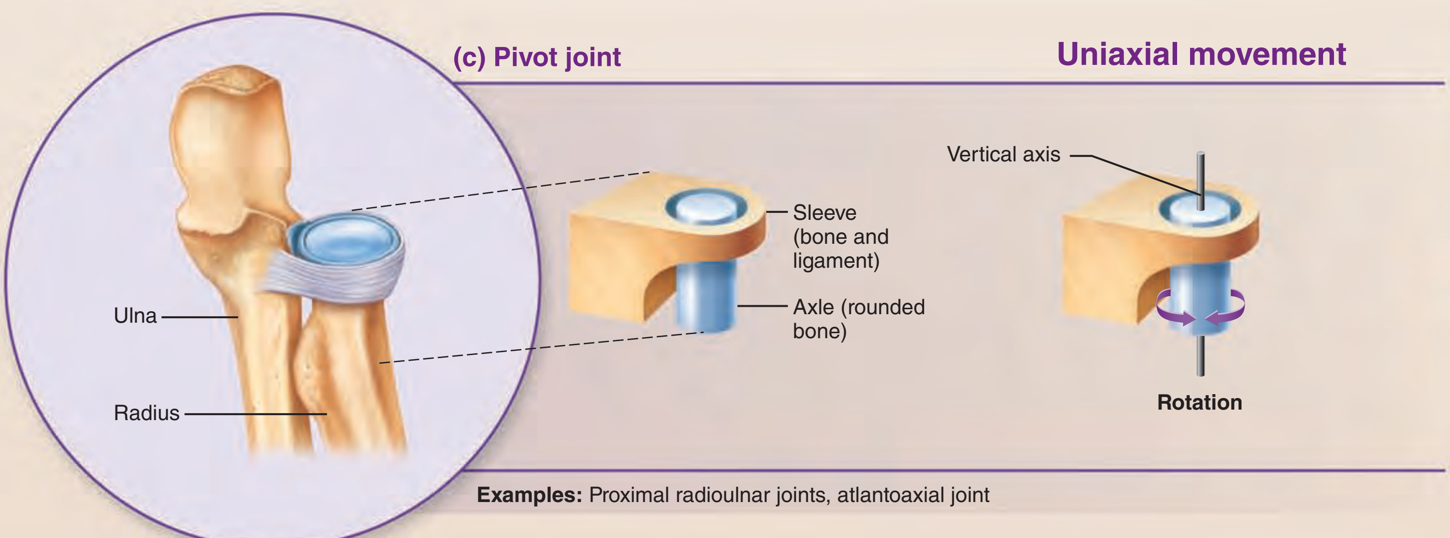
(f) Opposition

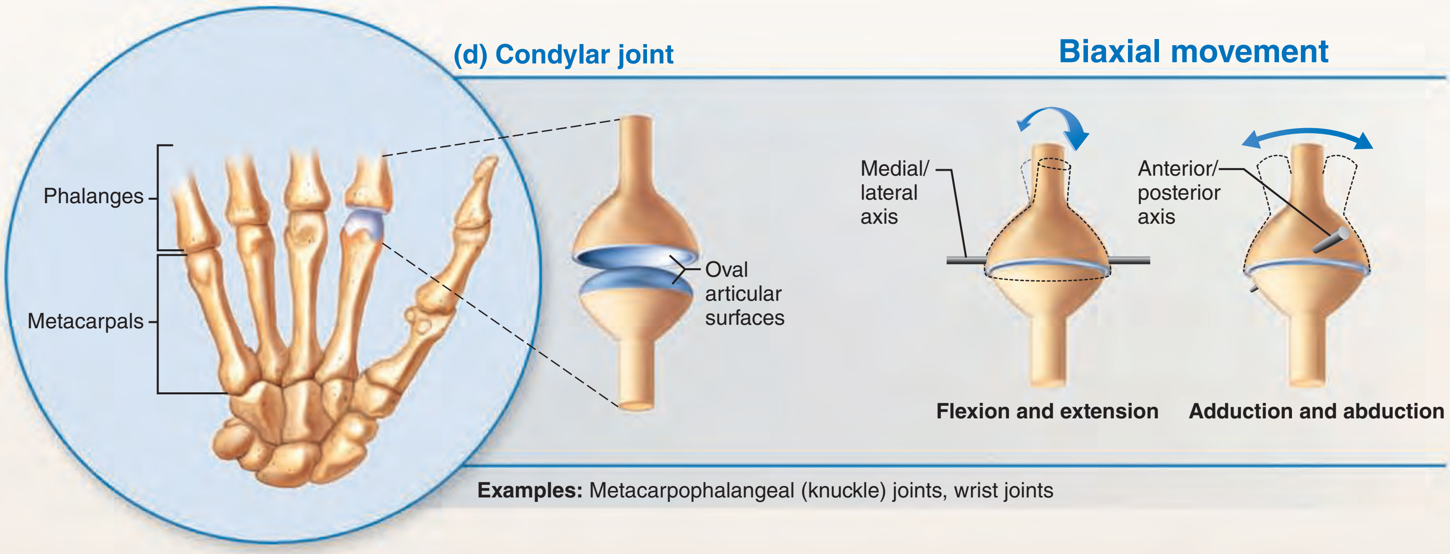
Figure 8.6 Special body movements.

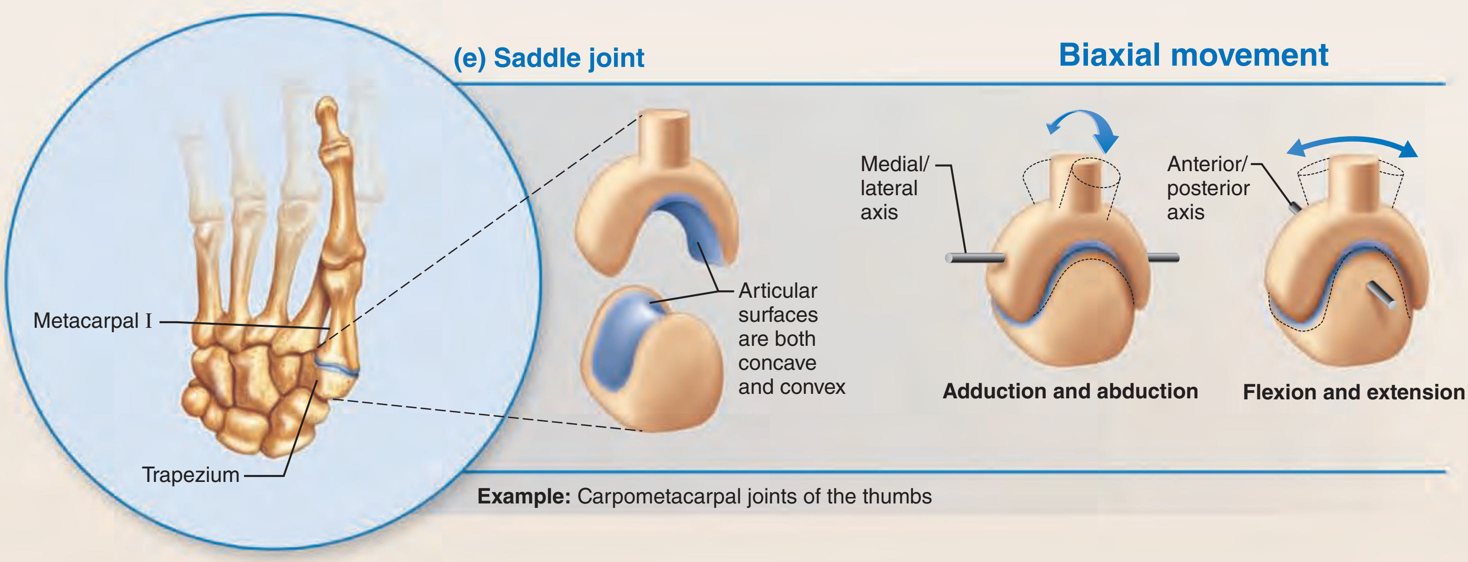
Figure 8.7 The shapes of the joint surfaces define the types of movements that can occur at a synovial joint; they also determine the classification of synovial joints into six structural types.

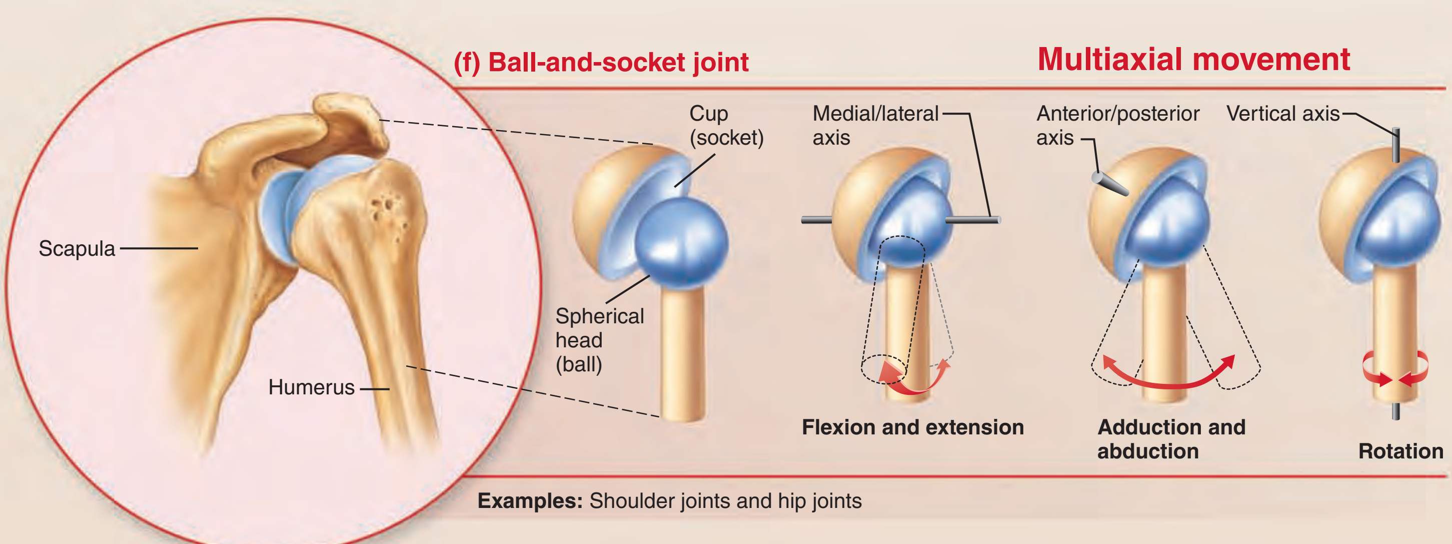







(d) Condylar joint
Biaxial movement
Phalanges
Metacarpals
Oval articular surfaces
Medial/ lateral axis
Anterior/ posterior axis
Flexion and extension
Adduction and abduction
Examples: Metacarpophalangeal (knuckle) joints, wrist joints


(e) Saddle joint
Biaxial movement
Metacarpal I
Trapezium
Articular surfaces are both concave and convex
Medial/ lateral axis
Anterior/ posterior axis
Adduction and abduction
Flexion and extension
Example: Carpometacarpal joints of the thumbs


(f) Ball-and-socket joint
Multiaxial movement
Scapula
Humerus
Cup (socket)
Spherical head (ball)
Medial/lateral axis
Anterior/posterior axis
Vertical axis
Flexion and extension
Adduction and abduction
Rotation
Examples: Shoulder joints and hip joints

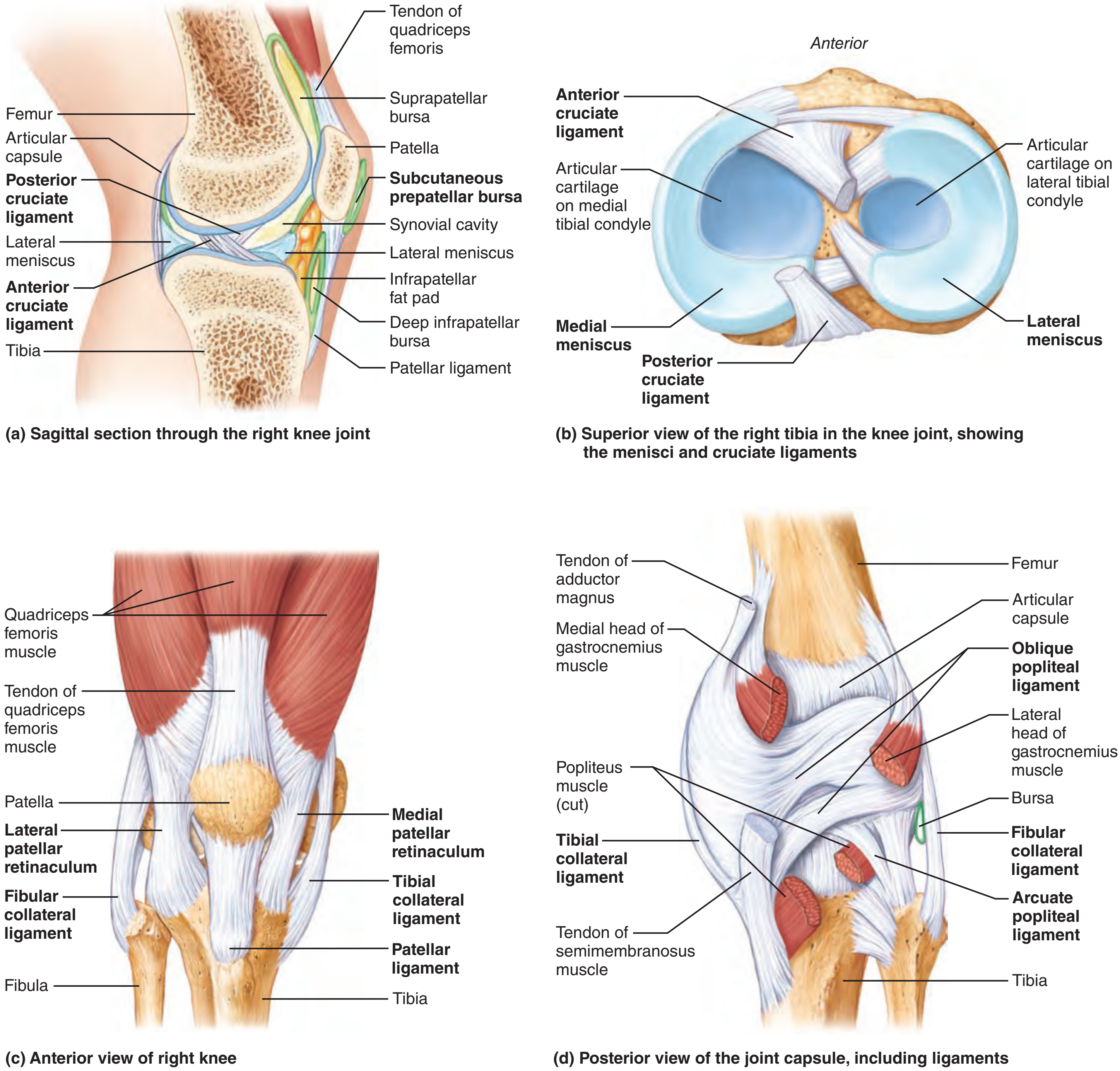


Figure 8.8 **The knee joint.**

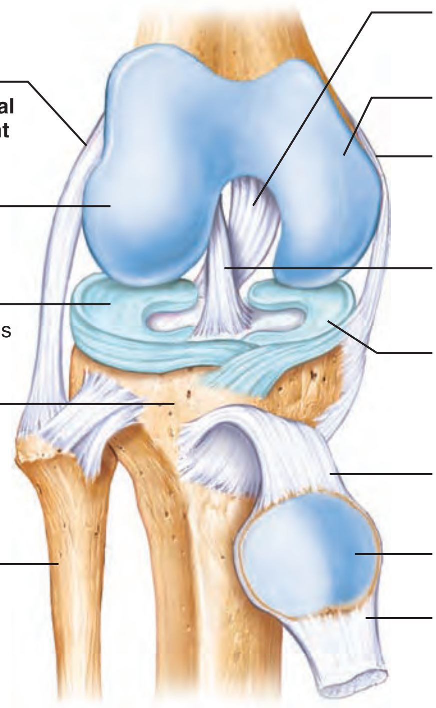
Selected Synovial Joints

✓ Describe the elbow, knee, hip, jaw, and shoulder joints in terms of articulating bones, anatomical characteristics of the joint, movements allowed, and joint stability.

In this section, we examine five joints in detail: knee, elbow, shoulder, hip, and temporomandibular (jaw) joint. All have the six distinguishing characteristics of synovial joints, and we will not discuss these common features again. Instead, we will emphasize the unique structural features, functional abilities, and, in certain cases, functional weaknesses of each of these joints.

Knee Joint

The knee joint is the largest and most complex joint in the body **(Figure 8.8)**. Despite its single joint cavity, the knee consists of three joints in one: an intermediate one between the patella and the lower end of the femur (the **femoropatellar joint**), and lateral and medial joints (collectively known as the **tibiofemoral joint**) between the femoral condyles above and the C-shaped **menisci**, or *semilunar cartilages*, of the tibia below (Figure 8.8b and e). Besides deepening the shallow tibial articular surfaces, the menisci help prevent side-to-side rocking of the femur on the tibia and absorb shock transmitted to the knee joint. However, the menisci are



(e) Anterior view of flexed knee, showing the cruciate ligaments (articular capsule removed, and quadriceps tendon cut and reflected distally)

(f) Photograph of an opened knee joint; view similar to (e)

Figure 8.8 *(continued)*

8

attached only at their outer margins and are frequently torn free.

The tibiofemoral joint acts primarily as a hinge, permitting flexion and extension. However, structurally it is a bicondylar joint. Some rotation is possible when the knee is partly flexed, and when the knee is extending. But, when the knee is fully extended, side-to-side movements and rotation are strongly resisted by ligaments and the menisci. The femoropatellar joint is a plane joint, and the patella glides across the distal end of the femur during knee flexion.

The knee joint is unique in that its joint cavity is only partially enclosed by a capsule. The relatively thin articular capsule is present only on the sides and posterior aspects of the knee, where it covers the bulk of the femoral and tibial condyles. Anteriorly, where the capsule is absent, three broad ligaments run from the patella to the tibia below. These are the **patellar ligament** flanked by the **medial** and **lateral patellar retinacula** (ret″ĭ-nak′u-lah; "retainers"), which merge imperceptibly into the articular capsule on each side (Figure 8.8c). The patellar ligament and retinacula are actually continuations of the tendon of the bulky quadriceps muscle of the anterior thigh. Physicians tap the patellar ligament to test the knee-jerk reflex.

The synovial cavity of the knee joint has a complicated shape, with several extensions that lead into "blind alleys." At least a dozen bursae are associated with this joint, some of which are shown in Figure 8.8a. For example, notice the *subcutaneous prepatellar bursa*, which is often injured when the knee is bumped anteriorly.

All three types of joint ligaments stabilize and strengthen the capsule of the knee joint. The ligaments of two of the types, capsular and extracapsular, all act to prevent hyperextension of the knee and are stretched taut when the knee is extended. These include the following:

- The extracapsular **fibular** and **tibial collateral ligaments** are also critical in preventing lateral or medial rotation when the knee is extended. The broad, flat tibial collateral ligament runs from the medial epicondyle of the femur to the medial condyle of the tibial shaft below and is fused to the medial meniscus (Figure 8.8c–e).
- The **oblique popliteal ligament** (pop″lĭ-te′al) is actually part of the tendon of the semimembranosus muscle that fuses with the joint capsule and helps stabilize the posterior aspect of the knee joint (Figure 8.8d).
- The **arcuate popliteal ligament** arcs superiorly from the head of the fibula over the popliteus muscle and reinforces the joint capsule posteriorly (Figure 8.8d).

The knee's *intracapsular ligaments* are called *cruciate ligaments* (kroo′she-āt) because they cross each other, forming an X (*cruci* = cross) in the notch between the femoral condyles. They act as restraining straps to help prevent anterior-posterior displacement of the articular surfaces and to secure the articulating bones when we stand (Figure 8.8a, b, e). Although these ligaments are in the joint capsule, they are *outside* the synovial cavity, and synovial membrane nearly covers their surfaces. Note that the two cruciate ligaments both run superiorly to the femur and are named for their *tibial* attachment site.

The **anterior cruciate ligament** attaches to the *anterior* intercondylar area of the tibia (Figure 8.8b). From there it passes posteriorly, laterally, and upward to attach to the femur on the medial side of its lateral condyle. This ligament prevents forward sliding of the tibia on the femur and checks hyperextension of the knee. It

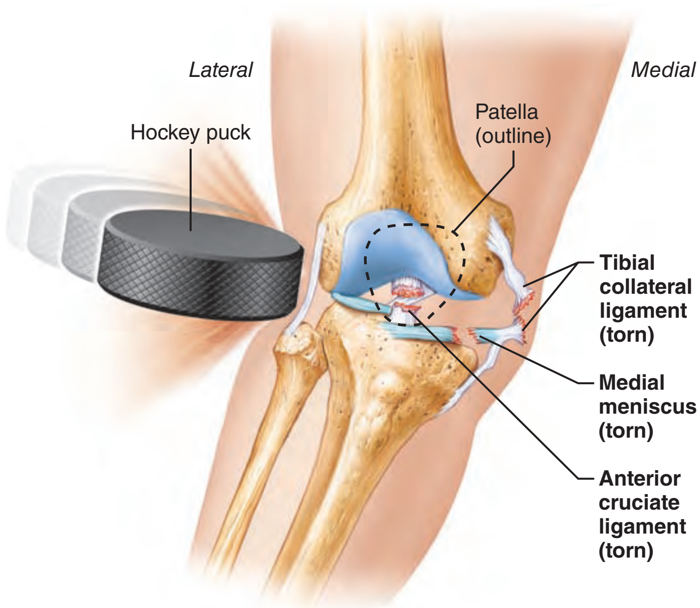


Figure 8.9 A common knee injury. Anterior view of a knee being hit by a hockey puck. Such blows to the lateral side tear both the tibial collateral ligament and the medial meniscus because the two are attached. The anterior cruciate ligament also tears.

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is somewhat lax when the knee is flexed, and taut when the knee is extended.

The stronger **posterior cruciate ligament** is attached to the *posterior* intercondylar area of the tibia and passes anteriorly, medially, and superiorly to attach to the femur on the lateral side of the medial condyle (Figure 8.8a, b). This ligament prevents backward displacement of the tibia or forward sliding of the femur.

The knee capsule is heavily reinforced by muscle tendons. Most important are the strong tendons of the quadriceps muscles of the anterior thigh and the tendon of the semimembranosus muscle posteriorly (Figure 8.8c and d). The greater the strength and tone of these muscles, the less the chance of knee injury.

The knees have a built-in locking device that provides steady support for the body in the standing position. As we begin to stand up, the wheel-shaped femoral condyles roll like ball bearings across the tibial condyles and the flexed leg begins to extend at the knee. Because the lateral femoral condyle stops rolling before the medial condyle stops, the femur *spins* (rotates) medially on the tibia, until the cruciate and collateral ligaments of the knee are twisted and taut and the menisci are compressed. The tension in the ligaments effectively locks the joint into a rigid structure that cannot be flexed again until it is unlocked. This unlocking is accomplished by the popliteus muscle (see Figure 8.8d and Table 10.15, p. 370). It rotates the femur laterally on the tibia, causing the ligaments to become untwisted and slack.

Homeostatic Imbalance 8.1

Of all body joints, the knees are most susceptible to sports injuries because of their high reliance on nonarticular factors for stability and the fact that they carry the body's weight. The knee can absorb a vertical force equal to nearly seven times body weight. However, it is very vulnerable to *horizontal* blows, such as those that occur during blocking and tackling in football and in ice hockey.

When thinking of common knee injuries, remember the 3 Cs: collateral ligaments, cruciate ligaments, and cartilages (menisci). Most dangerous are *lateral blows* to the extended knee. These forces tear the tibial collateral ligament and the medial meniscus attached to it, as well as the anterior cruciate ligament **(Figure 8.9)**. It is estimated that 50% of all professional football players have serious knee injuries during their careers.

Although less devastating than the injury just described, injuries that affect only the anterior cruciate ligament (ACL) are becoming more common, particularly as women's sports become more vigorous and competitive. Most ACL injuries occur when a runner changes direction quickly, twisting a hyperextended knee. A torn ACL heals poorly, so repair usually requires a graft taken from either the patellar ligament, the hamstring tendon, or the calcaneal tendon. ✚

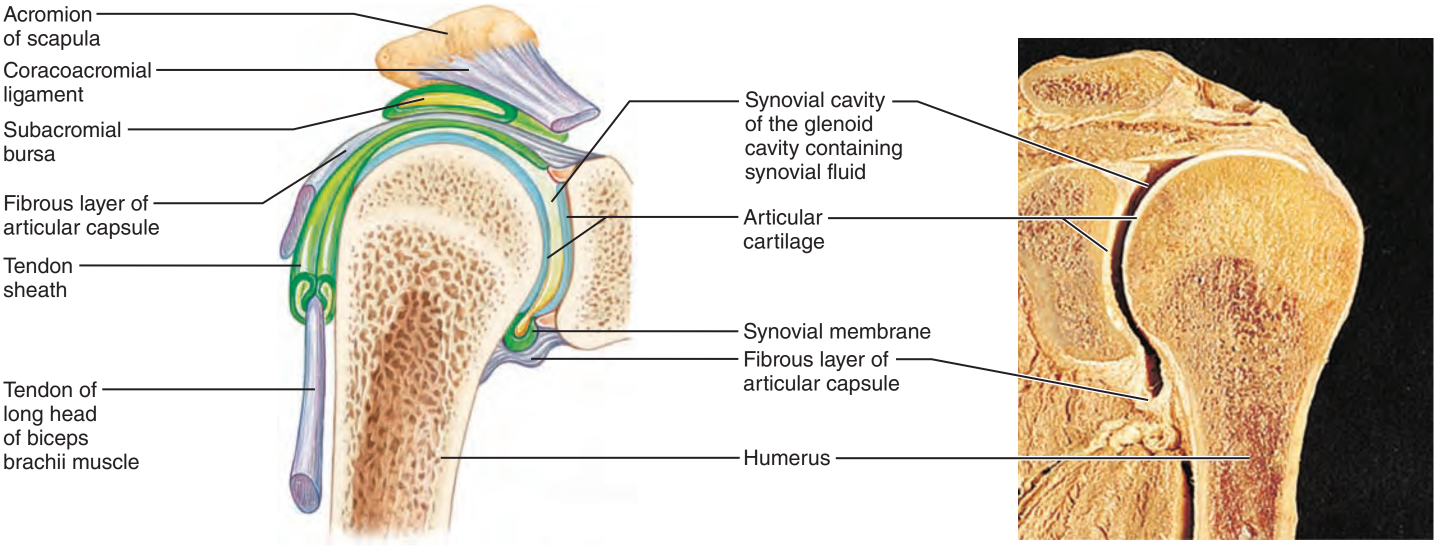
Shoulder (Glenohumeral) Joint

In the shoulder joint, stability has been sacrificed to provide the most freely moving joint of the body. The shoulder joint is a ball-and-socket joint. The large hemispherical head of the humerus fits in the small, shallow glenoid cavity of the scapula **(Figure 8.10)**, like a golf ball sitting on a tee. Although the glenoid cavity is slightly deepened by a rim of fibrocartilage, the **glenoid labrum** (*labrum* =lip), it is only about one-third the size of the humeral head and contributes little to joint stability (Figure 8.10d).

The articular capsule enclosing the joint cavity (from the margin of the glenoid cavity to the anatomical neck of the humerus) is remarkably thin and loose, qualities that contribute to this joint's freedom of movement. The few ligaments reinforcing the shoulder joint are located primarily on its anterior aspect. The superiorly located **coracohumeral ligament** (kor′ah-ko-hu′mer-ul) provides the only strong thickening of the capsule and helps support the weight of the upper limb (Figure 8.10c). Three **glenohumeral ligaments** (glĕ″no-hu′mer-ul) strengthen the front of the capsule somewhat but are weak and may even be absent (Figure 8.10c, d).

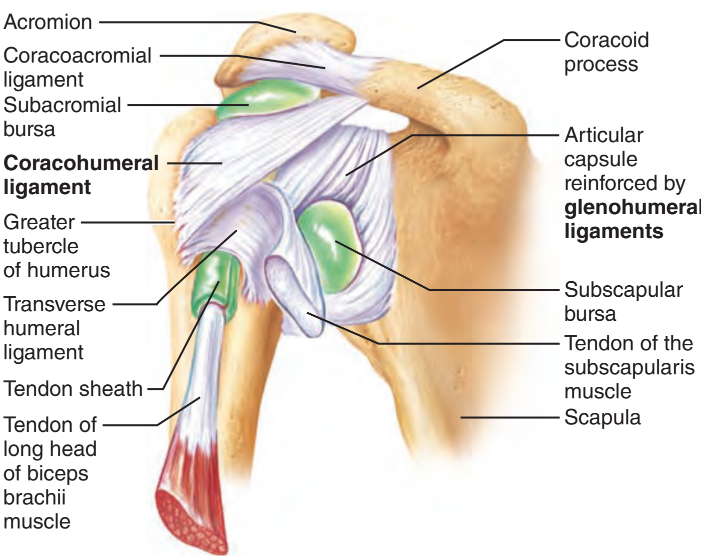
Muscle tendons that cross the shoulder joint contribute most to this joint's stability. The "superstabilizer" is the tendon of the long head of the biceps brachii muscle of the arm (Figure 8.10c). This tendon attaches to the superior margin of the glenoid labrum, travels through the joint cavity, and then runs within the intertubercular sulcus of the humerus. It secures the head of the humerus against the glenoid cavity.

Four other tendons (and the associated muscles) make up the **rotator cuff**. This cuff encircles the shoulder joint and blends with the articular capsule. The muscles include the subscapularis, supraspinatus, infraspinatus, and teres minor. (The rotator cuff muscles are illustrated in Figure 10.15, p. 351.) The rotator cuff can be severely stretched when the arm is vigorously circumducted; this is a common injury of baseball pitchers. As noted in Chapter 7, shoulder dislocations are fairly common. Because the shoulder's reinforcements are weakest anteriorly and inferiorly, the humerus tends to dislocate in the forward and downward direction.

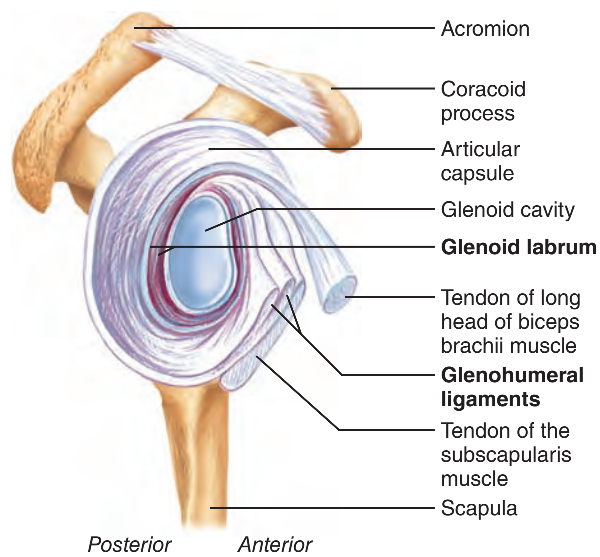


(a) Frontal section through right shoulder joint

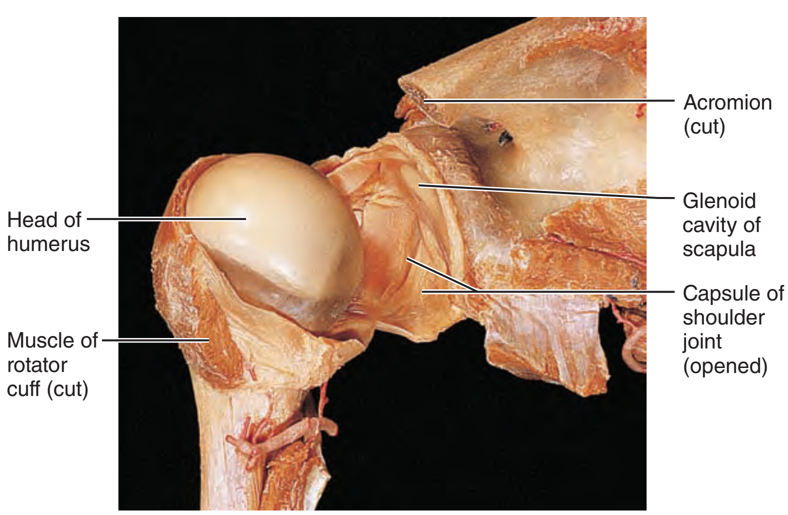
(b) Cadaver photo corresponding to (a)



(c) Anterior view of right shoulder joint capsule



(d) Lateral view of socket of right shoulder joint, humerus removed



(e) Anterior view of an opened shoulder joint

Figure 8.10 **The shoulder joint.**

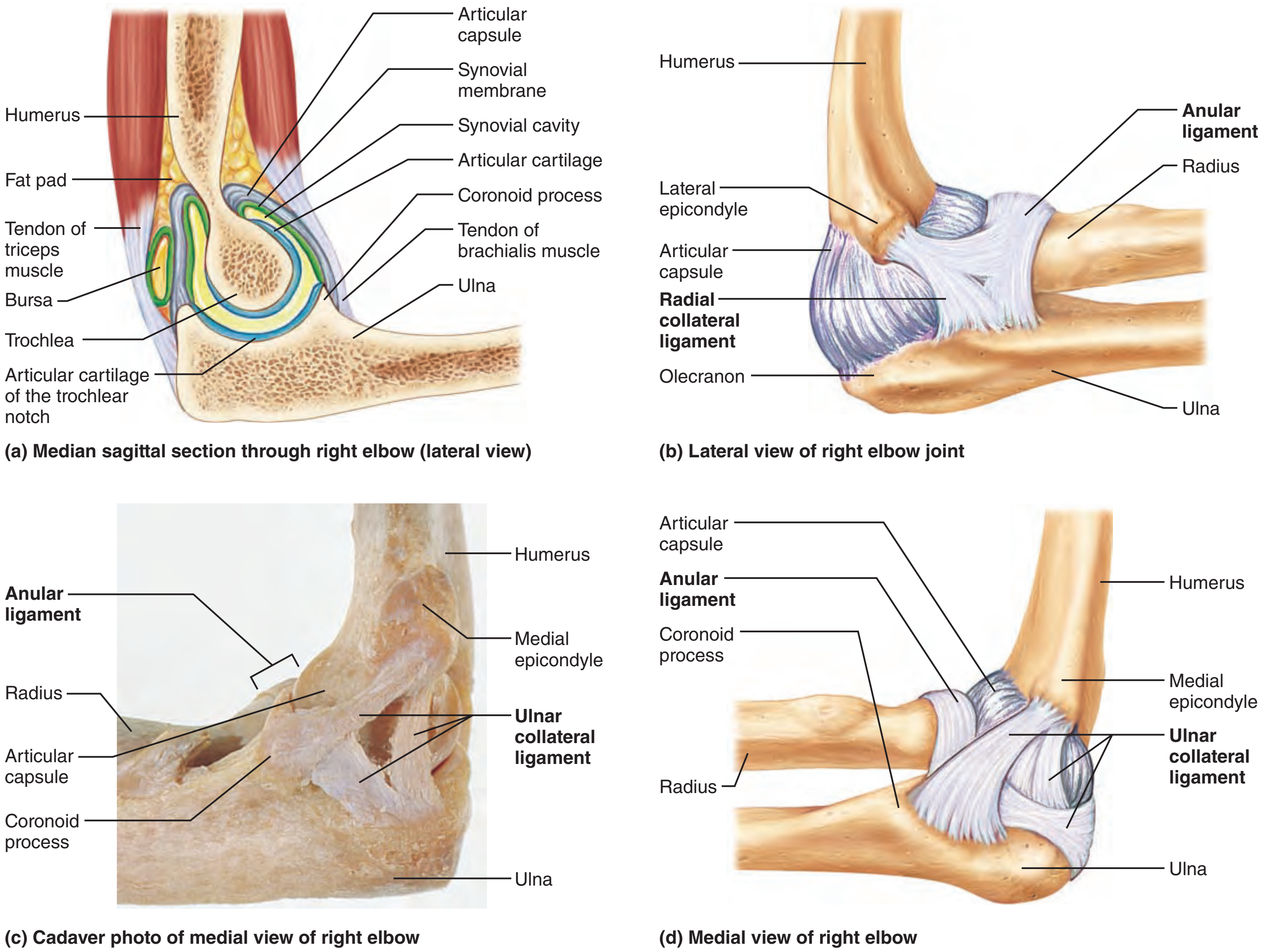


Figure 8.11 **The elbow joint.**

Elbow Joint

Our upper limbs are flexible extensions that permit us to reach out and manipulate things in our environment. Besides the shoulder joint, the most prominent of the upper limb joints is the elbow. The elbow joint provides a stable and smoothly operating hinge that allows flexion and extension only **(Figure 8.11)**. Within the joint, both the radius and ulna articulate with the condyles of the humerus, but it is the close gripping of the trochlea by the ulna's trochlear notch that forms the "hinge" and stabilizes this joint (Figure 8.11a). A relatively lax articular capsule extends inferiorly from the humerus to the ulna and radius, and to the **anular ligament** (an′u-lar) surrounding the head of the radius (Figure 8.11b, c).

Anteriorly and posteriorly, the articular capsule is thin and allows substantial freedom for elbow flexion and extension. However, side-to-side movements are restricted by two strong capsular ligaments: the **ulnar collateral ligament** medially, and the **radial collateral ligament**, a triangular ligament on the lateral side (Figure 8.11b, c, and d). Additionally, tendons of several arm muscles, such as the biceps and triceps, cross the elbow joint and provide security.

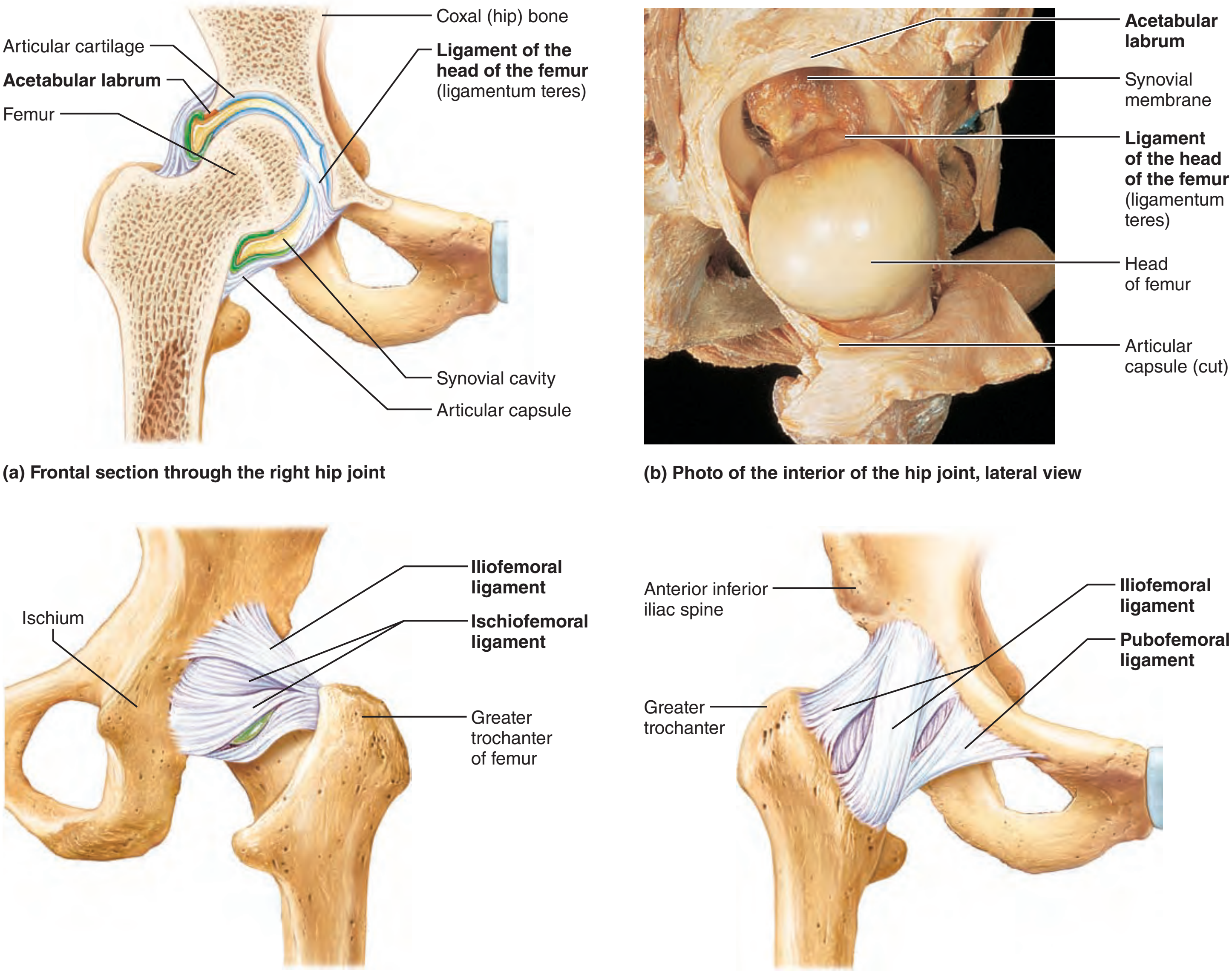
The radius is a passive "onlooker" in the angular elbow movements. However, its head rotates within the anular ligament during supination and pronation of the forearm.

Hip Joint

The **hip** (coxal) **joint**, like the shoulder joint, is a ball-and-socket joint. It has a good range of motion, but not nearly as wide as the shoulder's range. Movements occur in all possible planes but are limited by the joint's strong ligaments and its deep socket.

The hip joint is formed by the articulation of the spherical head of the femur with the deeply cupped acetabulum of the hip bone **(Figure 8.12)**. The depth of the acetabulum is enhanced by a circular rim of fibrocartilage called the **acetabular labrum** (as″ĕ-tab′u-lar) (Figure 8.12a, b). The labrum's diameter is less than that of the head of the femur, and these articular surfaces fit snugly together, so hip joint dislocations are rare.

The thick articular capsule extends from the rim of the acetabulum to the neck of the femur and completely encloses the joint. Several strong ligaments reinforce the capsule of the hip joint.



(a) Frontal section through the right hip joint

(b) Photo of the interior of the hip joint, lateral view

(c) Posterior view of right hip joint, capsule in place

(d) Anterior view of right hip joint, capsule in place

Figure 8.12 The hip joint.

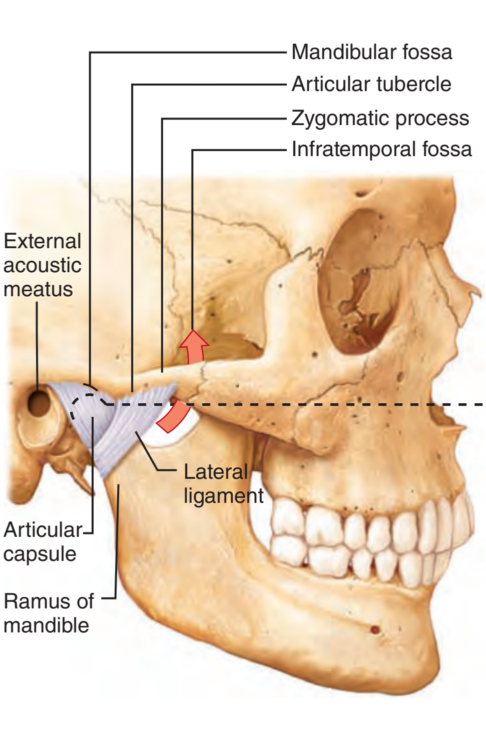
These include the **iliofemoral ligament** (il″e-o-fem′o-ral), a strong V-shaped ligament anteriorly; the **pubofemoral ligament** (pu″bo-fem′o-ral), a triangular thickening of the inferior part of the capsule; and the **ischiofemoral ligament** (is″ke-o-fem′o-ral), a spiraling posterior ligament (Figure 8.12c, d). These ligaments are arranged in such a way that they "screw" the femur head into the acetabulum when a person stands up straight, thereby providing more stability.

The **ligament of the head of the femur**, also called the *ligamentum teres*, is a flat intracapsular band that runs from the femur head to the lower lip of the acetabulum (Figure 8.12a, b). This ligament is slack during most hip movements, so it is not important in stabilizing the joint. In fact, its mechanical function (if any) is unclear, but it does contain an artery that helps supply the head of the femur. Damage to this artery may lead to severe arthritis of the hip joint.

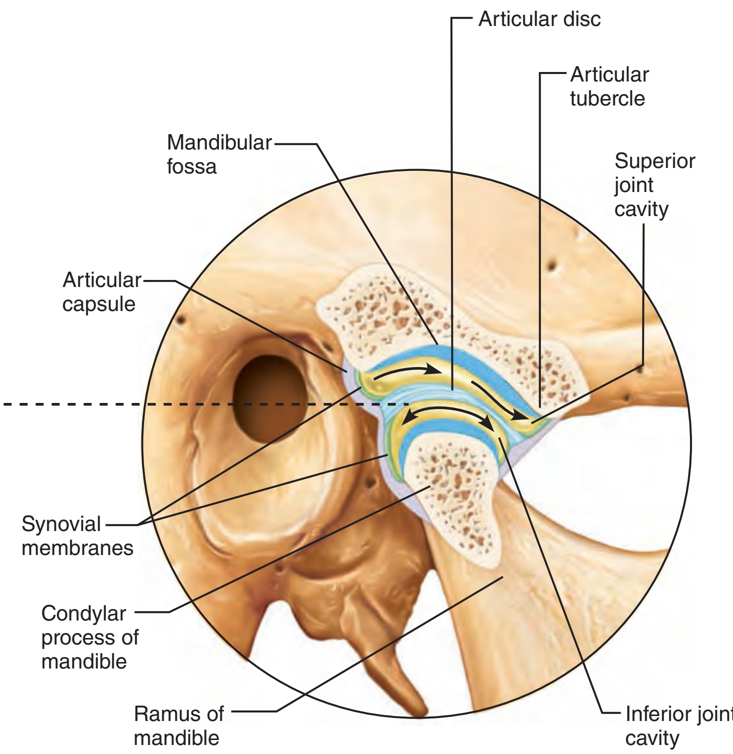
Muscle tendons that cross the joint and the bulky hip and thigh muscles that surround it contribute to its stability and strength. In this joint, however, stability comes chiefly from the deep socket that securely encloses the femoral head and the strong capsular ligaments.

Temporomandibular Joint

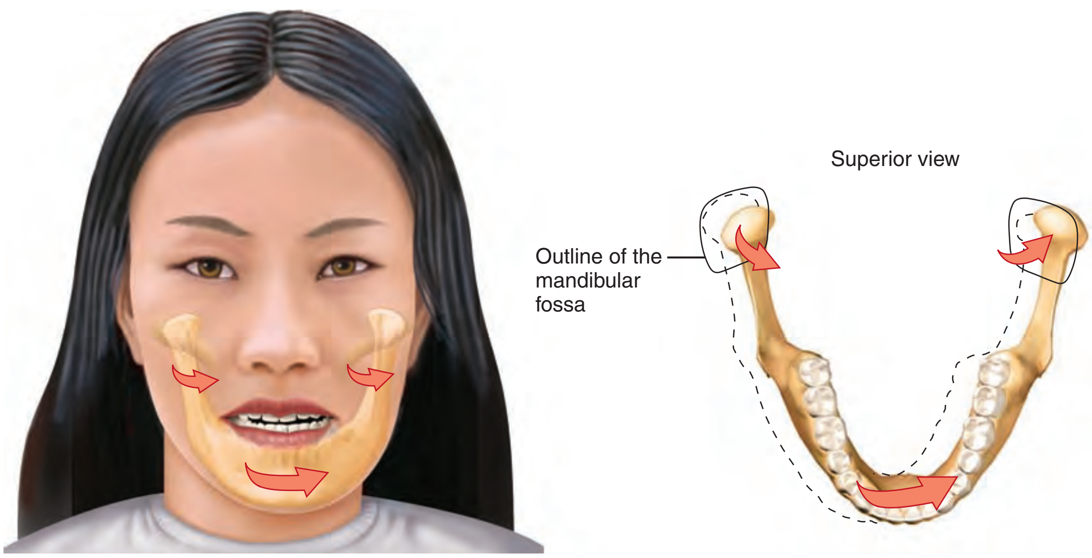
The **temporomandibular joint** (TMJ), or jaw joint, is a modified hinge joint. It lies just anterior to the ear **(Figure 8.13)**. At this joint, the condylar process of the mandible articulates with the inferior surface of the squamous part of the temporal bone. The mandible's condylar process is egg shaped, whereas the articular surface of the temporal bone has a more complex shape. Posteriorly, it forms the concave **mandibular fossa**; anteriorly it forms a dense knob called the **articular tubercle**. The lateral aspect of the loose articular capsule that encloses the joint is thickened into a **lateral ligament**. Within the capsule, an articular disc divides the synovial cavity into superior and inferior compartments (Figure 8.13a, b).



(a) Location of the joint in the skull



(b) Enlargement of a sagittal section through the joint



(c) Lateral excursion: lateral (side-to-side) movements of the mandible

Figure 8.13 The temporomandibular (jaw) joint. In **(b)**, note that the two parts of the joint cavity allow different movements, indicated by arrows. The inferior compartment of the joint cavity allows the condylar process of the mandible to rotate in opening and closing the mouth. The superior compartment lets the condylar process move forward to brace against the articular tubercle when the mouth opens wide, and also allows lateral excursion of this joint **(c)**.

Two distinct kinds of movement occur at the TMJ (Figure 8.13c). First, the concave inferior disc surface receives the condylar process of the mandible and allows the familiar hingelike movement of depressing and elevating the mandible while opening and closing the mouth. Second, the superior disc surface glides anteriorly along with the condylar process when the mouth is opened wide. This anterior movement braces the condylar process against the articular tubercle, so that the mandible is not forced through the thin roof of the mandibular fossa when one bites hard foods such as nuts or hard candies. The superior compartment also allows this joint to glide from side to side. As the posterior teeth are drawn into occlusion during grinding, the mandible moves with a side-to-side movement called *lateral excursion* (Figure 8.13c). This lateral jaw movement is unique to mammals and it is readily apparent in horses and cows as they chew.

Homeostatic Imbalance 8.2

Because of its shallow socket, the TMJ is the most easily dislocated joint in the body. Even a deep yawn can dislocate it. This joint almost always dislocates anteriorly, the condylar process of the mandible ending up in a skull region called the *infratemporal fossa* (Figure 8.13a). In such cases, the mouth remains wide open. To realign a dislocated TMJ, the physician places his or her thumbs in the patient's mouth between the lower molars and the cheeks, and then pushes the mandible inferiorly and posteriorly.

At least 5% of Americans suffer from painful temporomandibular disorders, the most common symptoms of which are pain in the ear and face, tenderness of the jaw muscles, popping sounds when the mouth opens, and joint stiffness. Usually caused by painful spasms of the chewing muscles, TMJ disorders often afflict people who grind their teeth; however, it can also result from jaw trauma or from poor occlusion of the teeth. Treatment usually focuses on getting the jaw muscles to relax by using massage, applying moist heat or ice, muscle-relaxant drugs, and adopting stress reduction techniques. For tooth grinders, use of a bite plate during sleep is generally recommended. ✚

☑ Check Your Understanding

11. Of the five joints studied in more detail—hip, shoulder, elbow, knee, and temporomandibular—which two have menisci? Which act mainly as a uniaxial hinge? Which depend mainly on muscles and their tendons for stability?

For answers, see Appendix H.

Homeostatic Imbalances of Joints

- ✓ Name the most common joint injuries and discuss the symptoms and problems associated with each.
- ✓ Compare and contrast the common types of arthritis.
- ✓ Describe the cause and consequences of Lyme disease.

Few of us pay attention to our joints unless something goes wrong with them. Although remarkably strong, joints are more likely to be injured by forces the bony skeleton can withstand. This is the price of our flexibility. Joint pain and malfunction can be caused by a number of factors besides traumatic injury, including inflammatory conditions and degenerative processes due to friction and wear.

Common Joint Injuries

For most of us, sprains and dislocations are the most common trauma-induced joint injuries, but cartilage injuries are equally threatening to athletes.

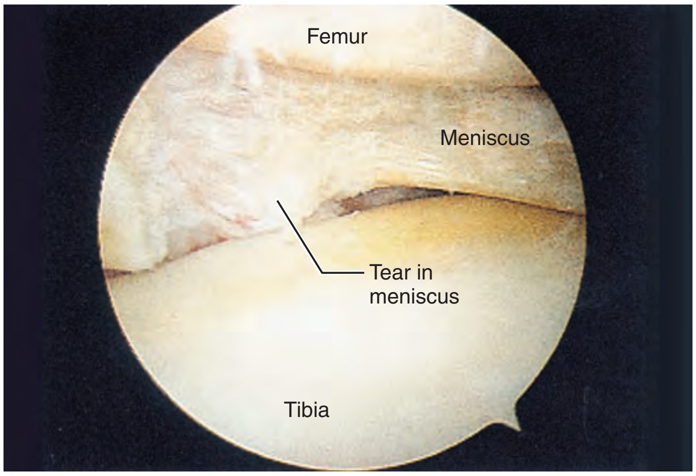


Figure 8.14 Arthroscopic photograph of a torn medial meniscus. (Courtesy of the author's tennis game.)

Cartilage Tears

Many aerobics devotees, encouraged to "feel the burn" during their workout, may feel the snap and pop of their overstressed cartilage instead. Although most cartilage injuries involve tearing of the knee menisci, tears and overuse damage to the articular cartilages of other joints is becoming increasingly common in competitive young athletes.

Cartilage tears typically occur when a meniscus is subjected to compression and shear stress at the same time. Cartilage is avascular and it rarely can obtain sufficient nourishment to repair itself, so it usually stays torn. Cartilage fragments (called loose bodies) can interfere with joint function by causing the joint to lock or bind, so most sports physicians recommend that the damaged cartilage be removed. Today, this can be done by **arthroscopic surgery** (ar-thro-skop′ik; "looking into joints"), a procedure that enables patients to be out of the hospital the same day. The arthroscope, a small instrument bearing a tiny lens and fiber-optic light source, enables the surgeon to view the joint interior, as in **Figure 8.14**. The surgeon can then repair a ligament, or remove cartilage fragments through one or more tiny slits, minimizing tissue damage and scarring. Removal of part of a meniscus does not severely impair knee joint mobility, but the joint is definitely less stable. Removal of the entire meniscus is an invitation to early onset of osteoarthritis in the joint. For younger patients a meniscal transplant may be an option to replace irreparably damaged cartilage. In the future, a tissue-engineered meniscus grown from your own stem cells may be implanted instead.

Sprains

In a **sprain**, the ligaments reinforcing a joint are stretched or torn. Common sites of sprains are the ankle, the knee, and the lumbar region of the spine. Partially torn ligaments will repair themselves, but they heal slowly because ligaments are so poorly vascularized. Sprains tend to be painful and immobilizing.

When ligaments are completely torn, there are three options:

- The torn ends of the ligament can be sewn together. This is difficult because trying to sew the hundreds of fibrous strands of a ligament together is like trying to sew two hairbrushes together.

- Certain ligaments, like the anterior cruciate ligament, are best repaired by replacing them with grafts. For example, a piece of tendon from a muscle can be attached to the articulating bones.
- For many ligaments, such as the knee's medial collateral ligament, we've come to realize that time and immobilization are just as effective as any surgical option.

Dislocations

A **dislocation (luxation)** occurs when bones are forced out of alignment. It is usually accompanied by sprains, inflammation, and difficulty in moving the joint. Dislocations may result from serious falls and are common contact sports injuries. Joints of the jaw, shoulders, fingers, and thumbs are most commonly dislocated. Like fractures, dislocations must be *reduced*; that is, the bone ends must be returned to their proper positions by a physician. *Subluxation* is a partial dislocation of a joint.

Repeat dislocations of the same joint are common because the initial dislocation stretches the joint capsule and ligaments. The resulting loose capsule provides poor reinforcement for the joint.

8

Inflammatory and Degenerative Conditions

Inflammatory conditions that affect joints include bursitis and tendonitis, various forms of arthritis, and Lyme disease.

Bursitis and Tendonitis

Bursitis is inflammation of a bursa and is usually caused by a blow or friction. Falling on one's knee may result in a painful bursitis of the prepatellar bursa, known as *housemaid's knee* or *water on the knee*. Prolonged leaning on one's elbows may damage the bursa close to the olecranon, producing *student's elbow*, or *olecranon bursitis*. Severe cases are treated by injecting anti-inflammatory drugs into the bursa. If excessive fluid accumulates, removing some fluid by needle aspiration may relieve the pressure.

Tendonitis is inflammation of tendon sheaths, typically caused by overuse. Its symptoms (pain and swelling) and treatment (rest, ice, and anti-inflammatory drugs) mirror those of bursitis.

Arthritis

The term **arthritis** describes over 100 different types of inflammatory or degenerative diseases that damage the joints. In all its forms, arthritis is the most widespread crippling disease in North America. One in five of us suffers its ravages. To a greater or lesser degree, all forms of arthritis have the same initial symptoms: pain, stiffness, and swelling of the joint.

Acute forms of arthritis usually result from bacterial invasion and are treated with antibiotics. Chronic forms of arthritis include osteoarthritis, rheumatoid arthritis, and gouty arthritis.

Osteoarthritis **Osteoarthritis (OA)** is the most common chronic arthritis. A chronic (long-term) degenerative condition, OA is often called "wear-and-tear arthritis." OA is most prevalent in the aged and is probably related to the normal aging process (although it is seen occasionally in younger people and some forms have a genetic basis). More women than men are affected, but nearly half of us will develop this condition by the age of 85.

Current theory holds that normal joint use prompts the release of (metalloproteinase) enzymes that break down articular cartilage, especially its collagen fibrils. In healthy individuals, this damaged cartilage is eventually replaced, but in people with OA, more cartilage is destroyed than replaced. Although its specific cause is unknown, OA may reflect the cumulative effects of years of compression and abrasion acting at joint surfaces, causing excessive amounts of the cartilage-destroying enzymes to be released. The result is softened, roughened, pitted, and eroded articular cartilages. Because this process occurs most where an uneven orientation of forces cause extensive microdamage, badly aligned or overworked joints are likely to develop OA.

As the disease progresses, the exposed bone tissue thickens and forms bony spurs (osteophytes) that enlarge the bone ends and may restrict joint movement. Patients complain of stiffness on arising that lessens somewhat with activity. The affected joints may make a crunching noise, called *crepitus* (krep′ĭ-tus), as they move and the roughened articular surfaces rub together. The joints most often affected are those of the cervical and lumbar spine and the fingers, knuckles, knees, and hips.

The course of osteoarthritis is usually slow and irreversible. In many cases, its symptoms are controllable with a mild pain reliever like aspirin or acetaminophen, along with moderate activity to keep the joints mobile. Rubbing a hot-pepper substance called capsaicin on the skin over the painful joints helps lessen the pain of OA. Glucosamine and chondroitin sulfate, nutritional supplements consisting of macromolecules normally present in cartilage, have been widely used by arthritis sufferers. However, several recent studies suggest that these supplements are no more effective than placebos. Osteoarthritis is rarely crippling, but it can be, particularly when the hip or knee joints are involved.

Rheumatoid Arthritis **Rheumatoid arthritis (RA)** (roo′mah-toid) is a chronic inflammatory disorder with an insidious onset. Though it usually arises between the ages of 30 and 50, it may occur at any age. It affects three times as many women as men. While not as common as osteoarthritis, rheumatoid arthritis affects millions, about 1% of all people.

In the early stages of RA, joint tenderness and stiffness are common. Many joints, particularly the small joints of the fingers, wrists, ankles, and feet, are afflicted at the same time and bilaterally. For example, if the right elbow is affected, most likely the left elbow is also affected. The course of RA is variable and marked by flare-ups (exacerbations) and remissions (*rheumat* =susceptible to change). Along with pain and swelling, its manifestations may include anemia, osteoporosis, muscle weakness, and cardiovascular problems.

RA is an *autoimmune disease*—a disorder in which the body's immune system attacks its own tissues. The initial trigger for this reaction is unknown, but various bacteria and viruses have been suspect. Perhaps these microorganisms bear molecules similar to some naturally present in the joints (possibly glycosaminoglycans, which are complex carbohydrates found in cartilage, joint fluid, and other connective tissues), and the immune system, once activated, attempts to destroy both.

RA begins with inflammation of the synovial membrane (*synovitis*) of the affected joints. Inflammatory cells (lymphocytes, macrophages, and others) migrate into the joint cavity from the blood and unleash a deluge of inflammatory chemicals

A CLOSER LOOK

Joints: From Knights in Shining Armor to Bionic Humans

The **technology** for fashioning **joints** in medieval suits of armor developed over centuries. The technology for creating the **prostheses** (artificial joints) used in medicine today developed, in relative terms, in a flash—less than 60 years. Unlike the joints in medieval **armor**, which was worn outside the body, today's artificial joints must function inside the body. The history of joint prostheses dates to the 1940s and 1950s, when World War II and the Korean War left large numbers of wounded who needed artificial limbs. Today, nearly 1 million Americans per year receive a total joint replacement, mostly because of the destructive effects of osteoarthritis or rheumatoid arthritis.

To produce durable, mobile joints requires substances that are strong, nontoxic, and resistant to the corrosive effects of organic acids in blood. In 1963, Sir John Charnley, an English orthopedic surgeon, revolutionized the therapy of arthritic hips with an artificial hip design that is still in use today. His device consisted of a metal ball on a stem and a cup-shaped polyethylene plastic socket anchored to the pelvis by methyl methacrylate cement. This cement proved to be exceptionally strong and relatively problem free. Hip prostheses were followed by knee prostheses, but not until 10 years later did smoothly operating total knee joint replacements become a reality. Today, the metal parts of the prostheses are strong cobalt and titanium alloys, and the number of knee replacements equals the number of hip replacements.

Replacements are now available for many other joints, including fingers, elbows, and shoulders. Total hip and knee replacements last about 10 to 15 years in elderly patients who do not excessively stress the joint. Most such operations are done to reduce pain and restore about 80% of original joint function.

Replacement joints are not yet strong or durable enough for young, active people, but making them so is a major goal. Another problem is that the prostheses work loose over time, so researchers are seeking to enhance the fit between implant and bone. One solution is to strengthen the cement that binds them (simply eliminating air bubbles from the cement increases its durability). Another solution is to use a cementless prosthesis, which allows the bone to grow into its surface, fixing it in place. In order for this to happen, a precise fit in the prosthesis and the bone must be achieved, something at which surgical robots such as ROBODOC excel.

Dramatic changes are also occurring in the way artificial joints are made. CAD/CAM (computer-aided design and computer-aided manufacturing) techniques have significantly reduced the time and cost of creating individualized joints. Fed the patient's X rays and medical information, the computer draws from a database of hundreds of normal joints and generates possible designs and modifications for a prosthesis. Once the best design is selected, the computer produces a program to direct the machines that make the prosthesis.

Joint replacement therapy is coming of age, but equally exciting are techniques that call on the ability of the patient's own tissues to regenerate.

- Bone marrow stimulation: Small holes poked through to the bone marrow allow mesenchymal stem cells from the bone marrow to migrate into the joint and produce new cartilage.
- Osteochondral grafting: Healthy bone and cartilage are removed from one part of the body and transplanted to the injured joint.
- Autologous chondrocyte implantation: Healthy chondrocytes are removed from the body and seeded onto a supporting matrix of tissue-engineered collagen. When subjected to mechanical pressure in the lab, the cells produce new cartilage, which is then implanted.
- Mesenchymal stem cell regeneration: Undifferentiated mesenchymal cells are removed from bone marrow and placed in a gel, which is packed into an area of eroded cartilage.

These techniques offer hope for younger patients, since they could stave off the need for a joint prosthesis for several years.

And so, through the centuries, the focus has shifted from jointed armor to artificial joints that can be put inside the body to restore lost function. Modern technology has accomplished what the armor designers of the Middle Ages never dreamed of.

A hip prosthesis.

X ray of right knee showing total knee replacement prosthesis (co-designed by Kenneth Gustke, M.D., of Florida Orthopedic Institute).

Figure 8.15 A hand deformed by rheumatoid arthritis. Inflammation has enlarged the synovial joints.

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that destroy body tissues when released inappropriately in large amounts as in RA. Synovial fluid accumulates, causing joint swelling, and in time, the inflamed synovial membrane thickens into a **pannus** ("rag"), an abnormal tissue that clings to the articular cartilages. The pannus erodes the cartilage (and sometimes the underlying bone) and eventually scar tissue forms and connects the bone ends. Later this scar tissue ossifies and the bone ends fuse together, immobilizing the joint. This end condition, called ankylosis (ang″kĭ-lo′sis; "stiff condition"), often produces bent, deformed fingers **(Figure 8.15)**. Not all cases of RA progress to the severely crippling ankylosis stage, but all cases do involve restriction of joint movement and extreme pain.

A wonder drug for RA sufferers is still undiscovered. The goal of current RA treatment is to go beyond simply alleviating the symptoms and instead to disrupt the relentless destruction of the joints by the autoimmune processes. Steroidal and nonsteroidal anti-inflammatory drugs decrease pain and inflammation, increasing joint mobility. More powerful immune suppressants (such as methotrexate) act to slow the autoimmune reaction. Several biologic agents are available to block the action of inflammatory chemicals. An important target of many of these agents is an inflammatory chemical called *tumor necrosis factor*, an important contributor to destruction of cartilage. Together, these drugs can dramatically slow the course of RA. As a last resort, replacing the joint with a joint prosthesis (artificial joint), may be an option to restore function (see *A Closer Look*, p. 271). Indeed, some RA sufferers have over a dozen artificial joints.

Gouty Arthritis Uric acid, a normal waste product of nucleic acid metabolism, is ordinarily excreted in urine without any problems. However, when blood levels of uric acid rise excessively (due to its excessive production or slow excretion), it may be deposited as needle-shaped urate crystals in the soft tissues of joints. An inflammatory response follows, leading to an agonizingly painful attack of **gouty arthritis** (gow′te), or **gout**. The initial attack typically affects one joint, often at the base of the great toe.

Gout is far more common in men than in women because men naturally have higher blood levels of uric acid (perhaps because estrogens increase the rate of its excretion). Because gout seems to run in families, genetic factors are definitely implicated.

Untreated gout can be very destructive; the articulating bone ends fuse and immobilize the joint. Fortunately, several drugs (colchicine, nonsteroidal anti-inflammatory drugs, glucocorticoids, and others) that terminate or prevent gout attacks are available. Patients are advised to drink plenty of water and to avoid alcohol excess (which promotes uric acid overproduction), and foods high in purine-containing nucleic acids, such as liver, kidneys, and sardines.

Lyme Disease

Lyme disease is an inflammatory disease caused by spirochete bacteria transmitted by the bite of ticks that live on mice and deer. It often results in joint pain and arthritis, especially in the knees, and is characterized by a skin rash, flu-like symptoms, and foggy thinking. If untreated, neurological disorders and irregular heartbeat may ensue.

Because symptoms vary from person to person, the disease is hard to diagnose. Antibiotic therapy is the usual treatment, but it takes a long time to kill the infecting bacteria.

☑ Check Your Understanding

12. What does the term "arthritis" mean?
13. How would you determine by looking at someone suffering from arthritis if he or she has OA or RA?
14. What is the cause of Lyme disease?

For answers, see Appendix H.

Developmental Aspects of Joints

✓ Discuss factors that promote or disturb joint homeostasis.

As bones form from mesenchyme in the embryo, the joints develop in parallel. By week 8, the synovial joints resemble adult joints in form and arrangement, and synovial fluid is being secreted. During childhood, a joint's size, shape, and flexibility are modified by use. Active joints have thicker capsules and ligaments, and larger bony supports.

Injuries aside, relatively few interferences with joint function occur until late middle age. Eventually advancing years take their toll and ligaments and tendons shorten and weaken. The intervertebral discs become more likely to herniate, and osteoarthritis rears its ugly head. Many people have osteoarthritis by the time they are in their 70s. The middle years also see an increased incidence of rheumatoid arthritis.

Exercise that coaxes joints through their full range of motion, such as regular stretching and aerobics, is the key to postponing the immobilizing effects of aging on ligaments and tendons, to keeping cartilages well nourished, and to strengthening the muscles that stabilize the joints. The key word for exercising is "prudently," because excessive or abusive use of the joints guarantees early onset of osteoarthritis. The buoyancy of water relieves much of the stress on weight-bearing joints, and people who swim or exercise in a pool often retain good joint function as long as they live. As with so many medical problems, it is easier to prevent joint problems than to cure or correct them.

Check Your Understanding

15. What is the effect of regular exercise on joint health and structure?

For answers, see Appendix H.

The importance of joints is obvious: The skeleton's ability to protect other organs and to move smoothly reflects their presence. Now that we are familiar with joint structure and with the movements that joints allow, we are ready to consider how the muscles attached to the skeleton cause body movements by acting across its joints.

Chapter Summary

1. Joints, or articulations, are sites where bones meet. Their functions are to hold bones together and to allow various degrees of skeletal movement.

Classification of Joints (pp. 249–250)

1. Joints are classified structurally as fibrous, cartilaginous, or synovial. They are classed functionally as synarthrotic, amphiarthrotic, or diarthrotic.

Fibrous Joints (pp. 250–251)

1. Fibrous joints occur where bones are connected by fibrous tissue; no joint cavity is present. Nearly all fibrous joints are synarthrotic.
2. **Sutures/syndesmoses/gomphoses.** The major types of fibrous joints are sutures, syndesmoses, and gomphoses.

Cartilaginous Joints (pp. 251–252)

1. In cartilaginous joints, the bones are united by cartilage; no joint cavity is present.
2. **Synchondroses/symphyses.** Cartilaginous joints include synchondroses and symphyses. Synchondroses are synarthrotic; all symphyses are amphiarthrotic.

Synovial Joints (pp. 252–269)

1. Most body joints are synovial joints, all of which are diarthrotic.

General Structure (pp. 252–253)

2. All synovial joints have a joint cavity enclosed by a fibrous layer lined with synovial membrane and reinforced by ligaments; articulating bone ends covered with articular cartilage; and synovial fluid in the joint cavity. Some (e.g., the knee) contain fibrocartilage discs that absorb shock.

Bursae and Tendon Sheaths (p. 253)

3. Bursae are fibrous sacs lined with synovial membrane and containing synovial fluid. Tendon sheaths are similar to bursae but are cylindrical structures that surround muscle tendons. Both allow adjacent structures to move smoothly over one another.

Factors Influencing the Stability of Synovial Joints (pp. 255–256)

4. Articular surfaces providing the most stability have large surfaces and deep sockets and fit snugly together.
5. Ligaments prevent undesirable movements and reinforce the joint.
6. The tone of muscles whose tendons cross the joint is the most important stabilizing factor in many joints.

Movements Allowed by Synovial Joints (pp. 256–258)

7. When a skeletal muscle contracts, the insertion (movable attachment) moves toward the origin (immovable attachment).
8. Synovial joints differ in their range of motion. Motion may be nonaxial (gliding), uniaxial (in one plane), biaxial (in two planes), or multiaxial (in all three planes).
9. Three common types of movements can occur when muscles contract across joints: (a) gliding movements, (b) angular movements (which include flexion, extension, abduction, adduction, and circumduction), and (c) rotation.
10. Special movements include supination and pronation, inversion and eversion, protraction and retraction, elevation and depression, opposition, dorsiflexion and plantar flexion.

Types of Synovial Joints (p. 258)

11. The six major categories of synovial joints are plane joints (nonaxial movement), hinge joints (uniaxial), pivot joints (uniaxial, rotation permitted), condylar joints (biaxial with angular movements in two planes), saddle joints (biaxial, like condylar joints, but with freer movement), and ball-and-socket joints (multiaxial and rotational movement).

Selected Synovial Joints (pp. 262–269)

12. The knee joint is the largest joint in the body. It is a hinge joint formed by the articulation of the tibial and femoral condyles (and anteriorly by the patella and patellar surface of the femur). Extension, flexion, and (some) rotation are allowed. Its articular surfaces are shallow and condylar. C-shaped menisci deepen the articular surfaces. The joint cavity is enclosed by a capsule only on the sides and posterior aspect. Several ligaments help prevent displacement of the joint surfaces. Muscle tone of the quadriceps and semimembranosus muscles is important in knee stability.
13. The shoulder joint is a ball-and-socket joint formed by the glenoid cavity of the scapula and the humeral head. The most freely movable joint of the body, it allows all angular and rotational movements. Its articular surfaces are shallow. Its capsule is lax and poorly reinforced by ligaments. The tendons of the biceps brachii and rotator cuff muscles help to stabilize it.
14. The elbow is a hinge joint in which the ulna (and radius) articulates with the humerus, allowing flexion and extension. Its articular surfaces are highly complementary and are the most important factor contributing to joint stability.
15. The hip joint is a ball-and-socket joint formed by the acetabulum of the hip bone and the femoral head. It is highly adapted for

weight bearing. Its articular surfaces are deep and secure. Its capsule is heavy and strongly reinforced by ligaments.

16. The temporomandibular joint is formed by (1) the condylar process of the mandible and (2) the mandibular fossa and articular tubercle of the temporal bone. This joint allows both a hingelike opening and closing of the mouth and an anterior gliding of the mandible. It often dislocates anteriorly and exhibits a number of TMJ disorders.

Homeostatic Imbalances of Joints (pp. 269–272)

Common Joint Injuries (pp. 269–270)

1. Cartilage injuries, particularly of the knee, are common in contact sports and may result from excessive compression and shear stress. The avascular cartilage is unable to repair itself.
2. Sprains involve stretching or tearing of joint ligaments. Because ligaments are poorly vascularized, healing is slow.
3. Dislocations involve displacement of the articular surfaces of bones. They must be reduced.

Inflammatory and Degenerative Conditions (pp. 270–272)

4. Bursitis and tendonitis are inflammations of a bursa and a tendon sheath, respectively.
5. Arthritis is joint inflammation or degeneration accompanied by stiffness, pain, and swelling. Acute forms generally result from bacterial infection. Chronic forms include osteoarthritis, rheumatoid arthritis, and gouty arthritis.
6. Osteoarthritis is a degenerative condition most common in the aged. Spine, knees, hips, knuckles, and fingers are most affected.
7. Rheumatoid arthritis, the most crippling arthritis, is an autoimmune disease involving severe inflammation of the joints.
8. Gouty arthritis, or gout, is joint inflammation caused by the deposit of urate salts in soft joint tissues.
9. Lyme disease is an infectious disease caused by the bite of a tick infected with spirochete bacteria.

Developmental Aspects of Joints (pp. 272–273)

1. Joints form from mesenchyme and in tandem with bone development in the embryo.
2. Excluding traumatic injury, joints usually function well until late middle age, at which time symptoms of connective tissue stiffening and osteoarthritis begin to appear. Prudent exercise delays these effects, whereas excessive exercise promotes the early onset of arthritis.

Review Questions

Multiple Choice/Matching

(Some questions have more than one correct answer. Select the best answer or answers from the choices given.)

1. Match the key terms to the appropriate descriptions.

   Key: **(a)** fibrous joints **(b)** cartilaginous joints **(c)** synovial joints

   ____ (1) exhibit a joint cavity
   ____ (2) types are sutures and syndesmoses
   ____ (3) bones connected by collagen fibers
   ____ (4) types include synchondroses and symphyses
   ____ (5) all are diarthrotic
   ____ (6) many are amphiarthrotic
   ____ (7) bones connected by a disc of hyaline cartilage or fibrocartilage
   ____ (8) nearly all are synarthrotic
   ____ (9) shoulder, hip, jaw, and elbow joints
2. Freely movable joints are **(a)** synarthroses, **(b)** diarthroses, **(c)** amphiarthroses.
3. Anatomical characteristics shared by all synovial joints include all except **(a)** articular cartilage, **(b)** a joint cavity, **(c)** an articular capsule, **(d)** presence of fibrocartilage.
4. Factors that influence the stability of a synovial joint include **(a)** shape of articular surfaces, **(b)** presence of strong reinforcing ligaments, **(c)** tone of surrounding muscles, **(d)** all of these.
5. The description "Articular surfaces deep and secure; capsule heavily reinforced by ligaments and muscle tendons; extremely stable joint" best describes **(a)** the elbow joint, **(b)** the hip joint, **(c)** the knee joint, **(d)** the shoulder joint.
6. Ankylosis means **(a)** twisting of the ankle, **(b)** tearing of ligaments, **(c)** displacement of a bone, **(d)** immobility of a joint due to fusion of its articular surfaces.
7. An autoimmune disorder in which joints are affected bilaterally and which involves pannus formation and gradual joint immobilization is **(a)** bursitis, **(b)** gout, **(c)** osteoarthritis, **(d)** rheumatoid arthritis.

Short Answer Essay Questions

8. Define joint.
9. Discuss the relative value (to body homeostasis) of immovable, slightly movable, and freely movable joints.
10. Compare the structure, function, and common body locations of bursae and tendon sheaths.
11. Joint movements may be nonaxial, uniaxial, biaxial, or multiaxial. Define what each of these terms means.
12. Compare and contrast the paired movements of flexion and extension with adduction and abduction.
13. How does rotation differ from circumduction?
14. Name two types of uniaxial, biaxial, and multiaxial joints.
15. What is the specific role of the menisci of the knee? Of the anterior and posterior cruciate ligaments?
16. The knee has been called "a beauty and a beast." Provide several reasons that might explain the negative (beast) part of this description.
17. Why are sprains and cartilage injuries a particular problem?
18. List the functions of the following elements of a synovial joint: fibrous layer of the capsule, synovial fluid, articular cartilage.

Critical Thinking and Clinical Application Questions

1. Sophie worked cleaning homes for 30 years so she could send her two children to college. Several times, she had been forced to call her employers to tell them she could not come in to work because one of her kneecaps was swollen and painful. What is Sophie's condition, and what probably caused it?

2. As Harry was running down the road, he tripped and his left ankle twisted violently to the side. When he picked himself up, he was unable to put any weight on that ankle. The diagnosis was severe dislocation and sprains of the left ankle. The orthopedic surgeon stated that she would perform a closed reduction of the dislocation and attempt ligament repair by using arthroscopy. (a) Is the ankle joint normally a stable joint? (b) What does its stability depend on? (c) What is a closed reduction? (d) Why is ligament repair necessary? (e) What does arthroscopy entail? (f) How will the use of this procedure minimize Harry's recuperation time (and suffering)?
3. Mrs. Bell, a 45-year-old woman, appeared at her physician's office complaining of unbearable pain in the interphalangeal joint of her right great toe. The joint was red and swollen. When asked about previous episodes, she recalled a similar attack two years earlier that disappeared as suddenly as it had come. Her diagnosis was arthritis. (a) What type? (b) What is the precipitating cause of this particular type of arthritis?
4. Grace heard on the evening TV news that the deer population in her state had been increasing rapidly in the past few years and it was common knowledge that deer walked the streets at night. After the program, she suddenly exclaimed, "So that's why those three boys in my son's class got Lyme disease last year." Explain what she meant by that comment.
5. Tony Bowers, an exhausted biology student, was attending a lecture. After 30 minutes or so, he lost interest and began to doze. As the lecture ended, the hubbub aroused him and he let go with a tremendous yawn. To his great distress, he couldn't close his mouth—his lower jaw was "stuck" open. What do you think had happened?

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AT THE CLINIC

Related Clinical Terms

Ankylosing spondylitis (ang′kĭ-lōz″ing spon″dĭ-li′tis; *ankyl* = crooked, bent; *spondyl* =vertebra) A variant of rheumatoid arthritis that chiefly affects males; it usually begins in the sacroiliac joints and progresses superiorly along the spine. The vertebrae become interconnected by fibrous tissue, causing the spine to become rigid ("poker back").

Arthrology (ar-throl′o-je; *logos* =study) The study of joints.

Arthroplasty ("joint reforming") Replacing a diseased joint with an artificial joint.

Chondromalacia patellae (kon-dro-mal-a′sĭ-ah; "softening of cartilage by the patella") Damage and softening of the articular cartilages on the posterior patellar surface and the anterior surface of the distal femur; most often seen in adolescent athletes. Produces a sharp pain in the knee when the leg is extended (in climbing stairs, for example). May result when the quadriceps femoris, the main group of muscles on the anterior thigh, pulls unevenly on the patella, persistently rubbing it against the femur in the knee joint; often corrected by exercises that strengthen weakened parts of the quadriceps muscles.

Rheumatism A term used by laypeople to indicate disease involving muscle or joint pain; consequently may be used to apply to arthritis, bursitis, etc.

Synovitis (sin″o-vi′tis) Inflammation of the synovial membrane of a joint. Caused by injury, infection, or arthritis. Excess synovial fluid accumulates in the joint cavity, a condition called *effusion* that causes the joint to swell, limiting joint movement.

Case Study Joints

In the previous chapter, you met Kayla Tanner, a 45-year-old mother of four who suffered a dislocated right hip in the bus accident on Route 91. Prior to the closed reduction, the doctors noted that her right thigh was flexed at the hip, adducted, and medially rotated. After the reduction, the hip was put through a gentle range of motion (ROM) to assess the joint. A widened joint space in the postreduction X ray showed that the reduction was not complete, but no bone fragments were visible in the joint space. Mrs. Tanner was scheduled for immediate surgery.

The surgeons discovered that the acetabular labrum was detached from the rim of the acetabulum and was lying deep within the joint space. The detached portion of the labrum was excised, and the hip was surgically reduced. During the early healing phase (first two weeks), Mrs. Tanner was kept in traction with the hip abducted.

1. Joints can be classified by structure and by function. How would you structurally and functionally classify the joint involved in the injury in this case?
2. Name the six distinguishing features that define the structural classification of the joint involved in this injury.
3. The doctors noted that there were no bone fragments in the joint space. What is normally found in this space?
4. Surgeons had to remove a portion of Mrs. Tanner's acetabular labrum. What is this structure and what function does it supply at this joint?
5. The doctors noted that Mrs. Tanner's thigh was flexed at the hip, adducted, and medially rotated. Describe what this means in terms of the position of her leg.
6. Hip dislocations can be classified as anterior or posterior depending on which direction the head of the femur is facing after it dislocates. Based on the description you provided in question 5, which type of dislocation did Mrs. Tanner suffer?
7. In order to assess the joint as part of Mrs. Tanner's rehabilitation, clinicians would want to assess all of the movements that normally occur at the hip. List all the movements that the clinicians will need to assess.

(Answers in Appendix H)