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.

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.

**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 G.

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**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‘né-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 cranial vault can be divided into a vault and a base. The **cranium**, 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**, or **floor**, 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 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 impulses 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. 214–215). 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 **orbit** 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 7.5b 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:
1. The coronal suture (kō-roi’-nul), where the parietal bones meet the frontal bone anteriorly (Figures 7.2a and 7.5)
2. The sagittal suture, where the parietal bones meet superiorly at the cranial midline (Figure 7.4b)
3. The lambdoid suture (la-mind’-oid), where the parietal bones meet the occipital bone posteriorly (Figures 7.2a, 7.4b, and 7.5)
4. The squamous (or squamosal) 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’-i-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). It also joins with the sphenoid bone in the cranial floor via its basilar region, which bears a midline projection called the pharyngeal tubercle (fah-rin’-je-ul) (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 rock-erlike occipital condyles articulate with the first vertebra of the spinal column in a way that permits a nodding ("yes") motion.
Figure 7.4 Anatomy of the anterior and posterior aspects of the skull. (See A Brief Atlas of the Human Body, Figures 1 and 7.)
Figure 7.5  Bones of the lateral aspect of the skull, external and internal views. (See A Brief Atlas of the Human Body, Figures 2 and 3.)
of the head. Hidden medially and superiorly to each occipital condyle is a hypoglossal canal (Figure 7.7), through which a cranial nerve (XII) of the same name passes.

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

**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 floor. The use of the terms temple and temporal, from the Latin word tempora, 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 four major areas, the squamous, tympanic, mastoid, and petrous regions. The flaring squamous region 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 condyle of the mandible (lower jawbone), forming the freely movable temporomandibular joint.

The tympanic region (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. Below the external acoustic meatus is the needle-like styloid process (sti’loid; “stakelike”), 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 7.12).

The mastoid region (mas’toid; “breast”) of the temporal bone exhibits the conspicuous mastoid process, 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 stylomastoid foramen, between the styloid and mastoid processes, allows cranial nerve VII (the facial nerve) to leave the skull (Figure 7.6).
Figure 7.6 Inferior aspect of the skull, mandible removed. (See A Brief Atlas of the Human Body, Figures 4 and 5.)
Figure 7.7 The floor of the cranial cavity. The fossae are named according to relative location as anterior, middle, and posterior fossae. (See A Brief Atlas of the Human Body, Figures 4 and 5.)
HOMEOSTATIC IMBALANCE

The mastoid process is full of air cavities, the mastoid sinuses, or mastoid air cells. Its position adjacent to the middle ear cavity (a high-risk area for infections spreading from the throat) puts it at risk for infection itself. 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.

The deep petrous (petrus) part of the temporal bone contributes to the cranial base (Figures 7.6 and 7.7). It looks like a miniature mountain ridge (petrous = rocky) between the occipital bone posteriorly and the sphenoid bone anteriorly. 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. Housed inside the petrous region are the middle and internal ear cavities, which contain sensory receptors for hearing and balance.

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 7.5b and c, and 7.7), transmits cranial nerves VII and VIII.

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’i-goid). Within the body of the sphenoid are the paired sphenoid sinuses (see Figures 7.5b and c, and 7.14).

The superior surface of the body bears a saddle-shaped prominence, the sella turcica (sel’ah ter’si-ka), 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 dorsal 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 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’rif-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 olfactory 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 gal’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 7.5b and c). Flanking the perpendicular plate on each side is a lateral mass riddled with the ethmoid sinuses, also called the ethmoidal air cells (Figures 7.10 and 7.15), 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 7.14a). 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**

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

For answers, see Appendix G.

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**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’di-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 mandibular condyle 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 margin (al-ve’o-lar), contains the sockets (alveoli) in which the teeth are embedded. In the midline of the mandibular body is a slight depression, 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.
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 margins. Just inferior to the nose the maxillae meet medially, forming the pointed anterior nasal spine at their junction. The palatine processes (pāl’lah-tin) of the maxillae project posteriorly from the alveolar margins and fuse medially at the intermaxillary suture, forming the anterior two-thirds of the hard palate, or bony roof of the mouth (Figures 7.5b and c 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.

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 7.15), 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 maxillae anteriorly, and with the zygomatic processes of the maxillae anteriorly. The zygomatic bones form the prominent cheeks and part of the inferolateral margins of the orbits.

Nasal Bones
The thin, basically rectangular nasal bones (nasal) 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 (lacrimal) 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 7.14a 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 (vomer; "plow") lies in the nasal cavity, where it forms part of the nasal septum (see Figures 7.4a and 7.14b). 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 7.14a). 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.

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 7.12). 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.

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.

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 7.13. 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 7.14). The roof of the nasal cavity is formed by the cribiform 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 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 7.14b). A sheet of cartilage called the septal cartilage completes the septum anteriorly.

The nasal septum and conchae are covered with a mucous-secreting mucosa that moistens and warms the entering air and helps cleanse it of debris. The scroll-shaped conchae increase
Figure 7.14 Bones of the nasal cavity. (See A Brief Atlas of the Human Body, Figure 15.)
TABLE 7.1  Bones of the Skull

<table>
<thead>
<tr>
<th>BONE COLOR CODE*</th>
<th>COMMENTS</th>
<th>IMPORTANT MARKINGS</th>
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<tbody>
<tr>
<td><strong>Cranial Bones</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontal (1)</td>
<td>Forms forehead, superior part of orbits, and most of the anterior cranial fossa; contains sinuses</td>
<td>Supraorbital foramina (notches): allow the supraorbital arteries and nerves to pass</td>
</tr>
<tr>
<td>(Figures 7.4a, 7.5, and 7.7)</td>
<td></td>
<td>Foramen magnum: allows passage of the spinal cord from the brain stem to the vertebral canal</td>
</tr>
<tr>
<td>Parietal (2)</td>
<td>Form most of the superior and lateral aspects of the skull</td>
<td>Hypoglossal canals: allow passage of the hypoglossal nerves (cranial nerve XII)</td>
</tr>
<tr>
<td>(Figures 7.4 and 7.5)</td>
<td></td>
<td>Occipital condyles: articulate with the atlas (first vertebra)</td>
</tr>
<tr>
<td>Occipital (1)</td>
<td>Forms posterior aspect and most of the base of the skull</td>
<td>External occipital protuberance and nuchal lines: sites of muscle attachment</td>
</tr>
<tr>
<td>(Figures 7.4b, 7.5, 7.6, and 7.7)</td>
<td></td>
<td>External occipital crest: attachment site of ligamentum nuchae</td>
</tr>
<tr>
<td>Temporal (2)</td>
<td>Form inferolateral aspects of the skull and contributes to the middle cranial fossa; has squamous, mastoid, tympanic, and petrous regions</td>
<td>Zygomatic process: helps to form the zygomatic arch, which forms the prominence of the cheek</td>
</tr>
<tr>
<td>(Figures 7.5, 7.6, 7.7, and 7.8)</td>
<td></td>
<td>Mandibular fossa: articular point of the mandibular condyle</td>
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<tr>
<td>Sphenoid (1)</td>
<td>Keystone of the cranium; contributes to the middle cranial fossa and orbits; main parts are the body, greater wings, lesser wings, and pterygoid processes</td>
<td>External acoustic meatus: canal leading from the external ear to the eardrum</td>
</tr>
<tr>
<td>(Figures 7.4a, 7.5, 7.6, 7.7, and 7.9)</td>
<td></td>
<td>Styloid process: attachment site for several neck muscles and for a ligament to the hyoid bone</td>
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<td></td>
<td></td>
<td>Mastoid process: attachment site for several neck and tongue muscles</td>
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<td></td>
<td></td>
<td>Stylomastoid foramen: allows cranial nerve VII (facial nerve) to pass</td>
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<td>Jugular foramen: allows passage of the internal jugular vein and cranial nerves IX, X, and XI</td>
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<td>Internal carotid foramen: allows passage of cranial nerves VII and VIII</td>
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<td></td>
<td>Carotid canal: allows passage of the internal carotid artery</td>
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<td></td>
<td></td>
<td>Sella turcica: hypophyseal fossa portion is the seat of the pituitary gland</td>
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<td></td>
<td></td>
<td>Optic canals: allow passage of optic nerves (cranial nerves II) and the ophthalmic arteries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Superior orbital fissures: allow passage of cranial nerves III, IV, VI, part of V (ophthalmic division), and ophthalmic vein</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Foramen rotundum (2): allows passage of the maxillary division of cranial nerve V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Foramen ovale (2): allows passage of the mandibular division of cranial nerve V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Foramen spinosum (2): allows passage of the middle meningeal artery</td>
</tr>
</tbody>
</table>
**TABLE 7.1**

<table>
<thead>
<tr>
<th>BONE COLOR CODE</th>
<th>COMMENTS</th>
<th>IMPORTANT MARKINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ethmoid (1)</strong></td>
<td>Helps to form the anterior cranial fossa; forms part of the nasal septum and the lateral walls and roof of the nasal cavity; contributes to the medial wall of the orbit</td>
<td>Crista galli: attachment point for the falx cerebri, a dural membrane fold&lt;br&gt;Cribriform plates: allow passage of filaments of the olfactory nerves (cranial nerve I)&lt;br&gt;Superior and middle nasal conchae: form part of lateral walls of nasal cavity; increase turbulence of air flow</td>
</tr>
<tr>
<td><strong>Auditory ossicles (malleus, incus, and stapes) (2 each)</strong></td>
<td>Found in middle ear cavity; involved in sound transmission; see Figure 15.25b, p. 575</td>
<td></td>
</tr>
</tbody>
</table>

**Facial Bones**

| Mandible (1) | The lower jaw | Coronoid processes: insertion points for the temporalis muscles<br>Mandibular condyles: articulate with the temporal bones in the temporomandibular joints of the jaw<br>Mandibular symphysis: medial fusion point of the mandibular bones<br>Alveoli: sockets for the teeth<br>Mandibular foramina: permit the inferior alveolar nerves to pass<br>Mental foramina: allow blood vessels and nerves to pass to the chin and lower lip |
| Maxilla (2) | Keystone bones of the face; form the upper jaw and parts of the hard palate, orbits, and nasal cavity walls | Zygomatic processes: help form the zygomatic arches<br>Palatine process: forms the anterior hard palate; meet medially in intermaxillary suture<br>Frontal process: forms part of lateral aspect of bridge of nose<br>Incisive fossa: permits blood vessels and nerves to pass through anterior hard palate (fused palatine processes)<br>Inferior orbital fissure: permits maxillary branch of cranial nerve V, the zygomatic nerve, and blood vessels to pass<br>Infraorbital foramen: allows passage of infraorbital nerve to skin of face |
| Zygomatic (2) | Form the cheeks and part of the orbits | Lacrimal fossa: houses the lacrimal sac, which helps to drain tears into the nasal cavity<br>Median palatine suture: medial fusion point of the horizontal plates of the palatine bones, which form the posterior part of the hard palate |
| Nasal (2) | Form the bridge of the nose | |
| Lacrimal (2) | Form part of the medial orbit walls | |
| Palatine (2) | Form posterior part of the hard palate and a small part of nasal cavity and orbit walls | |
| Vomer (1) | Inferior part of the nasal septum | |
| Inferior nasal concha (2) | Form part of the lateral walls of the nasal cavity | |

*The color code beside each bone name corresponds to the bone’s color in Figures 7.4 to 7.13. The number in parentheses ( ) following the bone name indicates the total number of such bones in the body.*
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.

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 7.15).

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 G.

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’té-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.

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’vi-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.

**HOMEOSTATIC IMBALANCE**

There are several types of abnormal spinal curvatures. 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.

*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 or cell-phone 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 7.17). 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
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 7.17a, 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.

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.

**Figure 7.17** Ligaments and fibrocartilage discs uniting the vertebrae.

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) 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 7.17c, 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, the disc can be partially 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.
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 G.

General Structure ofVertebrae

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 7.18). 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’i-kelz; “little feet”), short bony pillars projecting posteriorly from the vertebral body, form the sides of the arch. The laminae (lam’i-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, 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. 222.

Cervical Vertebrae

The seven cervical vertebrae, identified as C1–C7, are the smallest, lightest vertebrae (see Figure 7.16). The first two (C1 and C2) are unusual and we will skip them for the moment. The “typical” cervical vertebrae (C3–C7) have the following distinguishing features (see Figure 7.20 and Table 7.2):

1. The body is oval—wider from side to side than in the anteroposterior dimension.
2. Except in C7, the spinous process is short, projects directly back, and is bifid (bi’fid), or split at its tip.
3. The vertebral foramen is large and generally triangular.
4. Each transverse process contains a transverse foramen through which the vertebral arteries pass to service the brain.

The spinous process of C7 is not bifid and is much larger than those of the other cervical vertebrae (see Figure 7.20a). Because its spinous process is palpable through the skin, C7 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 vertebrae. They have no intervertebral disc between them, and they are highly modified, reflecting their special functions. The atlas (C1) has no body and no spinous process (Figure 7.19a 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 (C2) 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 ligaments (Figure 7.20a), 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 (T1–T12) all articulate with the ribs (see Table 7.2, Figure 7.16, and Figure 7.20b). The first looks much like C7, and the last four show a progression toward lumbar vertebral structure. The thoracic vertebrae increase in size from the first to the last. Unique characteristics of these vertebrae include the following:

1. 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 T10–T12 vary from this pattern by having only a single facet to receive their respective ribs.)

2. The vertebral foramen is circular.

3. The spinous process is long and points sharply downward.

4. With the exception of T11 and T12, the transverse processes have facets, the transverse costal facets, that articulate with the tubercles of the ribs.

5. 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 (L1–L5) 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 7.20). Other characteristics typical of these vertebrae:

1. The pedicles and laminae are shorter and thicker than those of other vertebrae.

2. 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.

3. The vertebral foramen is triangular.

4. 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 (S1–S5) in adults (Figure 7.21, and see Figure 7.16). It articulates superiorly (via its superior articular processes) with L5 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”; “high point of land projecting into the sea”), the anterosuperior margin of the first
Figure 7.20 Posterolateral views of articulated vertebrae. Notice the bulbous tip on the spinous process of C7, the vertebra prominens. (See *A Brief Atlas of the Human Body*, Figures 19, 20, and 21.)

Figure 7.21 The sacrum and coccyx. (See *A Brief Atlas of the Human Body*, Figure 22.)
### TABLE 7.2 Regional Characteristics of Cervical, Thoracic, and Lumbar Vertebrae

<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>CERVICAL (3–7)</th>
<th>THORACIC</th>
<th>LUMBAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body</td>
<td>Small, wide side to side</td>
<td>Larger than cervical; heart shaped; bears two costal facets</td>
<td>Massive; kidney shaped</td>
</tr>
<tr>
<td>Spinous process</td>
<td>Short; bifid; projects directly poste-</td>
<td>Long; sharp; projects inferiorly</td>
<td>Short; blunt; rectangular; projects directly posteriorly</td>
</tr>
<tr>
<td>riorly</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertebral foramen</td>
<td>Triangular</td>
<td>Circular</td>
<td>Triangular</td>
</tr>
<tr>
<td>Transverse processes</td>
<td>Contain foramina</td>
<td>Bear facets for ribs (except T₁₁ and T₁₂)</td>
<td>Thin and tapered</td>
</tr>
<tr>
<td>Superior and inferior articulating</td>
<td>Superior facets directed supero-</td>
<td>Superior facets directed posteri-</td>
<td>Superior facets directed postero-</td>
</tr>
<tr>
<td>processes</td>
<td>posteriorly</td>
<td>riorly</td>
<td>medially (or medially)</td>
</tr>
<tr>
<td></td>
<td>Inferior facets directed inferoan-</td>
<td>Inferior facets directed ante-</td>
<td>Inferior facets directed anterolaterally (or laterally)</td>
</tr>
<tr>
<td></td>
<td>teriorly</td>
<td>riorly</td>
<td></td>
</tr>
<tr>
<td>Movements allowed</td>
<td>Flexion and extension; lateral flexio-</td>
<td>Rotation; lateral flexion possible but restricted by ribs; flexion and</td>
<td>Flexion and extension; some lateral flexion; rotation prevented</td>
</tr>
<tr>
<td></td>
<td>n; rotation; the spine region with the</td>
<td>extension limited</td>
<td></td>
</tr>
<tr>
<td></td>
<td>greatest range of movement</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Superior View**

![Superior View](a) Cervical  
![Superior View](b) Thoracic  
![Superior View](c) Lumbar

**Right Lateral View**

![Right Lateral View](a) Cervical  
![Right Lateral View](b) Thoracic  
![Right Lateral View](c) Lumbar
sacral vertebra, bulges anteriorly into the pelvic cavity. The body’s center of gravity lies about 1 cm posterior to this 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 S₁–S₅).

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 7.21, 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 G.

### 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 dorsally, the ribs laterally, and the sternum and costal cartilages anteriorly. The costal cartilages secure the ribs to the sternum (Figure 7.22a).

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 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 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 (zi’foid; “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**

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 7.22). 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 7.22b).

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 (zi’f-i-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 7.22a). 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’té-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’té-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 7.23). 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
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.

**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 G.

**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, or shoulder, girdle consists of the clavicle (klav’-i-kl) anteriorly and the scapula (skap’-u-la) posteriorly (Figure 7.24 and Table 7.3 on p. 232). 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:

1. 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.
2. 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**

The clavicles ("little keys"), or collarbones, are slender, doubly curved bones that can be felt along their entire course as they extend horizontally across the superior thorax (Figure 7.24). Each clavicle is cone shaped at its medial sternal end, which articulates with the sternal manubrium, and flattened at its lateral acromial end (ah-kro’m-e-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 which runs to attach 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 7.24a and Figure 7.25). Interestingly, their name derives from a word meaning “spade” or “shovel,” for ancient cultures...
Figure 7.25  The scapula. View (c) is accompanied by a schematic representation of its orientation. (See A Brief Atlas of the Human Body, Figure 24.)
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 arm pit and ends superiorly in a small, shallow fossa, the glenoid cavity (gle’noyd; “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-oid); 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 G.

The Upper Limb

Arm

The humerus (hu’mer-us), the sole bone of the arm, is a typical long bone (Figure 7.26). 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’tal). These tubercles are sites of attachment of the rotator cuff muscles. The intertubercular sulcus guides 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 deltoïd 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 (trock’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 7.26c and d). The condyle pair is flanked by the medial and lateral epicondyles (muscle attachment sites). Directly above these epicondyles are the median 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.

Forearm

Two parallel long bones, the radius and the ulna, form the skeleton of the forearm, or antebrachium (an’te-bra’ke-um) (Figure 7.27). 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 intersosseous 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. 258).
Ulna

The ulna (uln’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) and coronoid processes, separated by a deep concavity, the trochlear notch (Figure 7.27c). 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 process “locks” into the olecranon fossa (Figure 7.26d), keeping the forearm from hyperextending (moving posteriorly beyond the elbow joint). The posterior olecranon process 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 7.27d). Medial to the head is a styl oid 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 7.27). 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 7.26c). 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 7.27d), which articulates with the ulna, and a lateral **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**

Colle's 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 7.28) 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.

The carpals are arranged in two irregular rows of four bones each (Figure 7.28). In the proximal row (lateral to medial) are the scaphoid (skaf’oid; “boat-shaped”), lunate (lu’nät; “moon-like”), triquetrum (tri-kwet’rum; “triangular”), and pisiform (pi’si-form; “pea-shaped”). Only the scaphoid and lunate articulate with the radius to form the wrist joint. The carpals of the distal row (lateral to medial) are the trapezium (tra’h-pee’ze-um; “little table”), trapezoid (tra’peh-zoid; “four-sided”), capitate (“head-shaped”), and hamate (ham’Bät; “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: Sally left the party to take Cindy home. As with all such memory jogs, the first letter of each word is the first letter of the term you need to remember.

**HOMEOSTATIC IMBALANCE**

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 1 to 5.
## Table 7.3 Bones of the Appendicular Skeleton, Part 1: Pectoral Girdle and Upper Limb

<table>
<thead>
<tr>
<th>Location</th>
<th>Bone(s)</th>
<th>Illustration</th>
<th>Location</th>
<th>Markings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pectoral girdle</strong> (Figures 7.24, 7.25)</td>
<td>Clavicle (2)</td>
<td><img src="image" alt="Clavicle" /></td>
<td>Clavicle is in superoanterior thorax; articulates medially with sternum and laterally with scapula</td>
<td>Acromial end; sternal end</td>
</tr>
<tr>
<td></td>
<td>Scapula (2)</td>
<td><img src="image" alt="Scapula" /></td>
<td>Scapula is in posterior thorax; forms part of the shoulder; articulates with humerus and clavicle</td>
<td>Glenoid cavity; spine; acromion; coracoid process; infraspinous, supraspinous, and subscapular fossae</td>
</tr>
<tr>
<td><strong>Upper limb</strong></td>
<td>Humerus (2)</td>
<td><img src="image" alt="Humerus" /></td>
<td>Humerus is sole bone of arm; between scapula and elbow</td>
<td>Head; greater and lesser tubercles; intertubercular sulcus; radial groove; deltoid tuberosity; trochlea; capitulum; coronoid and olecranon fossae; epicondyles; radial fossa</td>
</tr>
<tr>
<td><strong>Arm</strong> (Figure 7.26)</td>
<td>Ulna (2)</td>
<td><img src="image" alt="Ulna" /></td>
<td>Ulna is the medial bone of forearm between elbow and wrist; with the humerus forms elbow joint</td>
<td>Coronoid process; olecranon process; radial notch; trochlear notch; styloid process; head</td>
</tr>
<tr>
<td><strong>Forearm</strong> (Figure 7.27)</td>
<td>Radius (2)</td>
<td><img src="image" alt="Radius" /></td>
<td>Radius is the lateral bone of forearm; articulates with carpals to form part of the wrist joint</td>
<td>Head; radial tuberosity; styloid process; ulnar notch</td>
</tr>
<tr>
<td><strong>Hand</strong> (Figure 7.28)</td>
<td>Carpals (16)</td>
<td><img src="image" alt="Carpals" /></td>
<td>Carpals form a bony crescent at the wrist; arranged in two rows of four bones each</td>
<td>Metacarpals form the palm; one in line with each digit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Phalanges form the fingers; three in digits 2–5; two in digit 1 (the thumb)</td>
</tr>
</tbody>
</table>

*The number in parentheses ( ) following the bone name denotes the total number of such bones in the body.*
from thumb to little finger. The bases of the metacarpals articulate with the carpals proximally and each other medially and laterally (Figure 7.28). 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 1, 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 1 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’ekz). In most people, the third finger is the longest. Each hand contains 14 miniature long bones called phalanges (fa’lan’jéz). 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 G.

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 7.29 and 7.30 and Table 7.4, p. 236). 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 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 7.29). The deep, basinlike structure formed by the hip bones, together with the sacrum and coccyx, is called the bony pelvis.

Each large, irregularly shaped hip bone consists of three separate bones during childhood: the ilium, ischium, and pubis (Figure 7.30). In adults, these bones are firmly fused and their
Figure 7.30 Bones of the pelvic girdle. 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). (See A Brief Atlas of the Human Body, Figure 28.)
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 ala, 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 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 joints (Figure 7.29). The weight of the body is transmitted from the spine to the pelvis through the sacroiliac joints. Running inferio rly 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 7.29 and 7.30). Roughly L-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 sacrotuberal 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 7.29 and 7.30). 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 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 pubic bone 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-rá-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 fibrocartilaginous disc, forming the midline pubic symphysis joint. Inferior to this joint, the inferior pubic ramus 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.

Pelvic Structure and Childbearing

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 7.29). 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
### TABLE 7.4 Comparison of the Male and Female Pelves

<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>FEMALE</th>
<th>MALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>General structure and functional</td>
<td>Tilted forward; adapted for childbearing; true pelvis defines the</td>
<td>Tilted less far forward; adapted for support of a male’s heavier</td>
</tr>
<tr>
<td>modifications</td>
<td>birth canal; cavity of the true pelvis is broad, shallow, and has a</td>
<td>build and stronger muscles; cavity of the true pelvis is narrow and</td>
</tr>
<tr>
<td></td>
<td>greater capacity</td>
<td>deep</td>
</tr>
<tr>
<td>Bone thickness</td>
<td>Less; bones lighter, thinner, and smoother</td>
<td>Greater; bones heavier and thicker, and markings are more prominent</td>
</tr>
<tr>
<td>Acetabula</td>
<td>Smaller; farther apart</td>
<td>Larger; closer</td>
</tr>
<tr>
<td>Pubic angle/arch</td>
<td>Broader (80° to 90°); more rounded</td>
<td>Angle is more acute (50° to 60°)</td>
</tr>
<tr>
<td>Anterior view</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sacrum</td>
<td>Wider; shorter; sacral curvature is accentuated</td>
<td>Narrow; longer; sacral promontory more ventral</td>
</tr>
<tr>
<td>Coccyx</td>
<td>More movable; straighter</td>
<td>Less movable; curves ventrally</td>
</tr>
<tr>
<td>Greater sciatic notch</td>
<td>Wide and shallow</td>
<td>Narrow and deep</td>
</tr>
<tr>
<td>Left lateral view</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pelvic inlet (brim)</td>
<td>Wider; oval from side to side</td>
<td>Narrow; basically heart shaped</td>
</tr>
<tr>
<td>Pelvic outlet</td>
<td>Wider; ischial tuberosities shorter, farther apart and everted</td>
<td>Narrower; ischial tuberosities longer, sharper, and point more</td>
</tr>
<tr>
<td>Posteroinferior view</td>
<td></td>
<td>medially</td>
</tr>
</tbody>
</table>
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 28.18c). 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?

For answers, see Appendix G.

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. 242).

Thigh

The femur (fe’mur; “thigh”), the single bone of the thigh (Figure 7.31), 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/cm² (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.

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 7.32). 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 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 proximal 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 distal 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
Figure 7.32 The tibia and fibula of the right leg. (See A Brief Atlas of the Human Body, Figure 30.)
quarter turn. The fibula does not bear weight, but several muscles originate from it.

**HOMEOSTATIC IMBALANCE**

A *Pott's fracture* occurs at the distal end of the fibula, the tibia, or both. It is a common sports injury. (See Figure 7.32e.)

**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 G.

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**Foot**

- Name the arches of the foot and explain their importance.

The skeleton of the foot includes the bones of the *tarsus*, the bones of the *metatarsus*, and the *phalanges*, or toe bones (Figure 7.33). 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.

**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*ei*-form; “wedge-shaped”). The cuboid and cuneiform bones articulate with the metatarsal bones anteriorly.

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**Figure 7.33 Bones of the right foot.** (See A Brief Atlas of the Human Body, Figure 31a, c, and d.)
**Metatarsus**

The **metatarsus** consists of five small, long bones called **metatarsals**. These are numbered 1 to 5 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 7.34), 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.

**HOMEOSTATIC IMBALANCE**

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.

**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 G.*
Bones of the Appendicular Skeleton, Part 2: Pelvic Girdle and Lower Limb

**TABLE 7.5**

<table>
<thead>
<tr>
<th>BODY REGION</th>
<th>BONES*</th>
<th>ILLUSTRATION</th>
<th>LOCATION</th>
<th>MARKINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvic girdle</td>
<td>Coxal (2) (hip)</td>
<td><img src="image" alt="Anterior view of pelvic girdle and left lower limb" /></td>
<td></td>
<td>liiac cret; anterior and poste-rior iliac spines; auricular sur-face; greater and lesser sciatic notches; obturator foramen; ischial tuberosity and spine; acetabulum; pubic arch; pu-bic crest; pubic tuberclke</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower limb</td>
<td>Femur (2)</td>
<td></td>
<td>Head; greater and lesser tro-chaners; neck; lateral and medial condyles and epicon-dyles; gluteal tuberosity; linea aspera</td>
<td></td>
</tr>
<tr>
<td>Thigh</td>
<td>Patella (2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kneecap</td>
<td>Tibia (2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg</td>
<td>Fibula (2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foot</td>
<td>7 Tarsals (14)</td>
<td>talus calcaneus navicular cuboid lateral cuneiform intermediate cuneiform medial cuneiform</td>
<td>5 Metatarsals (10)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>14 Phalanges (28)</td>
<td>distal middle proximal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

**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 7.35](#)). 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 1-½ to 2 years after birth. The others are replaced by bone by the end of the first year.
HOMEOSTATIC IMBALANCE

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 7.36). 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 7.38). 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 7.38 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 7.37).

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) may appear during the early school years, when rapid growth of the limb bones stretches many muscles. During the preschool years, lordosis is often present, but this is usually rectified as the abdominal
During youth, growth of the skeleton not only increases overall body height but also changes body proportions (Figure 7.38). 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). 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.

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 G.

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 *Making Connections* in Chapter 6 (pp. 192–193).

**RELATED CLINICAL TERMS**

**Chiropractic** (ki’ro-prak’tik) A system of treating disease by manipulating the vertebral column based on the theory 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 (1 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.