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

DID YOU GET IT?

11. What are the three main parts of the axial skeleton?

12. Johnny was vigorously exercising the only joints in the skull that are freely movable. What would you guess he was doing?

13. Which skull bone(s) form the "keystone of the face"?

14. Which bone has the cribriform plate and crista galli?

15. Which bones are connected by the coronal suture? By the sagittal suture?

For answers, see Appendix D.

Vertebral Column (Spine)

- ✓ Name the parts of a typical vertebra, and explain in general how the cervical, thoracic, and lumbar vertebrae differ from one another.
- ✓ Discuss the importance of the intervertebral discs and spinal curvatures.
- ✓ Explain how the abnormal spinal curvatures (scoliosis, lordosis, and kyphosis) differ from one another.

Serving as the axial support of the body, the **vertebral column,** or **spine,** extends from the skull, which it supports, to the pelvis, where it transmits the weight of the body to the lower limbs. Some people think of the vertebral column as a rigid supporting rod, but that picture is inaccurate. Instead, the spine is formed from 26 irregular bones connected and reinforced by ligaments in such a way that a flexible, curved structure results (**Figure 5.16**). Running through the central cavity of the vertebral column is the delicate spinal cord, which the vertebral column surrounds and protects.

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

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

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

HOMEOSTATIC IMBALANCE

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

The discs and the S-shaped structure of the vertebral column work together to prevent shock to the head when we walk or run. They also make the body trunk flexible. The spinal curvatures in the thoracic and sacral regions are referred to as **primary curvatures** because they are present when we are born. Together the two primary curvatures produce the C-shaped spine of the newborn baby (**Figure 5.17**). The curvatures in the cervical and lumbar regions are referred to as **secondary curvatures** because they develop

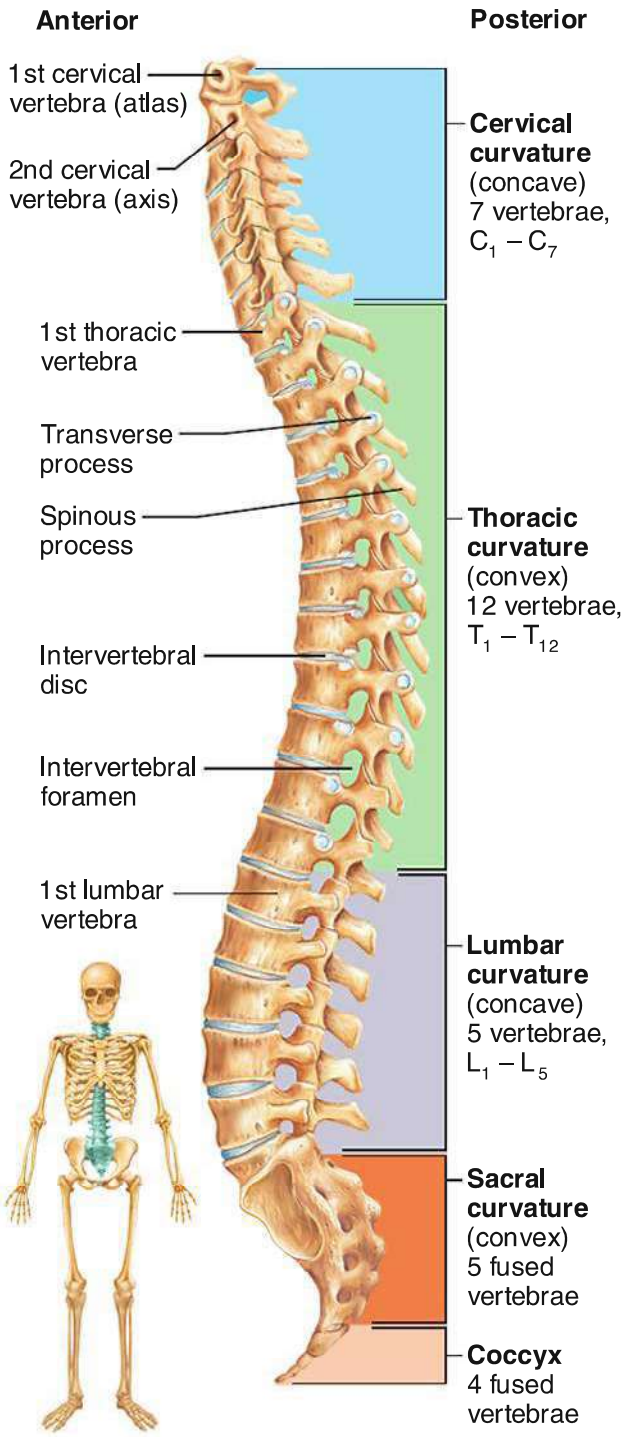


Figure 5.16 **The vertebral column.** Thin discs between the thoracic vertebrae allow great flexibility in the thoracic region; thick discs between the lumbar vertebrae reduce flexibility. Notice that the terms *convex* and *concave* refer to the curvature of the posterior aspect of the vertebral column.

Figure 5.17 **The C-shaped spine typical of a newborn.**

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

HOMEOSTATIC IMBALANCE

Why do they do "spine checks" in middle school? The answer is that they are looking for abnormal spinal curvatures. There are several types of abnormal spinal curvatures. **Figure 5.18** shows three of these—**scoliosis** (sko″le-o′sis), **kyphosis** (ki-fo′sis), and **lordosis** (lor-do′sis). These abnormalities may be congenital (present at birth) or result from disease, poor posture, or unequal muscle pull on the spine. As you look at these diagrams, try to pinpoint how each of these conditions differs from the normal healthy spine.

All vertebrae have a similar structural pattern (**Figure 5.19**). The common features of vertebrae include the following:

- **Body** or **centrum:** disclike, weight-bearing part of the vertebra facing anteriorly in the vertebral column.
- **Vertebral arch:** arch formed from the joining of all posterior extensions, the **laminae** and **pedicles,** from the vertebral body.
- **Vertebral foramen:** canal through which the spinal cord passes.
- **Transverse processes:** two lateral projections from the vertebral arch.

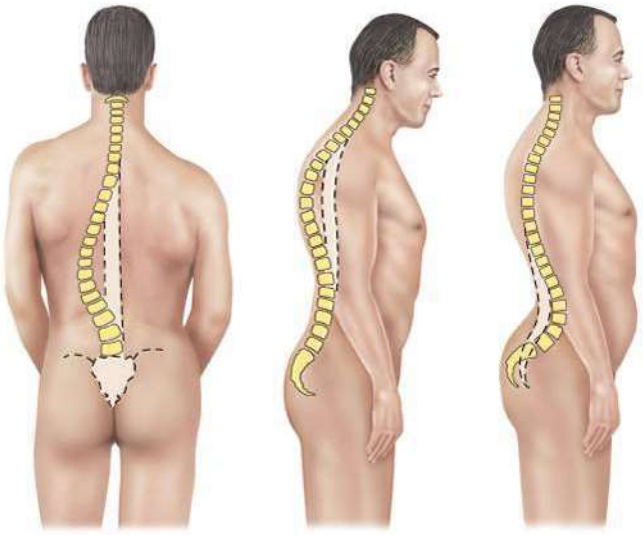


Figure 5.18 **Abnormal spinal curvatures.**

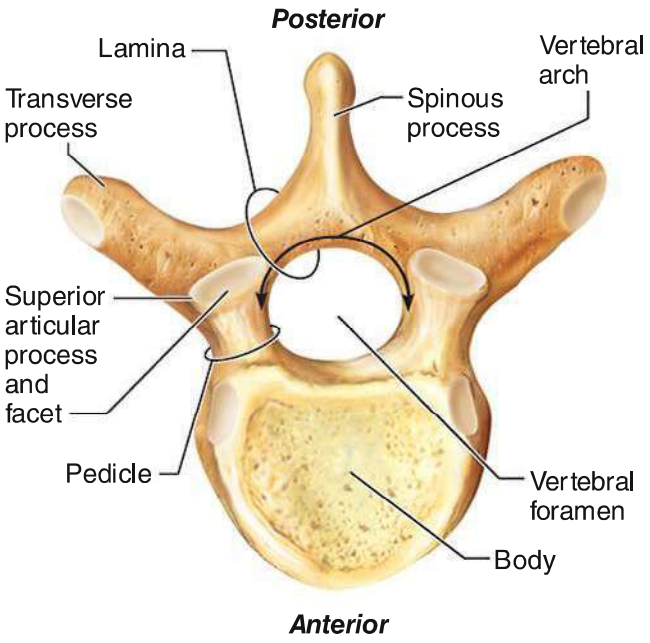


Figure 5.19 **A typical vertebra, superior view.** (Inferior articulating surfaces are not shown.)

- **Spinous process:** single projection arising from the posterior aspect of the vertebral arch (actually the fused laminae).
- **Superior and inferior articular processes:** paired projections lateral to the vertebral foramen, allowing a vertebra to form joints with adjacent vertebrae (see also **Figure 5.20**).

In addition to these common features, vertebrae in the different regions of the spine have very specific structural characteristics. We describe these unique regional characteristics of the vertebrae next.

Cervical Vertebrae

The seven **cervical vertebrae** (identified as C_1 to C_7) form the neck region of the spine. The first two vertebrae (*atlas* and *axis*) are different because they perform functions not shared by the other cervical vertebrae. As you can see in Figure 5.20a, the **atlas** (C_1) has no body. The superior surfaces of its transverse processes contain large depressions that receive the occipital condyles of the skull. This joint allows you to nod "yes." The **axis** (C_2) acts as a pivot for the rotation of the atlas (and skull) above. It has a large upright process, the **dens,** which acts as the pivot point. The joint between C_1 and C_2 allows you to rotate your head from side to side to indicate "no."

The "typical" cervical vertebrae (C_3 through C_7) are shown in Figure 5.20b. They are the smallest, lightest vertebrae, and most often their spinous processes are short and divided into two branches. The transverse processes of the cervical vertebrae contain foramina (openings) through which the vertebral arteries pass on their way to the brain above. Any time you see these foramina in a vertebra, you should know immediately that it is a cervical vertebra.

Thoracic Vertebrae

The 12 **thoracic vertebrae** (T_1 to T_{12}) are all typical. They are larger than the cervical vertebrae and are distinguished by the fact that they are the only vertebrae to articulate with the ribs. As seen in Figure 5.20c, the body is somewhat heart-shaped and has two costal facets (articulating surfaces) on each side, which receive the heads of the ribs. The two transverse processes of each thoracic vertebra articulate with the nearby knoblike tubercles of the ribs. The spinous process is long and hooks sharply downward, causing the vertebra to look like a giraffe's head viewed from the side.

Lumbar Vertebrae

The five **lumbar vertebrae** (L_1 to L_5) have massive, blocklike bodies. Their short, hatchet-shaped spinous processes (Figure 5.20d) make them look like a moose head from the lateral aspect. Because most of the stress on the vertebral column occurs in the lumbar region, these are the sturdiest of the vertebrae.

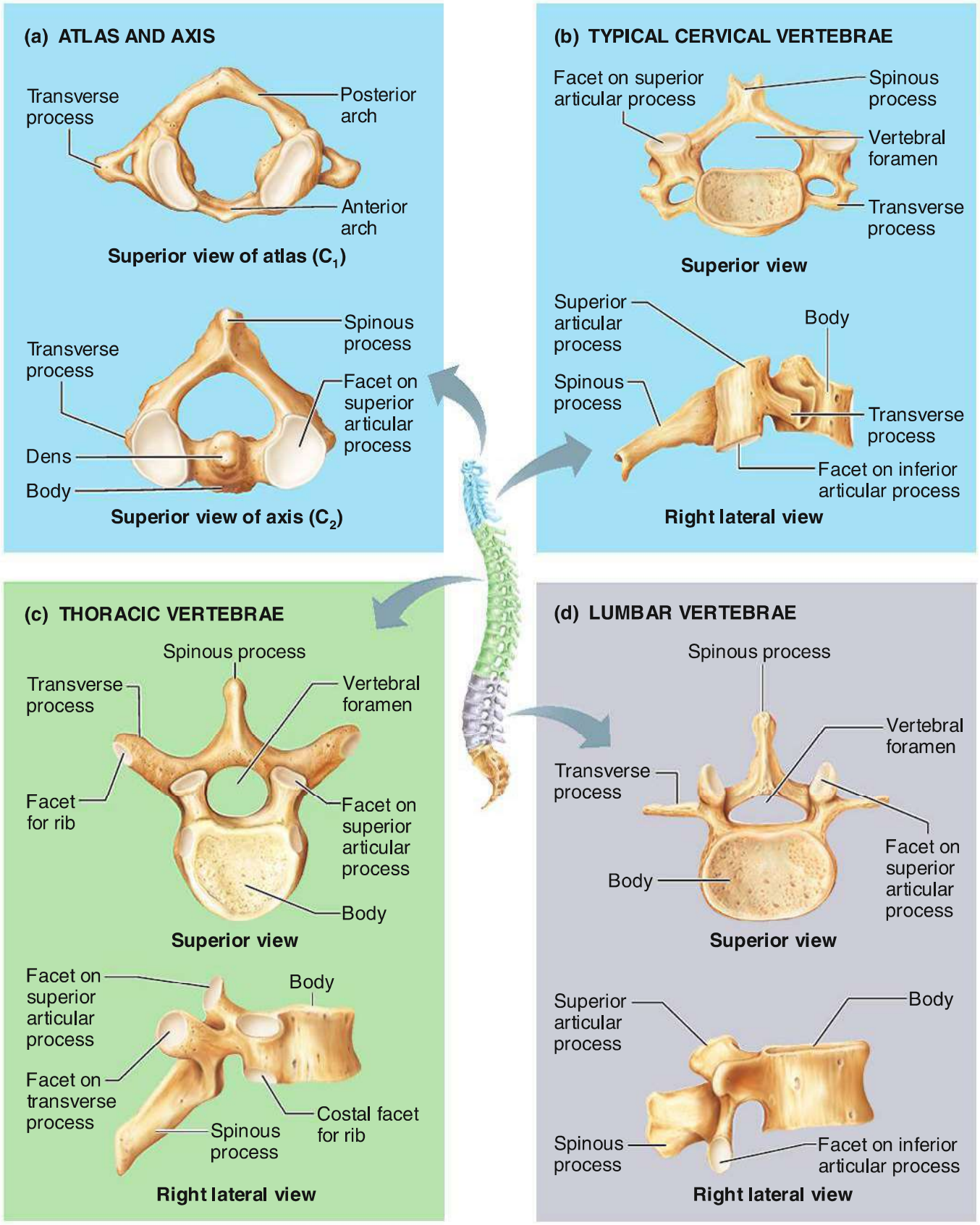


Figure 5.20 Regional characteristics of vertebrae.

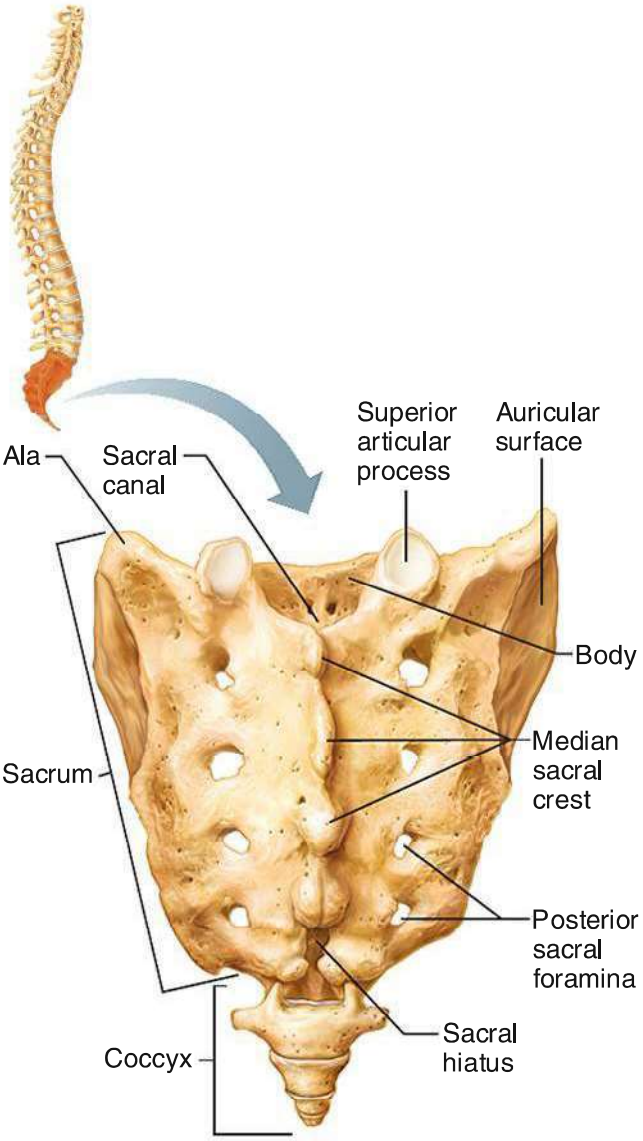


Figure 5.21 **Sacrum and coccyx, posterior view.**

Sacrum

The **sacrum** (sa′krum) is formed by the fusion of five vertebrae (**Figure 5.21**). Superiorly it articulates with L_5, and inferiorly it connects with the coccyx. The winglike **alae** articulate laterally with the hip bones, forming the sacroiliac joints. The sacrum forms the posterior wall of the pelvis. Its posterior midline surface is roughened by the **median sacral crest,** the fused spinous processes of the sacral vertebrae. This is flanked laterally by the *posterior sacral framina*. The vertebral canal continues inside the sacrum as the **sacral canal** and terminates in a large inferior opening called the **sacral hiatus.**

Coccyx

The **coccyx** is formed from the fusion of three to five tiny, irregularly shaped vertebrae (see Figure 5.21). It is the human "tailbone," a remnant of the tail that other vertebrate animals have.

Thoracic Cage

- ✓ Name the components of the thoracic cage.
- ✓ Describe how a true rib differs from a false rib.

The sternum, ribs, and thoracic vertebrae make up the **bony thorax.** The bony thorax is routinely called the **thoracic cage** because it forms a protective, cone-shaped cage of slender bones around the organs of the thoracic cavity (heart, lungs, and major blood vessels). The bony thorax is shown in **Figure 5.22**.

Sternum

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

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

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

Palpate your sternal angle and jugular notch.

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

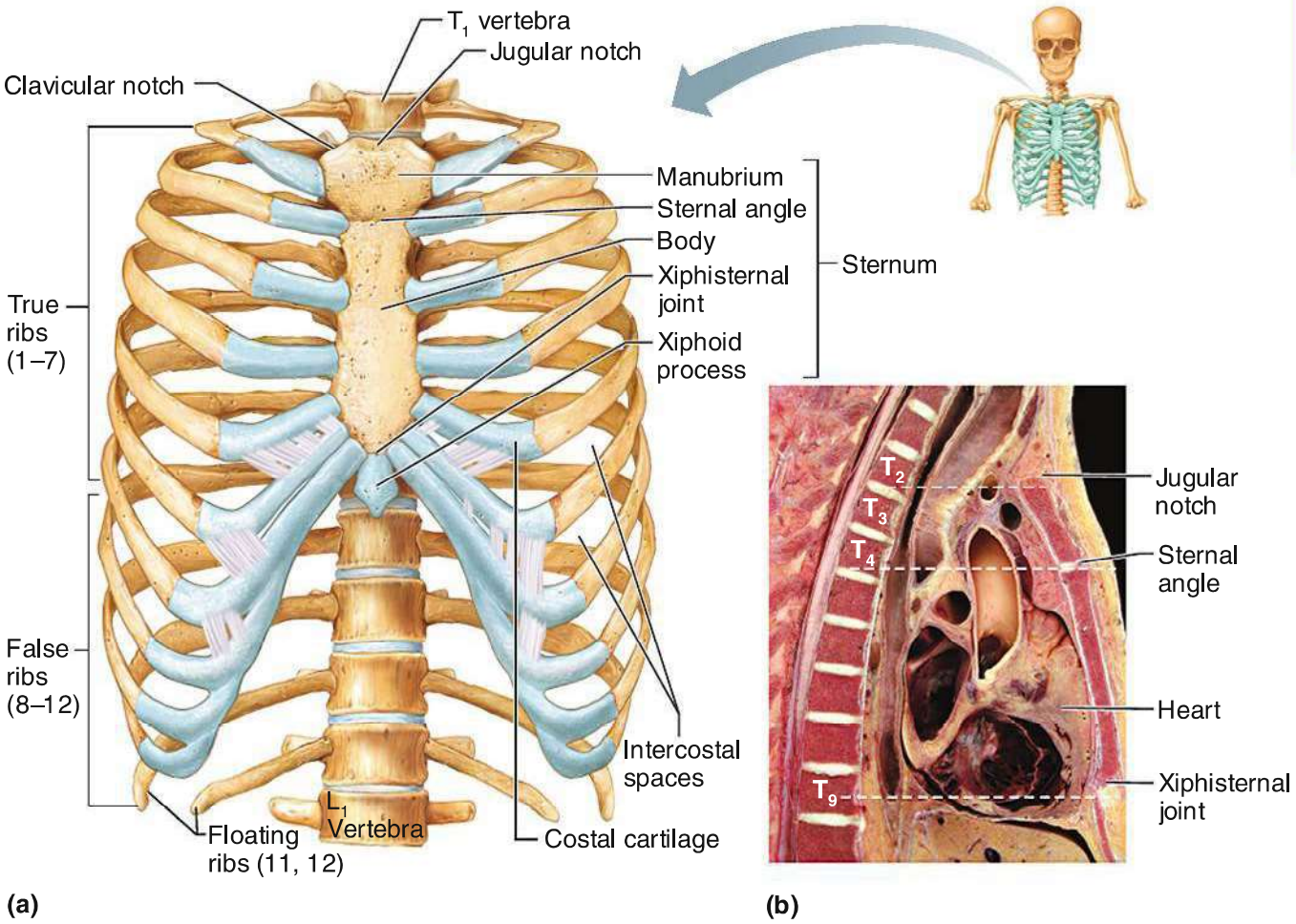


Figure 5.22 **The bony thorax (thoracic cage).** **(a)** Anterior view. **(b)** Midsagittal section through the thorax, showing the relationship of the key parts of the sternum to the vertebral column.

sternal puncture. Because the heart lies immediately posterior to the sternum, the physician must take extreme care not to penetrate through the sternum during this procedure.

Ribs

Twelve pairs of **ribs** form the walls of the bony thorax. (Contrary to popular misconception, men do *not* have one rib fewer than women!) All the ribs articulate with the vertebral column posteriorly and then curve downward and toward the anterior body surface. The **true ribs,** the first seven pairs, attach directly to the sternum by costal cartilages. **False ribs,** the next five pairs, either attach indirectly to the sternum or are not attached to the sternum at all. The last two pairs of false ribs lack the sternal attachments, so they are also called **floating ribs.**

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

DID YOU GET IT?

16. What are the five major regions of the vertebral column?
17. How can you distinguish a lumbar vertebra from a cervical vertebra?
18. What is a true rib? A false rib?
19. Besides the ribs and sternum, there is a third group of bones forming the thoracic cage. What is it?
20. What bone class do the ribs and skull bones fall into?

For answers, see Appendix D.

Appendicular Skeleton

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

The *appendicular skeleton* is shaded gold in Figure 5.8. It is composed of 126 bones of the limbs (appendages) and the pectoral and pelvic girdles, which attach the limbs to the axial skeleton.

Bones of the Shoulder Girdle

Each **shoulder girdle,** or **pectoral girdle,** consists of two bones—a clavicle and a scapula (**Figure 5.23**).

The **clavicle** (klav′ĭ-kl), or *collarbone,* is a slender, doubly curved bone. It attaches to the manubrium of the sternum medially (at its sternal end) and to the scapula laterally, where it helps to form the shoulder joint. The clavicle acts as a brace to hold the arm away from the top of the thorax and helps prevent shoulder dislocation. When the clavicle is broken, the whole shoulder region caves in medially, which shows how important its bracing function is.

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

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

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

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

Bones of the Upper Limbs

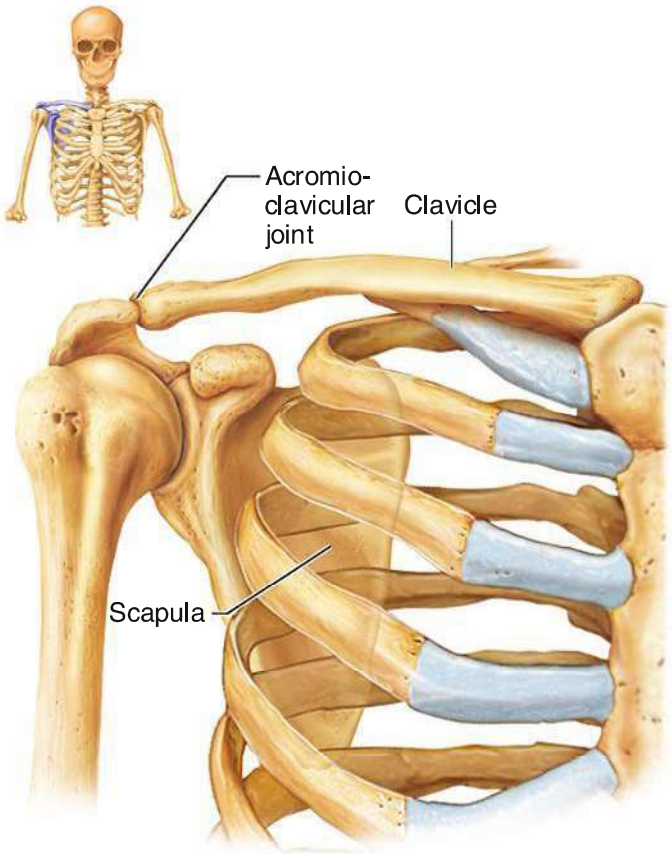
Thirty separate bones form the skeletal framework of each upper limb (**Figures 5.24** and **5.25**). They form the foundations of the arm, forearm, and hand.

Arm

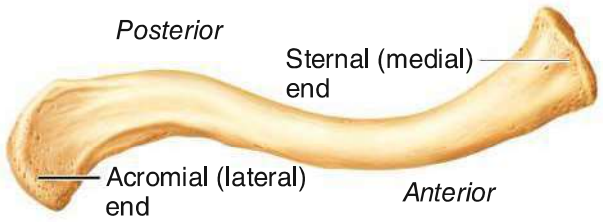
The arm is formed by a single bone, the **humerus** (hu′mer-us), which is a typical long bone (see Figure 5.24a and b). At its proximal end is a rounded head that fits into the shallow glenoid cavity of the scapula. Immediately inferior to the head is a slight constriction called the **anatomical neck.** Anterolateral to the head are two bony projections separated by the **intertubercular sulcus**—the **greater** and **lesser tubercles,** which are sites of muscle attachment. Just distal to the tubercles is the **surgical neck,** so named because it is the most frequently fractured part of the humerus. In the midpoint of the shaft is a roughened area called the **deltoid tuberosity,** where the large, fleshy deltoid muscle of the shoulder attaches. Nearby, the **radial groove** runs obliquely down the posterior aspect of the shaft. This groove marks the course of the radial nerve, an important nerve of the upper limb. At the distal end of the humerus is the medial **trochlea** (trok′le-ah), which looks somewhat like a spool, and the lateral ball-like **capitulum** (kah-pit′u-lum). Both of these processes articulate with bones of the forearm. Above the trochlea anteriorly is a depression, the **coronoid fossa;** on the posterior surface is the **olecranon** (o-lek′rah-non) **fossa.** These two depressions, which are flanked by **medial** and **lateral epicondyles,** allow the corresponding processes of the ulna to move freely when the elbow is bent and extended.

Forearm

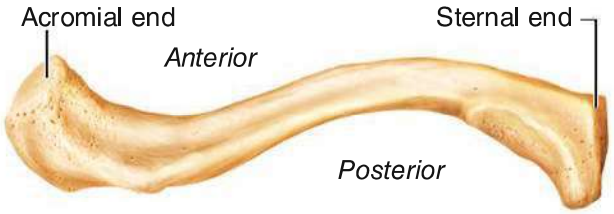
Two bones, the radius and the ulna, form the skeleton of the forearm (see Figure 5.24c). When the body is in the anatomical position, the **radius**



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

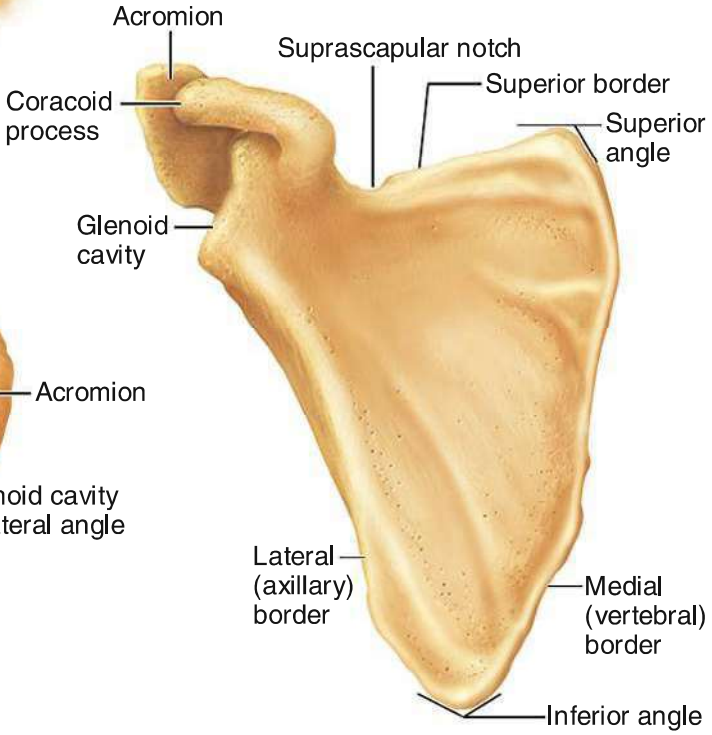


Superior view

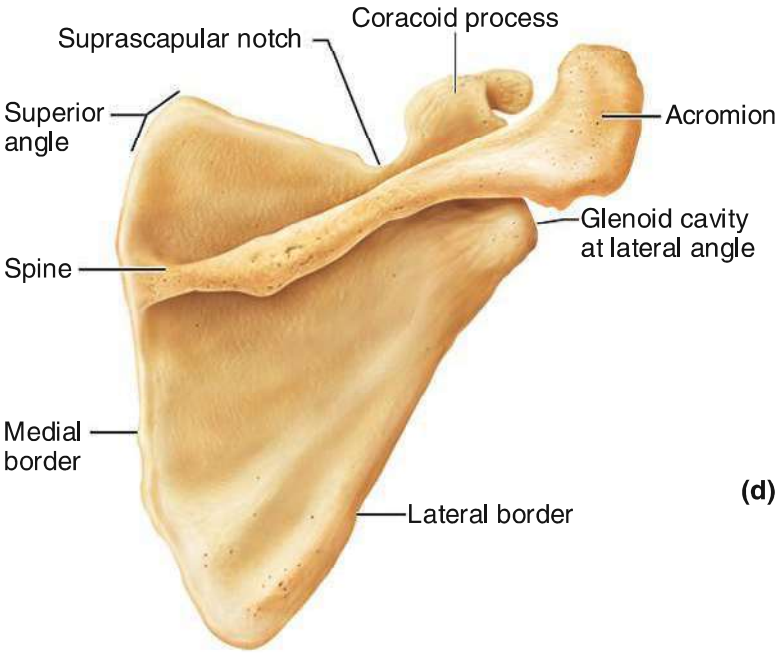


Inferior view

(b) Right clavicle, superior and inferior views



(d) Right scapula, anterior aspect



(c) Right scapula, posterior aspect

Figure 5.23 Bones of the shoulder girdle.

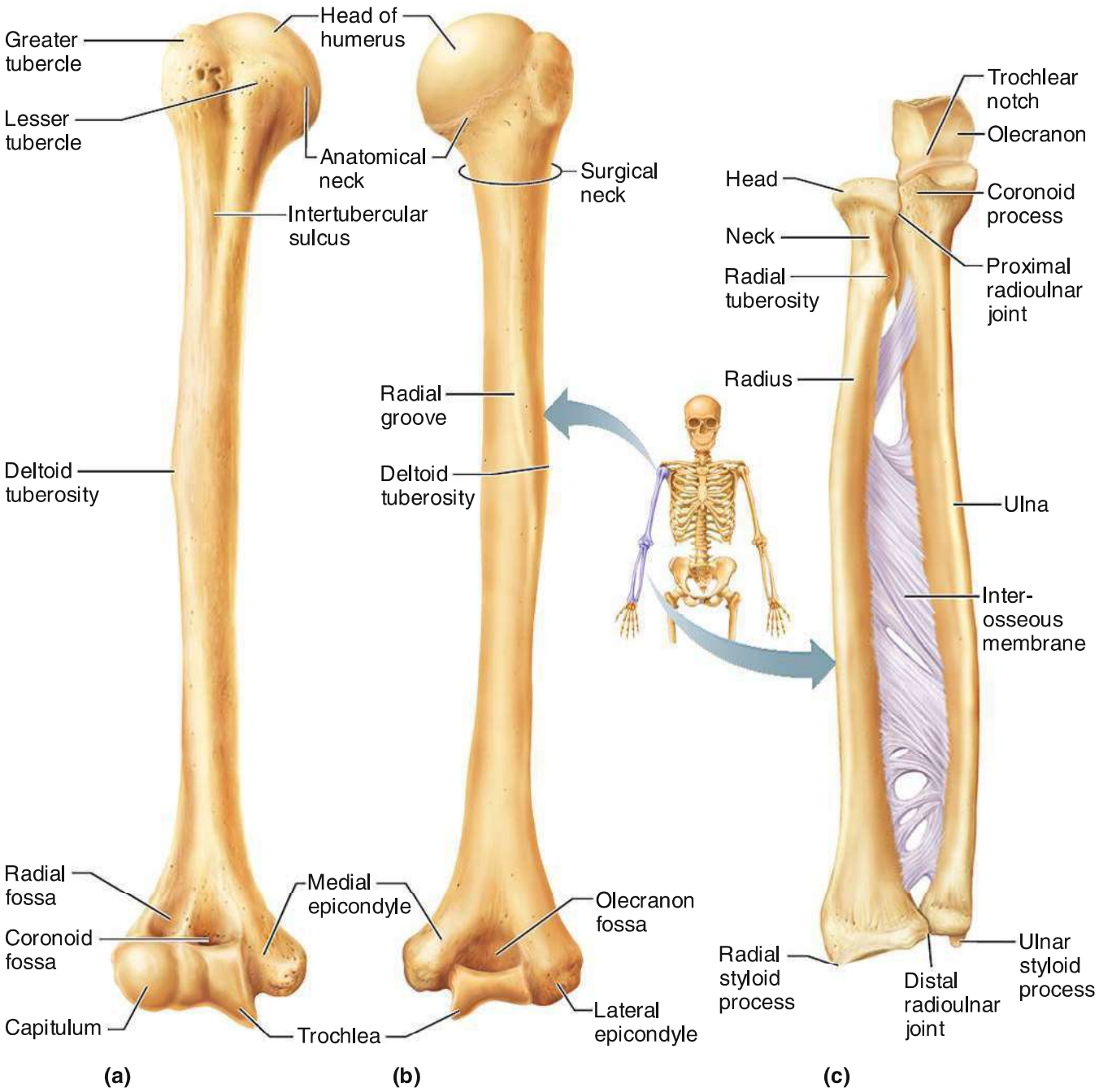


Figure 5.24 Bones of the right arm and forearm. (a) Humerus, anterior view. **(b)** Humerus, posterior view. **(c)** Anterior view of the bones of the forearm: the radius and the ulna.

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

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

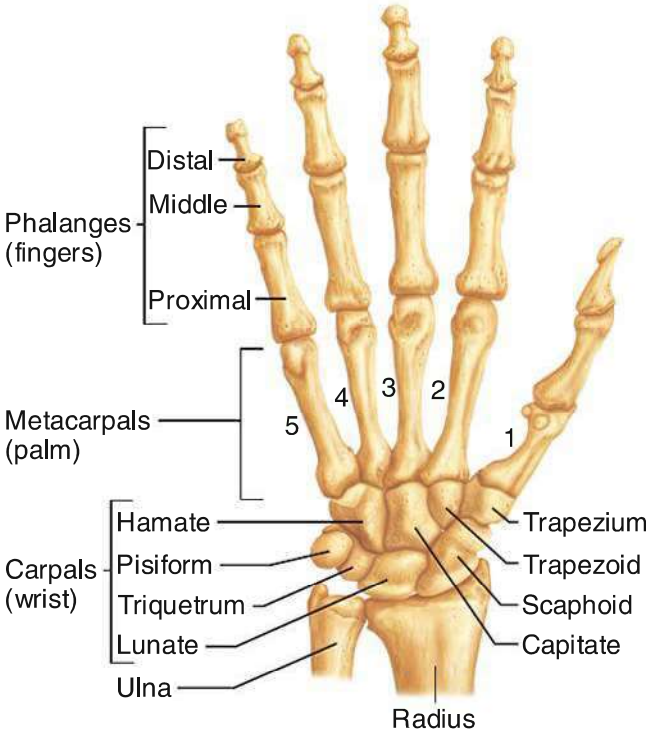


Figure 5.25 **Bones of the right hand, anterior view.**

When the upper limb is in the anatomical position, the **ulna** is the medial bone (on the little-finger side) of the forearm. On its proximal end are the anterior **coronoid process** and the posterior **olecranon,** which are separated by the **trochlear notch.** Together these two processes grip the trochlea of the humerus in a pliers-like joint.

Hand

The skeleton of the hand consists of the carpals, the metacarpals, and the phalanges (Figure 5.25). The eight **carpal bones,** arranged in two irregular rows of four bones each, form the part of the hand called the **carpus** or, more commonly, the *wrist.* The carpals are bound together by ligaments that restrict movements between them. (In case you need to learn their names, the individual carpal bones are identified in Figure 5.25.)

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

DID YOU GET IT?

21. Contrast the general function of the axial skeleton to that of the appendicular skeleton.

22. What is the single point of attachment of the shoulder girdle to the axial skeleton?

23. What bone forms the skeleton of the arm?

24. Where are the carpals found, and what type (long, short, irregular, or flat) of bone are they?

25. Which bones of the upper limb have a styloid process?

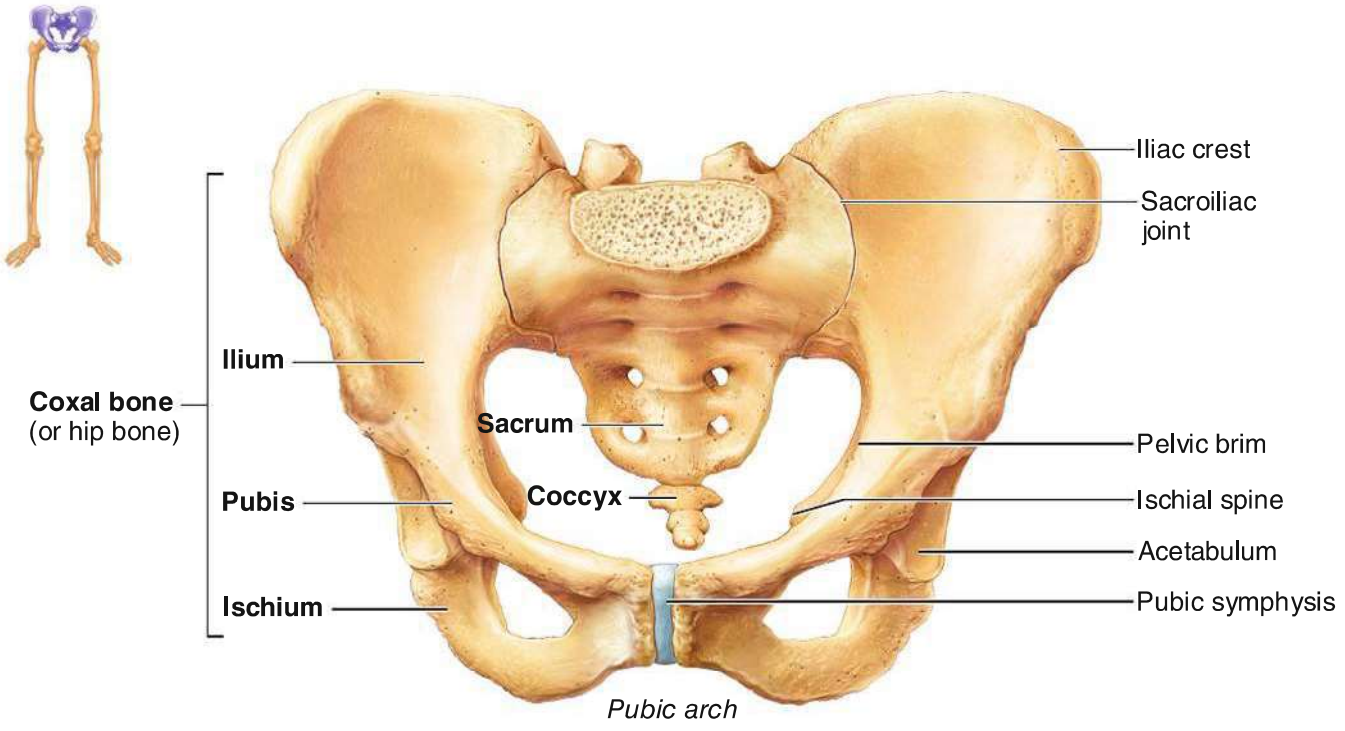
For answers, see Appendix D.

Bones of the Pelvic Girdle

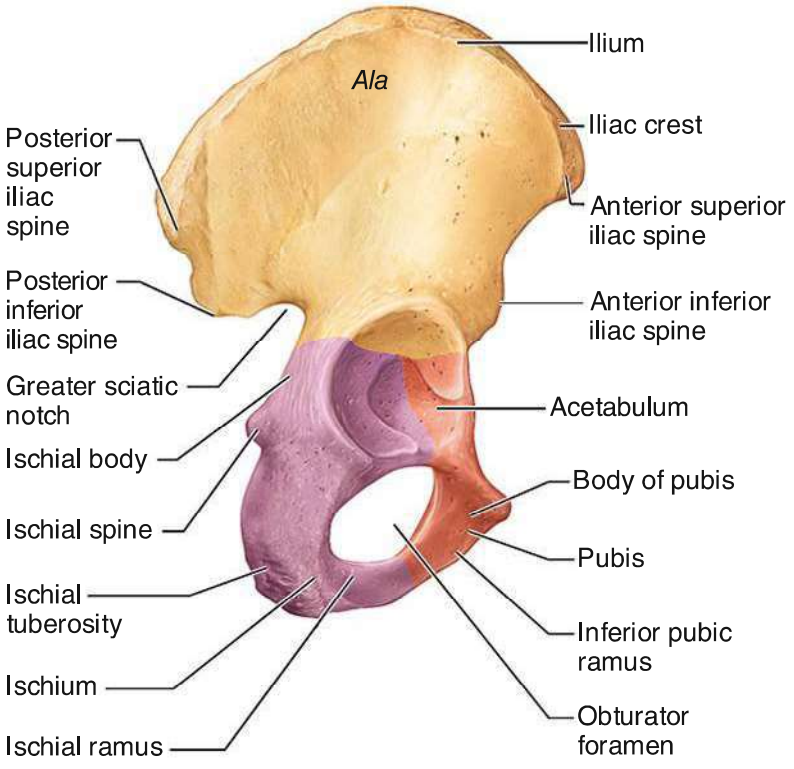
The **pelvic girdle** is formed by two **coxal** (kok′sal) **bones,** or **ossa coxae,** commonly called **hip bones,** and the sacrum (described on p. 156). Together with the coccyx, the pelvic girdle forms the *pelvis* (**Figure 5.26**). Note that the terms *pelvic girdle* and *bony pelvis* have slightly different meanings (pelvic girdle = 2 coxal bones and sacrum; bony pelvis = 2 coxal bones, sacrum, and coccyx).

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

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



(a)



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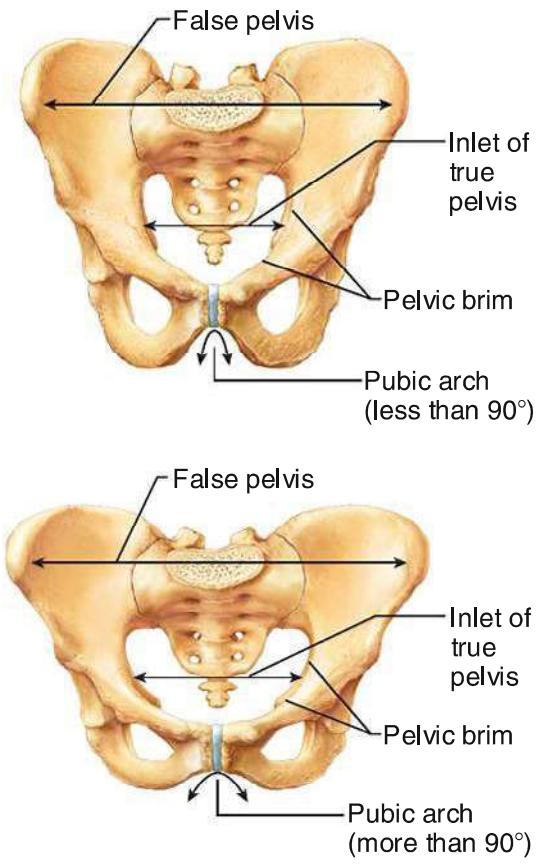

(c)

Figure 5.26 **The bony pelvis.** **(a)** Articulated pelvis. **(b)** Right coxal (hip) bone, showing the point of fusion of the ilium, ischium, and pubic bones. **(c)** Comparison of the pelves of the male (above) and female (below).

ends anteriorly in the **anterior superior iliac spine** and posteriorly in the **posterior superior iliac spine.** Small inferior spines are located below these.

The **ischium** (is′ke-um) is the "sit-down bone," so called because it forms the most inferior part of the coxal bone. The **ischial tuberosity** is a roughened area that receives body weight when you are sitting. The **ischial spine,** superior to the tuberosity, is another important anatomical landmark, particularly in the pregnant woman, because it narrows the outlet of the pelvis through which the baby must pass during birth. Another important structural feature of the ischium is the **greater sciatic notch,** which allows blood vessels and the large sciatic nerve to pass from the pelvis posteriorly into the thigh. Injections in the buttock should always be given well away from this area.

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

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

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

Of course, individual pelvic structures vary, but there are fairly consistent differences between a male and a female pelvis. Look at Figure 5.26c and notice the following characteristics that differ in the pelvis of the man and woman:

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

DID YOU GET IT?

26. What three bones form the hip bone? What two bones form each pectoral girdle?

27. In what three ways does the bony pelvis of a woman differ from that of a man?

For answers, see Appendix D.

Bones of the Lower Limbs

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

Thigh

The **femur** (fe′mur), or *thigh bone,* is the only bone in the thigh (**Figure 5.27a** and b). It is the heaviest, strongest bone in the body. Its proximal end has a ball-like head, a neck, and **greater** and **lesser trochanters** (separated anteriorly by the **intertrochanteric line** and posteriorly by the **intertrochanteric crest**). These markings and the **gluteal tuberosity,** located on the shaft, all serve as sites for muscle attachment. The head of the femur articulates with the acetabulum of the hip bone in a deep, secure socket. However, the neck of the femur is a common fracture site, especially in old age.

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