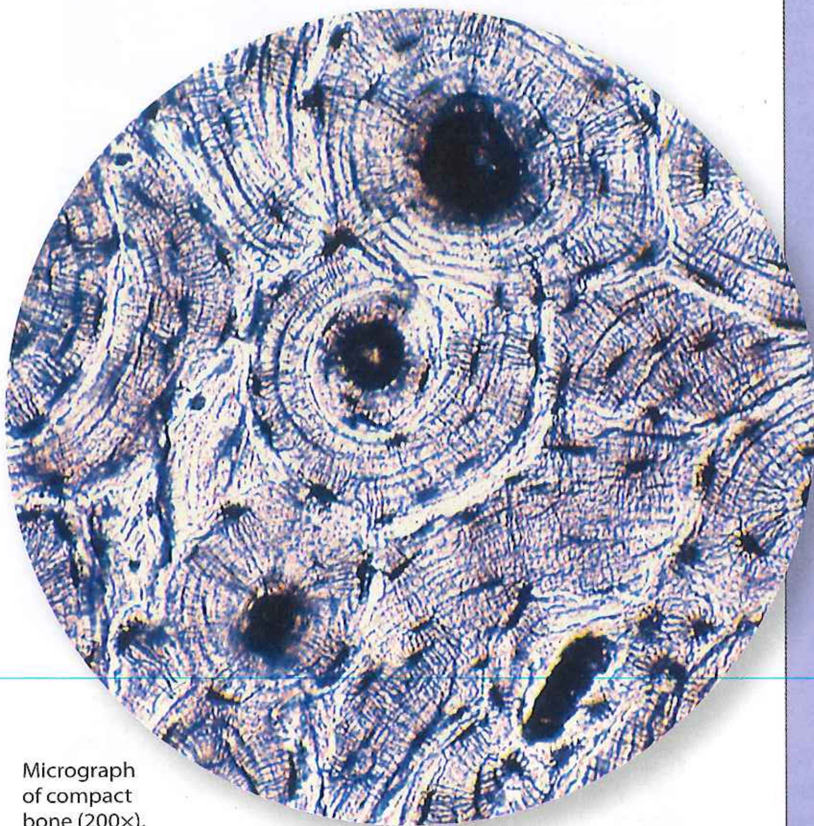
7 Skeletal System



Micrograph of compact bone (200×).

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Module 5: Skeletal System

Learning Outcomes

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

7.1 Introduction

1 Discuss the active tissues found in a bone. (p. 202)
2 List the general functions of the skeletal system. (p. 202)
3 Classify bones according to their shapes, and name an example from each group. (p. 202)

7.2 Bone Structure

4 Describe the macroscopic and microscopic structure of a long bone, and list the functions of these parts. (p. 203)

7.3 Bone Development and Growth

5 Distinguish between intramembranous and endochondral bones, and explain how such bones develop and grow. (p. 204)
6 Describe the effects of sunlight, nutrition, hormonal secretions, and exercise on bone development and growth. (p. 209)

7.4 Bone Function

7 Discuss the major functions of bones. (p. 211)

7.5 Skeletal Organization

8 Distinguish between the axial and appendicular skeletons, and name the major parts of each. (p. 214)

7.6 Skull–7.12 Lower Limb

9 Locate and identify the bones and the major features of the bones that comprise the skull, vertebral column, thoracic cage, pectoral girdle, upper limb, pelvic girdle, and lower limb. (p. 217)
10 Describe the differences between male and female skeletons. (p. 242)

7.13 Life-Span Changes

11 Describe life-span changes in the skeletal system. (p. 247)

LEARN PRACTICE ASSESS

Understanding Words

acetabul-, vinegar cup: *acetabul*um—depression of the hip bone that articulates with the head of the femur.

ax-, axis: *ax*ial skeleton—upright portion of the skeleton that supports the head, neck, and trunk.

-blast, bud, a growing organism in early stages: osteo*blast*—cell that will form bone tissue.

canal-, channel: *canal*iculus—tubular passage.

carp-, wrist: *carp*als—wrist bones.

-clast, break: osteo*clast*—cell that breaks down bone tissue.

clav-, bar: *clav*icle—bone that articulates with the sternum and scapula.

condyl-, knob, knuckle: *condyl*e—rounded, bony process.

corac-, a crow's beak: *corac*oid process—beaklike process of the scapula.

cribr-, sieve: *cribr*iform plate—portion of the ethmoid bone with many small openings.

crist-, crest: *crist*a galli—bony ridge that projects upward into the cranial cavity.

fov-, pit: *fov*ea capitis—pit in the head of a femur.

glen-, joint socket: *glen*oid cavity—depression in the scapula that articulates with the head of a humerus.

inter-, among, between: *inter*vertebral disc—structure between vertebrae.

intra-, inside: *intra*membranous bone—bone that forms within sheetlike masses of connective tissue.

lamell-, thin plate: *lamell*a—thin, bony plate.

meat-, passage: external acoustic *meat*us—canal of the temporal bone that leads inward to parts of the ear.

odont-, tooth: *odont*oid process—toothlike process of the second cervical vertebra.

poie-, make, produce: hemato*poie*sis—process that forms blood cells.

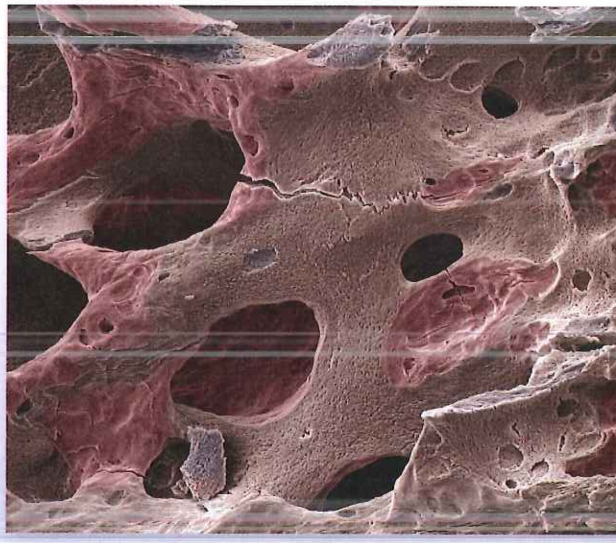
Preventing Fragility Fractures

Skeletal health is a matter of balance. Before age thirty, cells that form new bone counter cells that degrade it, so that living bone is in a constant state of remodeling. Then the balance shifts so that bone is lost, especially in women past menopause, due to hormonal changes. This imbalance may progress to osteopenia or the more severe osteoporosis.

A "fragility fracture" is a telltale sign of dangerously low bone density. This is a fracture that happens after a fall from less than standing height, which a strong, healthy skeleton could resist. Fragility fractures occur in 1.5 million people in the United States each year, yet despite this warning sign, only one-fourth to one-third of them are followed up with bone scans and treatment to build new bone tissue. Since 1995, five new drugs have become available to treat osteoporosis. One class, the bisphosphonates, actually builds new bone.

Osteopenia and osteoporosis are common. The surgeon general estimates that half of all people over age fifty have one of these conditions, which amounts to 10 million with osteoporosis and another 35 million with osteopenia. Screening is advised for all individuals over age sixty-five, as well as for those with risk factors. The most telling predictor is a previous fragility fracture. Other risk factors include a family history of osteoporosis, recent height loss, and older age.

Osteopenia and osteoporosis are not just concerns of older people approaching retirement age. People of all ages can take steps to avoid developing these preventable conditions. Researchers think that what puts people at risk is failure to attain maximal possible bone density by age thirty. To keep bones as strong as possible for as long as possible, it is essential to get at least 30 minutes of exercise daily (some of which should be weight-bearing), consume enough daily calcium (1,000–1,200 mg) and vitamin D (400–1,000 IU), and not smoke. There is much you can do to promote skeletal health—at any age. ■



Scanning electron micrograph (SEM) of bone in osteoporosis.

7.1 INTRODUCTION

A bone may appear to be inert because of nonliving material in the extracellular matrix of bone tissue. However, bone also includes active, living tissues: bone tissue, cartilage, dense connective tissue, blood, and nervous tissue. Bones are not only alive, but also multifunctional. Bones, the organs of the **skeletal system,** support and protect softer tissues, provide points of attachment for muscles, house blood-producing cells, and store inorganic salts.

Bones are classified according to their shapes—long, short, flat, or irregular (fig. 7.1).

- **Long bones** have long longitudinal axes and expanded ends. Examples of long bones are the forearm and thigh bones.
- **Short bones** are cubelike, with roughly equal lengths and widths. The bones of the wrists and ankles are this type. A special type of short bone is a **sesamoid bone,** or **round bone**. This type of bone is usually small and nodular and embedded in a tendon adjacent to a joint, where the tendon is compressed (see fig. 7.45*c*). The kneecap (patella) is a sesamoid bone.
- **Flat bones** are platelike structures with broad surfaces, such as the ribs, the scapulae, and some bones of the skull.
- **Irregular bones** have a variety of shapes, and most are connected to several other bones. Irregular bones include the vertebrae that compose the backbone, and many facial bones.

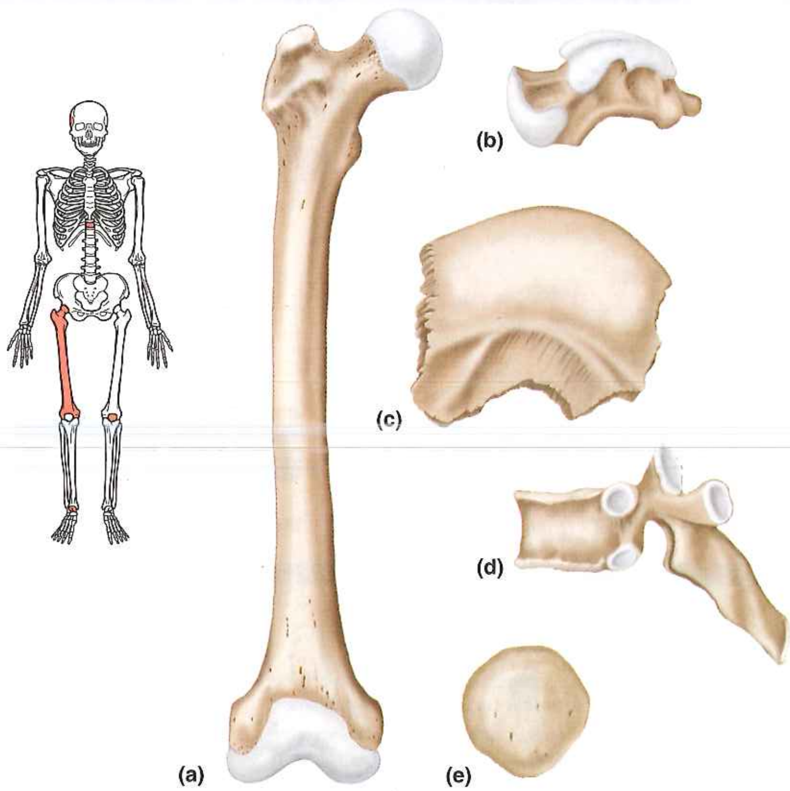


FIGURE 7.1 Bones are classified by shape. (*a*) The femur of the thigh is a long bone, (*b*) the talus of the ankle is a short bone, (*c*) a parietal bone of the skull is a flat bone, (*d*) a vertebra of the backbone is an irregular bone, and (*e*) the patella of the knee is a sesamoid bone. The whole-skeleton location icon highlights the bones used as examples for classification.

PRACTICE

1 Name the living tissues in bone.
2 List functions of the skeletal system.
3 Explain how bones are classified.

7.2 BONE STRUCTURE

The bones of the skeletal system vary greatly in size and shape. However, bones are similar in structure, development, and function.

Parts of a Long Bone

The femur, the long bone in the thigh, illustrates the structure of a bone (fig. 7.2). At each end of a long bone is an expanded portion called an **epiphysis** (e-pif′ĭ-sis) (pl., *epiphyses*), which articulates (or forms a joint) with another bone.

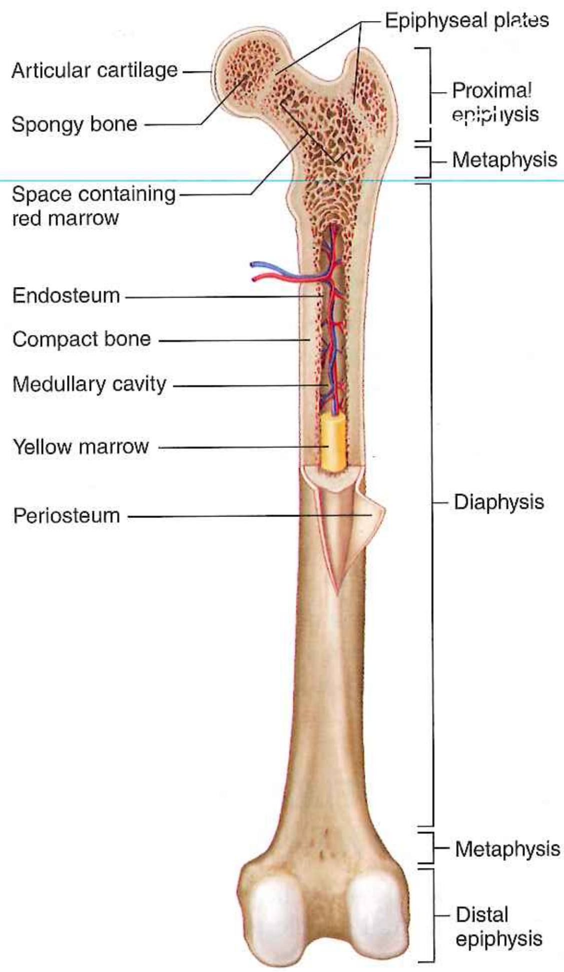


FIGURE 7.2 APR Major parts of a long bone.

Q: *Name the bone.*

Answer can be found in Appendix G on page 938.

One epiphysis, called the proximal epiphysis, is nearest to the torso. The other, called the distal epiphysis, is farthest from the torso. On its outer surface, the articulating portion of the epiphysis is coated with a layer of hyaline cartilage called **articular cartilage** (ar-tik′u-lar kar′tĭ-lij). The shaft of the bone is called the **diaphysis** (di-af′ĭ-sis). The **metaphysis** (met″ah-fi′-sis) is the widening part of the bone between the diaphysis and the epiphysis.

A bone is enclosed by a tough, vascular covering of dense connective tissue called the **periosteum** (per″e-os′te-um), except for the articular cartilage on its ends. The periosteum is firmly attached to the bone, and the periosteal fibers are continuous with connected ligaments and tendons. The periosteum also helps form and repair bone tissue.

A bone's shape makes possible its functions. Bony projections called *processes*, for example, provide sites for attachment of ligaments and tendons; grooves and openings are passageways for blood vessels and nerves; and a depression of one bone might articulate with a process of another.

The wall of the diaphysis is mainly composed of tightly packed tissue called **compact bone** (kom′pakt bōn), or cortical (kor′ti-kal) bone. This type of bone has a continuous extracellular matrix with no gaps (fig. 7.3*a*). The epiphyses, on the other hand, are largely composed of **spongy bone** (spunj′e bōn), or cancellous (kan-sel′es) bone, with thin layers of compact bone on their surfaces (fig. 7.3*b*). Spongy bone consists of many branching bony plates called **trabeculae** (trah-bek′u-le). Irregular connecting spaces between these plates help reduce the bone's weight. The bony plates are most highly developed in the regions of the epiphyses subjected to compressive forces. Both compact and spongy bone are strong and resist bending.

Most bones have compact bone overlying spongy bone, with the relative amounts of each varying in the differently shaped bones. Short, flat, and irregular bones typically consist of a mass of spongy bone either covered by a layer of compact bone or sandwiched between plates of compact bone (fig. 7.3*c*).

Compact bone in the diaphysis of a long bone forms a semirigid tube with a hollow chamber called the **medullary cavity** (med′u-lār″e kav′ĭ-te) that is continuous with the spaces of the spongy bone. A thin membrane containing bone-forming cells, called **endosteum** (en-dos′tē-um), lines these areas, and a specialized type of soft connective tissue called **marrow** (mar′o) fills them. The two forms of marrow, red and yellow, are described later in this chapter (see also fig. 7.2).

Microscopic Structure

Recall from chapter 5 (p. 169) that bone cells called **osteocytes** (os′te-o-sītz) are in tiny, bony chambers called *lacunae*, forming concentric circles around *central canals* (Haversian canals). Osteocytes transport nutrients and wastes to and from nearby cells by means of cellular processes passing through *canaliculi*. The extracellular matrix of bone tissue is largely collagen and inorganic salts. Collagen gives bone its

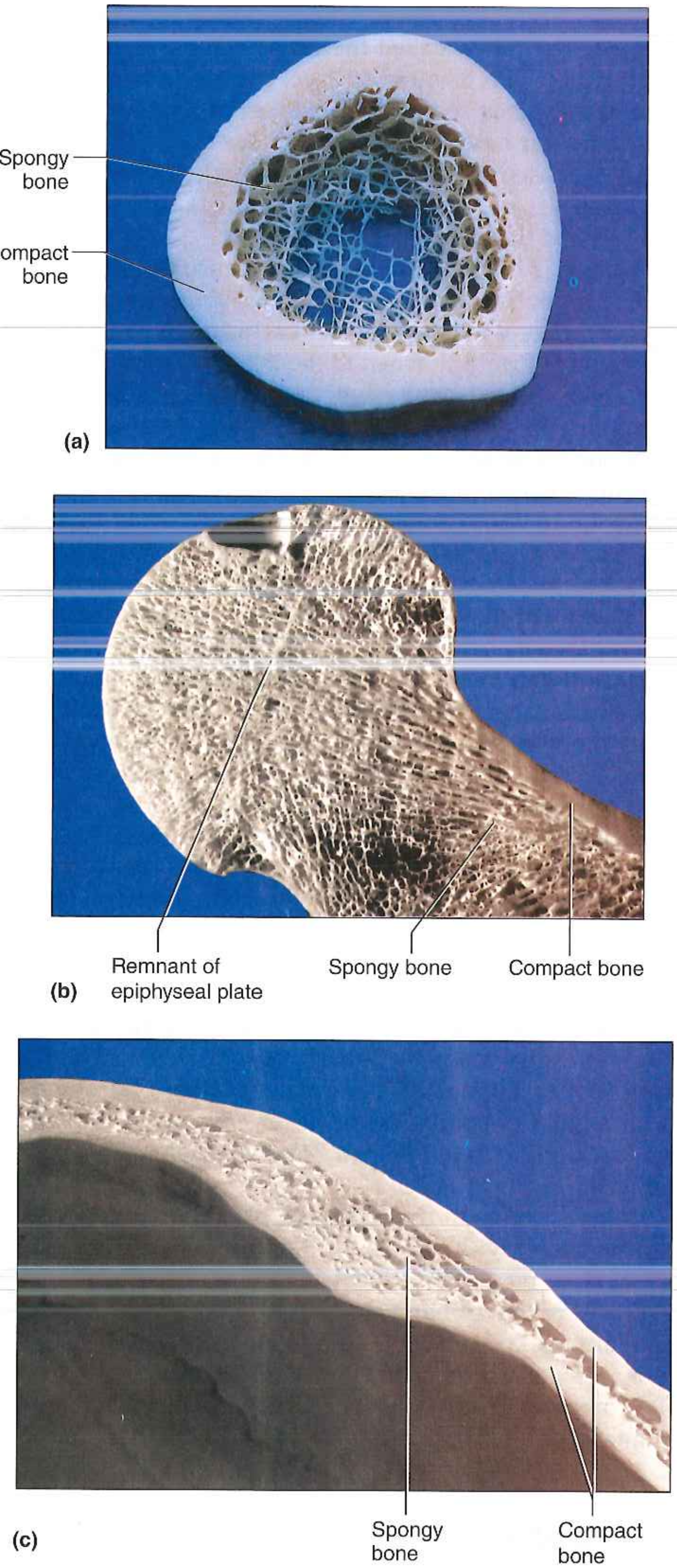


FIGURE 7.3 AP|R Compact bone and spongy bone. *(a)* In a femur, the wall of the diaphysis consists mostly of compact bone. *(b)* The epiphyses of the femur contain spongy bone enclosed by a thin layer of compact bone. (c) This skull bone contains a layer of spongy bone sandwiched between plates of compact bone.

Q: *What type of section has been cut from a long bone in (a)?*

Answer can be found in Appendix G on page 938.

strength and resilience, and inorganic salts make it hard and resistant to crushing.

Compact Bone

In compact bone, the osteocytes and layers of extracellular matrix concentrically clustered around a central canal form a cylinder-shaped unit called an **osteon** (os'te-on), sometimes called an Haversian system (figs. 7.4 and 7.5). Many of these units cemented together form the substance of compact bone. The osteons run longitudinally with the axis of the bone, functioning as weight-bearing pillars, resisting compression.

Each central canal contains blood vessels and nerve fibers surrounded by loose connective tissue. Blood in these vessels nourishes bone cells associated with the central canal via gap junctions between osteocytes.

Central canals extend longitudinally through bone tissue, and transverse *perforating canals* (Volkmann's canals) connect them. Perforating canals contain larger blood vessels and nerves by which the smaller blood vessels and nerve fibers in central canals communicate with the surface of the bone and the medullary cavity (see fig. 7.4).

Spongy Bone

Spongy bone is also composed of osteocytes and extracellular matrix, but the bone cells do not aggregate around central canals. Instead, the cells lie within the trabeculae and get nutrients from substances diffusing into the canaliculi that lead to the surfaces of these thin, bony plates.

> Severe bone pain is one symptom of sickle cell disease, which is inherited. Under low oxygen conditions, abnormal hemoglobin (an oxygen-carrying protein) bends the red blood cells that contain it into sickle shapes, obstructing circulation. Radiographs can reveal blocked arterial blood flow in bones of sickle cell disease patients.

PRACTICE

4 List five major parts of a long bone.
5 How do compact and spongy bone differ in structure?
6 Describe the microscopic structure of compact bone.

7.3 BONE DEVELOPMENT AND GROWTH AP|R

Parts of the skeletal system begin to form during the first few weeks of prenatal development, and bony structures continue to grow and develop into adulthood. Bones form when bone tissue, including a bony matrix mostly of calcium phosphate, replaces existing connective tissue in one of two ways. Bones that originate within sheetlike layers of connective tissues are called *intramembranous bones.* Bones that

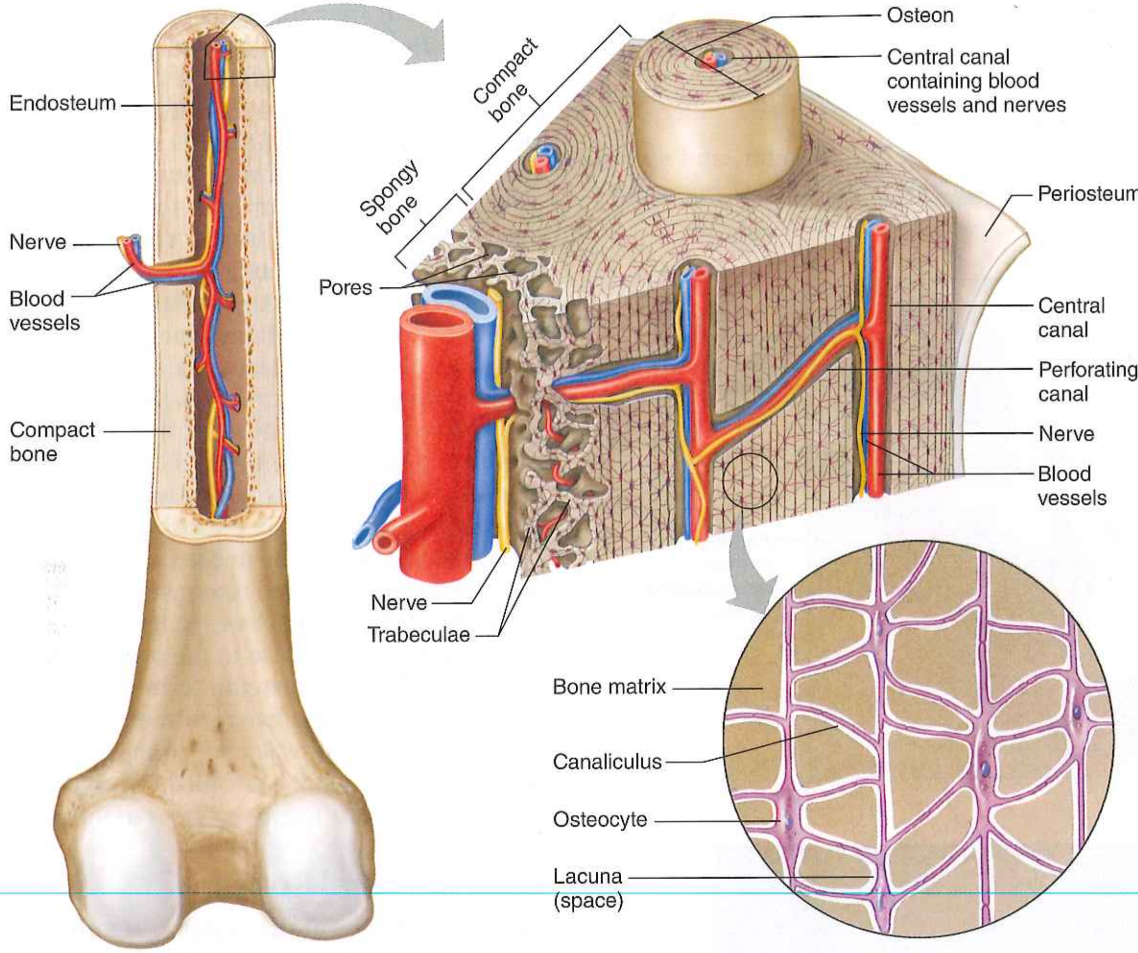


FIGURE 7.4 AP|R Compact bone is composed of osteons cemented together by bone matrix. Drawing is not to scale.

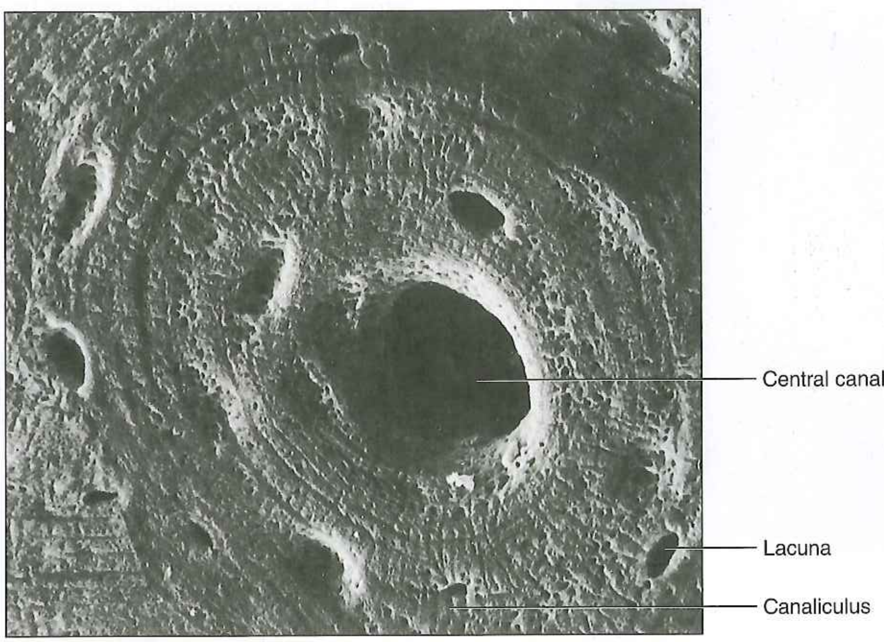


FIGURE 7.5 AP|R Scanning electron micrograph of a single osteon in compact bone (575×). *Tissues and Organs: A Text-Atlas of Scanning Electron Microscopy,* by R. G. Kessel and R. H. Kardon. © 1979 W. H. Freeman and Company.

begin as masses of cartilage later replaced by bone tissue are called *endochondral bones* (fig. 7.6).

Intramembranous Bones

The flat bones of the skull, clavicles, sternum, and some facial bones, including the mandible, maxillae, and zygomatic bones, are **intramembranous bones** (in″trah-mem′brah-nus bōnz). During their development (osteogenesis), membrane-like layers of unspecialized, or relatively undifferentiated, connective tissues appear at the sites of the future bones. Dense networks of blood vessels supply these connective tissue layers, which may form around the vessels. The partially differentiated progenitor cells that are part of the connective tissues enlarge and further differentiate into bone-forming cells called **osteoblasts** (os′te-o-blasts), which, in turn, deposit bony matrix around themselves. As a result, spongy bone forms in all directions along blood vessels within the layers of connective tissues. Later, some spongy bone may become compact bone as spaces fill with bone matrix.

As development continues, the osteoblasts may become completely surrounded by extracellular matrix, and in this manner, they become secluded within lacunae. At the same time, extracellular matrix enclosing the cellular processes of the osteoblasts gives rise to canaliculi. Once isolated in lacunae, these cells are called *osteocytes* (fig. 7.7).

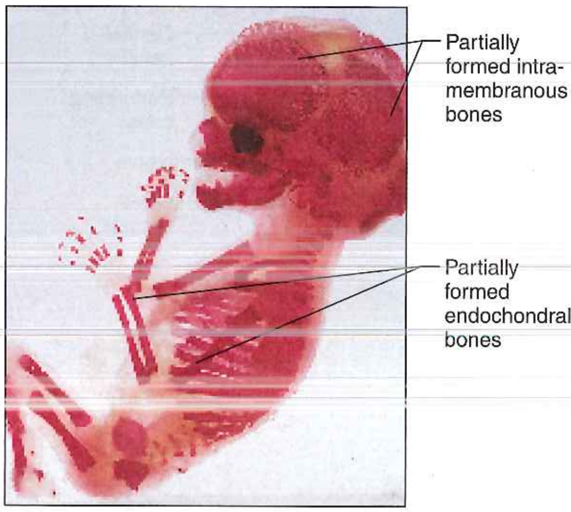
Cells of the connective tissue that persist outside the developing bone give rise to the periosteum. Osteoblasts on the inside of the periosteum form a layer of compact bone over the surface of the newly formed spongy bone.

This process of replacing connective tissue to form an intramembranous bone is called *intramembranous ossification*. Table 7.1 lists the major steps of the process.

Endochondral Bones

Most of the bones of the skeleton are **endochondral bones** (en′do-kon′dral bōnz). They develop from masses of hyaline cartilage shaped like future bony structures. These cartilaginous models grow rapidly for a time and then begin to change extensively. Cartilage cells enlarge and their lacunae grow. The surrounding matrix breaks down, and soon the cartilage cells die and degenerate.

As the cartilage decomposes, a periosteum forms from connective tissue that encircles the developing structure. Blood vessels and partially differentiated connective tissue



(a)

(b)

FIGURE 7.6 Fetal skeleton. (*a*) Note the stained bones of this fourteen-week fetus. (*b*) Bones can fracture even before birth. This fetus has numerous broken bones (arrows) because of an inherited defect in collagen called osteogenesis imperfecta, which causes brittle bones.

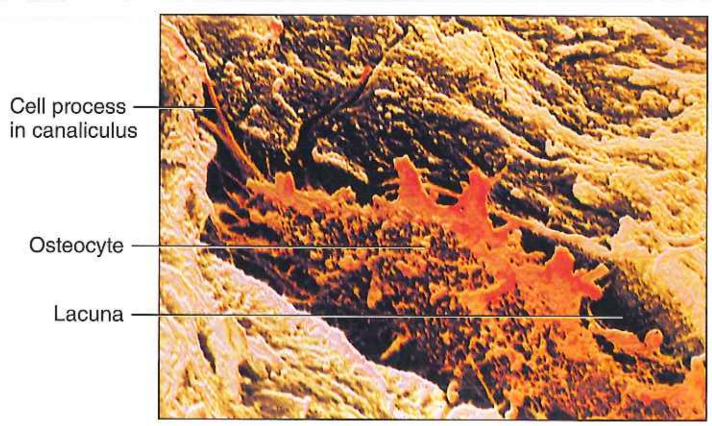


FIGURE 7.7 Scanning electron micrograph (falsely colored) of an osteocyte isolated in a lacuna (4,700×).

TABLE 7.1 | Major Steps in Bone Development

Intramembranous Ossification	Endochondral Ossification
1. Sheets of relatively undifferentiated connective tissue appear at sites of future bones.	1. Masses of hyaline cartilage form models of future bones.
2. Partially differentiated connective tissue cells collect around blood vessels in these layers.	2. Cartilage tissue breaks down. Periosteum develops.
3. Connective tissue cells further differentiate into osteoblasts, which deposit spongy bone.	3. Blood vessels and differentiating osteoblasts from the periosteum invade the disintegrating tissue.
4. Osteoblasts become osteocytes when bony matrix completely surrounds them.	4. Osteoblasts form spongy bone in the space occupied by cartilage.
5. Connective tissue on the surface of each developing structure forms a periosteum.	5. Osteoblasts beneath the periosteum deposit a thin layer of compact bone.
6. Osteoblasts on the inside of the periosteum deposit compact bone over the spongy bone.	6. Osteoblasts become osteocytes when bony matrix completely surrounds them.

cells invade the disintegrating tissue. Some of the invading cells further differentiate into osteoblasts and begin to form spongy bone in the spaces previously housing the cartilage. Once completely surrounded by the bony matrix, osteoblasts are called osteocytes. As ossification continues, osteoblasts beneath the periosteum deposit compact bone around the spongy bone.

The process of forming an endochondral bone by the replacement of hyaline cartilage is called *endochondral ossification.* Its major steps are listed in table 7.1 and illustrated in figure 7.8.

In a long bone, bone tissue begins to replace hyaline cartilage in the center of the diaphysis. This region is called the *primary ossification center,* and bone develops from it toward the ends of the cartilaginous structure. Meanwhile, osteoblasts from the periosteum deposit a thin layer of compact bone around the primary ossification center. The epiphyses of the developing bone remain cartilaginous and continue to grow. Later, *secondary ossification centers* appear in the epiphyses, and spongy bone forms in all directions from them. As spongy bone is deposited in the diaphysis and in the epiphysis, a band of cartilage called the **epiphyseal plate** (ep″ĭ-fiz′e-al plāt) remains between the two ossification centers (see figs. 7.2, 7.3*b,* and 7.8).

Growth at the Epiphyseal Plate

In a long bone, the diaphysis is separated from the epiphysis by an epiphyseal plate. The cartilaginous cells of the epiphyseal plate form four layers, each of which may be several

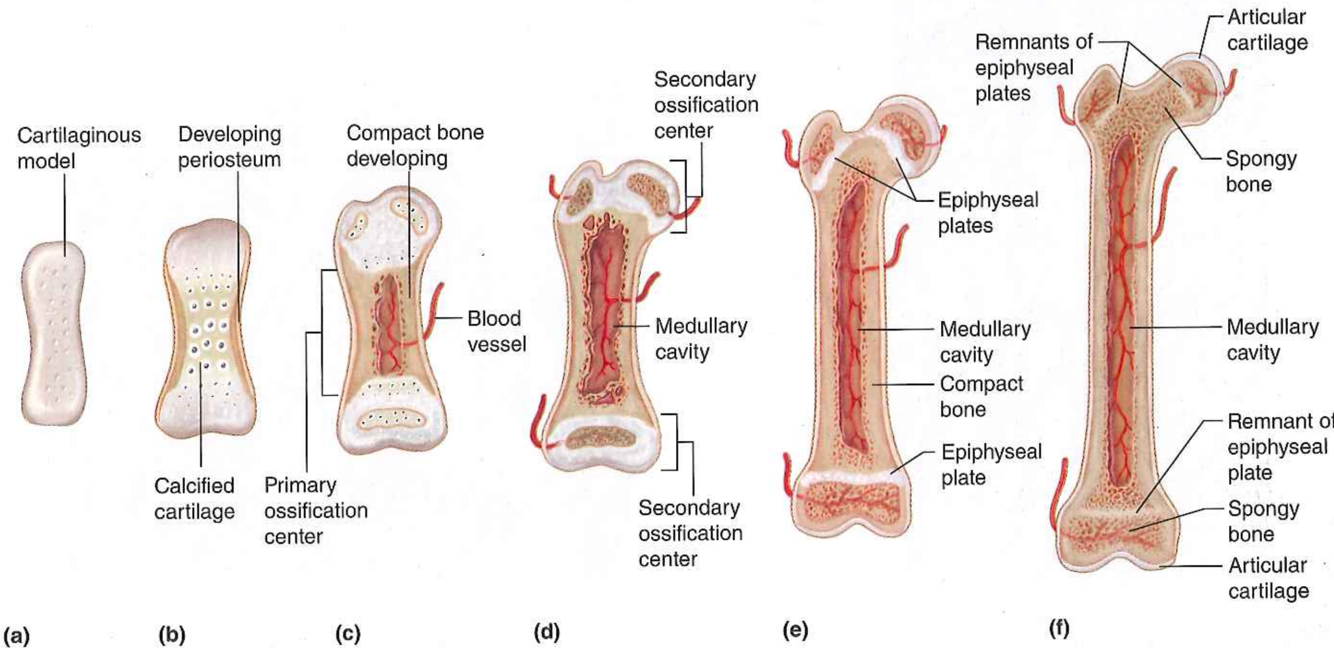


FIGURE 7.8 Major stages (*a–d* fetal, *e* child, *f* adult) in the development of an endochondral bone. (Relative bone sizes are not to scale.)

cells thick, as shown in figure 7.9. The first layer, or *zone of resting cartilage,* is closest to the end of the epiphysis. It is composed of resting cells that do not actively participate in growth. This layer anchors the epiphyseal plate to the bony tissue of the epiphysis.

The second layer of the epiphyseal plate, or *zone of proliferating cartilage,* includes rows of many young cells undergoing mitosis. As new cells appear and as extracellular matrix forms around them, the cartilaginous plate thickens.

The rows of older cells, left behind when new cells appear, form the third layer, or *zone of hypertrophic cartilage,* enlarging and thickening the epiphyseal plate still more. Consequently, the entire bone lengthens. At the same time, invading osteoblasts, which secrete calcium salts, accumulate in the extracellular matrix adjacent to the oldest cartilaginous cells, and as the extracellular matrix calcifies, the cells begin to die.

The fourth layer of the epiphyseal plate, or *zone of calcified cartilage,* is thin. It is composed of dead cells and calcified extracellular matrix.

In time, large, multinucleated cells called **osteoclasts** (os′te-o-klasts) break down the calcified matrix. These large cells originate from the fusion of single-nucleated white blood cells called monocytes (see chapter 14, p. 535). Osteoclasts secrete an acid that dissolves the inorganic component of the calcified matrix, and their lysosomal enzymes digest the organic components. Osteoclasts also phagocytize components of the bony matrix. After osteoclasts remove the extracellular matrix, bone-building osteoblasts invade the region and deposit bone tissue in place of the calcified cartilage.

In bone cancers, abnormally active osteoclasts destroy bone tissue. Interestingly, advanced cancer of the prostate gland can have the opposite effect. If such cancer cells reach the bone marrow, they stimulate osteoblast activity. This promotes formation of new bone on the surfaces of the bony trabeculae.

A long bone continues to lengthen while the cartilaginous cells of the epiphyseal plates are active. However, once

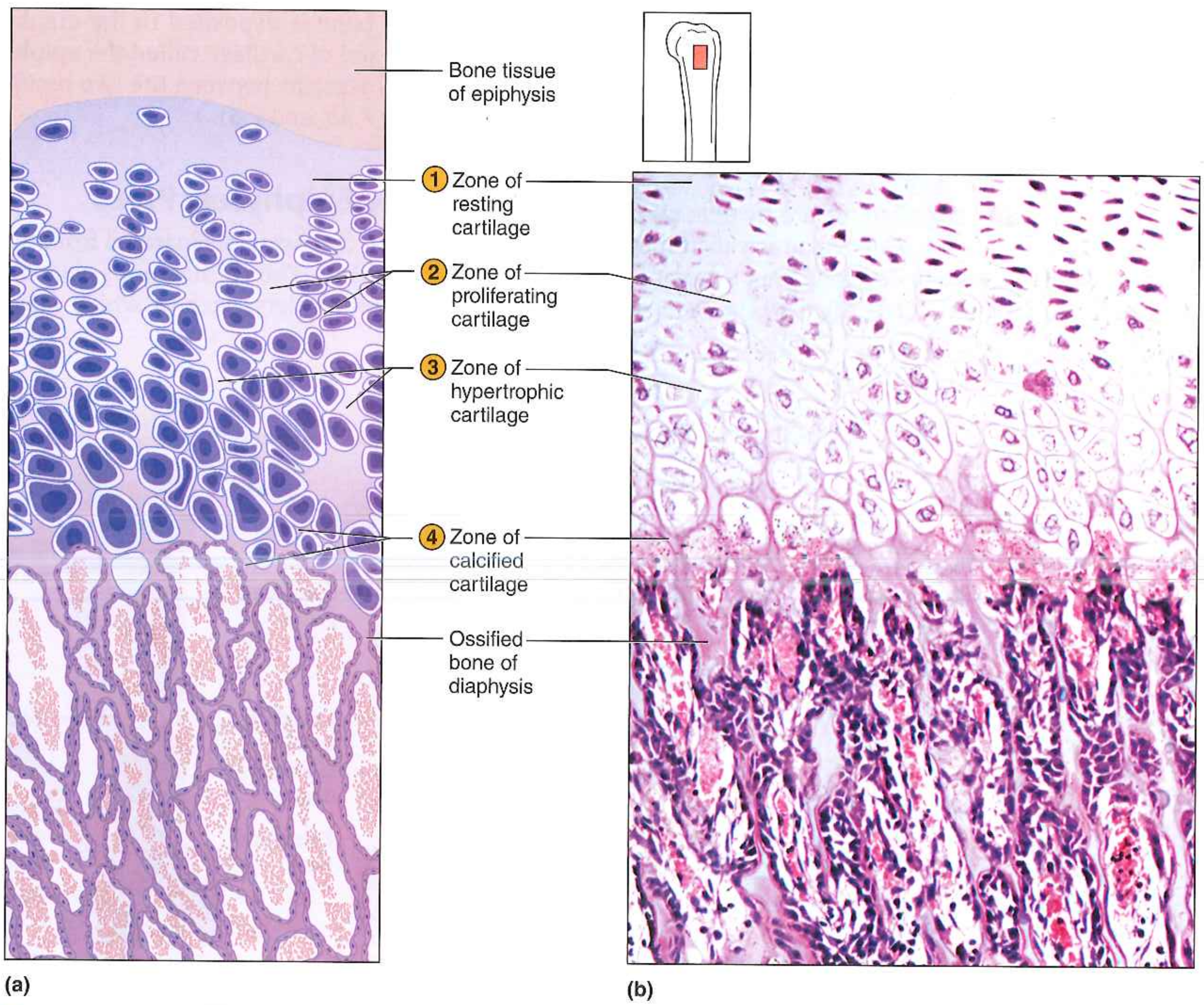


FIGURE 7.9 Epiphyseal plate. (*a*) The cartilaginous cells of an epiphyseal plate lie in four layers, each of which may be several cells thick. (*b*) A micrograph of an epiphyseal plate (100×).

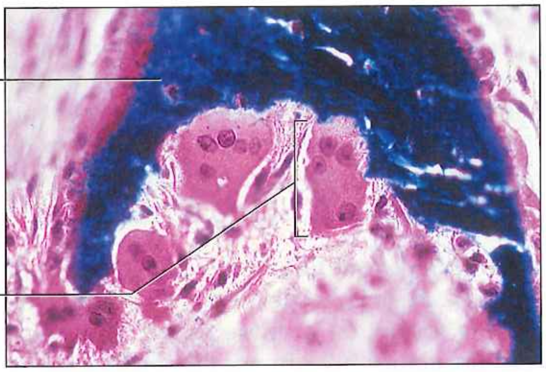


FIGURE 7.10 Micrograph of bone-resorbing osteoclasts (800×).

the ossification centers of the diaphysis and epiphyses meet and the epiphyseal plates ossify, lengthening is no longer possible in that end of the bone.

A developing bone thickens as compact bone is deposited on the outside, just beneath the periosteum. As this compact bone forms on the surface, osteoclasts erode other bone tissue on the inside (fig. 7.10). The resulting space becomes the medullary cavity of the diaphysis, which later fills with marrow.

The bone in the central regions of the epiphyses and diaphysis remains spongy, and hyaline cartilage on the ends of the epiphyses persists throughout life as articular cartilage. Table 7.2 lists the ages at which various bones ossify.

> If a child's long bones are still growing, a radiograph will reveal epiphyseal plates (fig. 7.11). If an epiphyseal plate is damaged as a result of a fracture before it ossifies, elongation of that long bone may prematurely cease, or if growth continues, it may be uneven. For this reason, injuries to the epiphyses of a young person's bones are of special concern. Surgery is used on an epiphysis to equalize growth of bones developing at very different rates.

PRACTICE

7 Describe the development of an intramembranous bone.
8 Explain how an endochondral bone develops.
9 List the steps in the growth of a long bone.

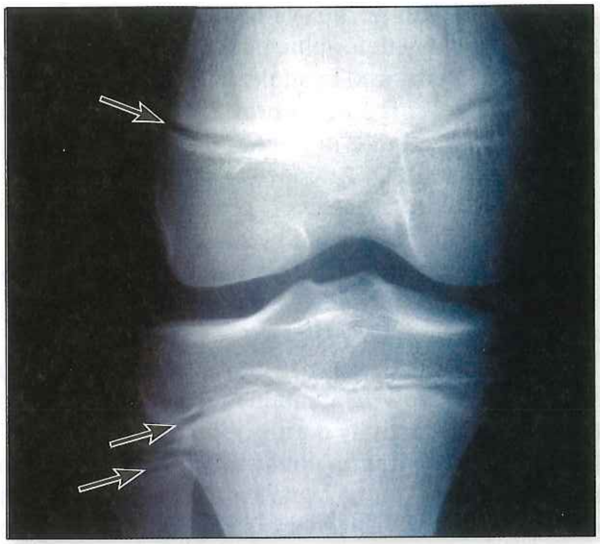


FIGURE 7.11 Radiograph showing epiphyseal plates (arrows) in a child's bones indicates that the bones are still lengthening.

Homeostasis of Bone Tissue

After the intramembranous and endochondral bones form, the actions of osteoclasts and osteoblasts continually remodel them. **Bone remodeling** occurs throughout life as osteoclasts resorb bone tissue and osteoblasts replace the bone. These opposing processes of *resorption* and *deposition* occur on the surfaces of the endosteum and periosteum. The rate of bone remodeling is not uniform among the types of bones; remodeling of spongy bone is faster than that of compact bone. The total mass of bone tissue in an adult skeleton normally remains nearly constant because of the tight regulation of bone remodeling. These ongoing processes replace 10% to 20% of the skeleton each year.

Factors Affecting Bone Development, Growth, and Repair

A number of factors influence bone development, growth, and repair. These include nutrition, exposure to sunlight, hormonal secretions, and physical exercise. For example, vitamin D is necessary for proper absorption of calcium in the small intestine. Without this vitamin, calcium is poorly absorbed

TABLE 7.2 | Ossification Timetable

Age	Occurrence
Third month of prenatal development	Ossification in long bones begins.
Fourth month of prenatal development	Most primary ossification centers have appeared in the diaphyses of bones.
Birth to 5 years	Secondary ossification centers appear in the epiphyses.
5 to 12 years (females) 5 to 14 years (males)	Ossification rapidly spreads from the ossification centers.
15 to 18 years (females) 17 to 20 years (males)	Bones of the upper limbs and scapulae completely ossified.
16 to 21 years (females) 18 to 23 years (males)	Bones of the lower limbs and hip bones completely ossified.
21 to 23 years (females) 23 to 25 years (males)	Bones of the sternum, clavicles, and vertebrae completely ossified.
By 23 years (females) By 25 years (males)	Nearly all bones completely ossified.

and the inorganic salt portion of bone matrix lacks calcium, softening and thereby deforming bones. In children, this condition is called *rickets,* and in adults, it is called *osteomalacia.*

Vitamin D is scarce in natural foods, except for eggs, but it is readily available in milk and other dairy products fortified with vitamin D. An inactive form of vitamin D also forms when dehydrocholesterol, produced by skin cells or obtained in the diet, is carried by the blood to the skin and exposed to ultraviolet light. This inactive form of vitamin D is then processed in the liver and kidneys to become the active form of vitamin D.

Vitamins A and C are also required for normal bone development and growth. Vitamin A is necessary for osteoblast and osteoclast activity during normal development. This is why deficiency of vitamin A may retard bone development. Vitamin C is required for collagen synthesis. Deficiency inhibits bone development. Osteoblasts cannot produce enough collagen in the extracellular matrix of the bone tissue, and as a result, bones are abnormally slender and fragile.

About 90% of the protein that is part of bone is collagen. Less abundant bone proteins are important too.

- Osteocalcin is activated by vitamin K to bind calcium, which in bone is part of the compound hydroxyapatite, the main component of bone matrix.
- Osteonectin binds hydroxyapatite and collagen and stimulates mineral crystal deposition in bone.
- Osteopontin speeds bone remodeling.
- Bone morphogenetic proteins include growth factors that induce bone and cartilage formation. They are used in spinal fusion procedures.

Hormones secreted by the pituitary gland, thyroid gland, parathyroid glands, and ovaries or testes affect bone growth and development. The pituitary gland secretes **growth hormone,** which stimulates division of cartilage cells in the epiphyseal plates. In the absence of this hormone, the long bones of the limbs fail to develop normally, and the child has *pituitary dwarfism.* He or she is very short but has normal body proportions. If excess growth hormone is released before the epiphyseal plates ossify, height may exceed 8 feet—a condition called *pituitary gigantism.* In an adult, secretion of excess growth hormone causes *acromegaly,* in which the hands, feet, and jaw enlarge (see chapter 13, pp. 499–500).

The thyroid hormone thyroxine stimulates replacement of cartilage in the epiphyseal plates of long bones with bone tissue. This hormone increases cellular metabolism, including stimulating osteoblast activity. In contrast to the bone-forming activity of thyroid hormone, parathyroid hormone stimulates an increase in the number and activity of osteoclasts, which break down bone (see chapter 13, pp. 505–507).

Abnormal swings in blood sugar are less likely in individuals who exercise regularly. Part of the reason may be that the bone protein osteocalcin appears to act as a hormone, released from bones after the stress of exercise. Osteocalcin works with another hormone, insulin, to help the body regulate blood sugar levels more precisely.

Both male and female sex hormones (called testosterone and estrogens, respectively) from the testes and ovaries promote formation of bone tissue. Beginning at puberty, these hormones are abundant, causing the long bones to grow considerably (see chapter 22, pp. 837, 848). However, sex hormones also stimulate ossification of the epiphyseal plates, and consequently they stop bone lengthening at a relatively early age. The effect of estrogens on the epiphyseal plates is somewhat stronger than that of testosterone. For this reason, females typically reach their maximum heights earlier than males.

Physical stress also stimulates bone growth. For example, when skeletal muscles contract, they pull at their attachments on bones, and the resulting stress stimulates the bone tissue to thicken and strengthen (hypertrophy). Conversely, with lack of exercise, the same bone tissue wastes, becoming thinner and weaker (atrophy). This is why the bones of athletes are usually stronger and heavier than those of nonathletes (fig. 7.12). It is also why fractured bones immobilized in casts may shorten. Clinical Application 7.1 describes what happens when a bone breaks.

Astronauts experience a 1% loss of bone mass per month in space. Under microgravity conditions, osteoblast activity decreases and osteoclast activity increases, with greater loss in spongy compared to compact bone. Researchers predict that a 50% bone loss could occur on a space flight that would last several years, such as a mission to Mars.

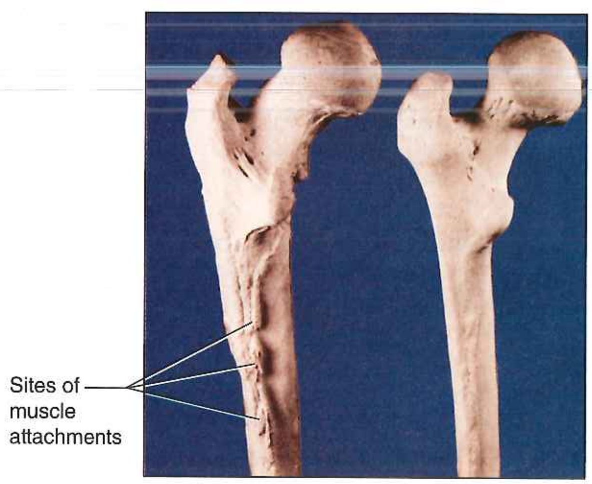


FIGURE 7.12 Note the increased amount of bone at the sites of muscle attachments in the femur on the left. The thickened bone is better able to withstand the forces resulting from muscle contraction.

PRACTICE

10 Explain how nutritional factors affect bone development.
11 What effects do hormones have on bone growth?
12 How does physical exercise affect bone structure?

7.4 BONE FUNCTION

Bones shape, support, and protect body structures, as well as aid body movements. They house tissues that produce blood cells and store various inorganic salts.

Support, Protection, and Movement

Bones give shape to structures such as the head, face, thorax, and limbs. They also support and protect. For example, the bones of the lower limbs, pelvis, and vertebral column support the body's weight. The bones of the skull protect the eyes, ears, and brain. Bones of the rib cage and shoulder girdle protect the heart and lungs, whereas bones of the pelvic girdle protect the lower abdominal and internal reproductive organs. Whenever limbs or other body parts move, bones and muscles interact.

Blood Cell Formation

The process of blood cell formation, called **hematopoiesis** (hem″ah-to-poi-e′sis), or hemopoiesis, begins in the yolk sac, which lies outside the embryo (see chapter 23, p. 878). Later in development, blood cells are manufactured in the liver and spleen, and still later, they form in bone marrow.

Marrow is a soft, netlike mass of connective tissue in the medullary cavities of long bones, in the irregular spaces of spongy bone, and in the larger central canals of compact bone tissue. The two types of marrow are red and yellow. In *red marrow*, red blood cells (erythrocytes), white blood cells (leukocytes), and blood platelets form. The color comes from the red, oxygen-carrying pigment **hemoglobin** in red blood cells.

The distribution of the two types of marrow changes with age. In an infant, the cavities of most bones house red marrow, but with time, yellow marrow replaces much of it. *Yellow marrow* stores fat and does not produce blood cells. In an adult, red marrow is primarily found in the spongy bone of the skull, ribs, sternum, clavicles, vertebrae, and hip bones. If the blood cell supply is deficient, some yellow marrow may become red marrow and produce blood cells. Chapter 14 (p. 527) discusses blood cell formation in more detail.

Inorganic Salt Storage

Recall that the extracellular matrix of bone tissue includes collagen and inorganic mineral salts. The salts account for about 70% of the extracellular matrix by weight and are mostly small crystals of a type of calcium phosphate called *hydroxyapatite*. The chapter-opening vignette discusses osteoporosis, a condition that results from loss of bone mineral.

The human body requires calcium for a number of vital metabolic processes, including muscle cell contraction, nerve impulse conduction, and blood clot formation. When the blood is low in calcium, parathyroid hormone stimulates osteoclasts to break down bone tissue, releasing calcium salts from the extracellular matrix into the blood. On the other hand, very high blood calcium inhibits osteoclast activity, and calcitonin from the thyroid gland stimulates osteoblasts to form bone tissue, storing excess calcium in the extracellular matrix (fig. 7.13). This response is particularly important in developing bone matrix in children. The

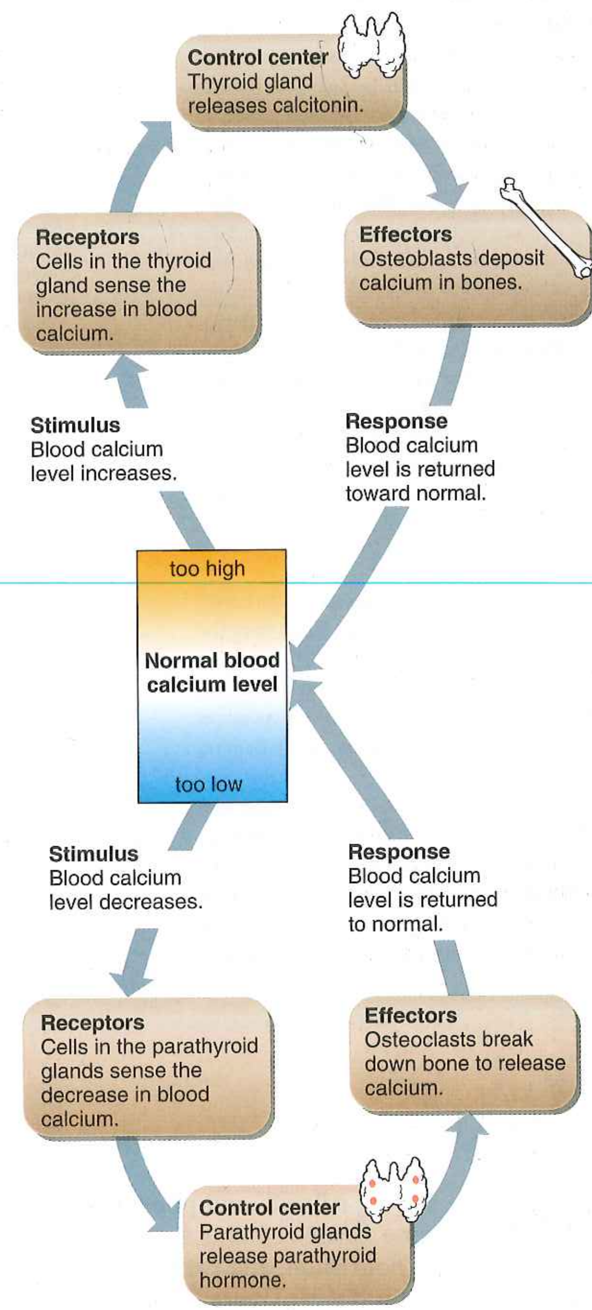


FIGURE 7.13 AP|R Hormonal regulation of bone calcium resorption and deposition.

Q: *What three components of a homeostatic mechanism (see fig. 1.6, p. 18) does this figure show?*

Answer can be found in Appendix G on page 938.

7.1 CLINICAL APPLICATION

Fractures

When seven-year-old Jacob fell from the tree limb, he had been hanging about eight feet from the ground. He landed in a crumpled heap, crying, with his right leg at an abnormal angle. Emergency medical technicians immobilized the leg and took Jacob to the emergency department at the nearest hospital, where an X ray indicated a broken tibia. He spent the next six weeks with his leg in a cast, and the bone continued to heal over several months. By the next summer, Jacob was again climbing trees—but more carefully.

Many of us have had fractured, or broken, bones. A fracture is classified by its cause and the nature of the break. For example, a break due to injury is a traumatic fracture, whereas one resulting from disease is a *spontaneous,* or *pathologic, fracture.* A broken bone exposed to the outside by an opening in the skin is termed a *compound (open) fracture.* It has the added danger of infection, because microorganisms can enter through the broken skin. A break protected by uninjured skin is a *closed fracture.* Figure 7A shows several types of traumatic fractures.

Repair of a Fracture

When a bone breaks, blood vessels in it also break, and the periosteum is likely to tear. Blood from the broken vessels spreads through the damaged area and soon forms a *hematoma,* which is a localized collection of blood that usually is clotted. Vessels in surrounding tissues dilate, swelling and inflaming tissues.

Within days or weeks, developing blood vessels and large numbers of osteoblasts originating from the periosteum invade the hematoma. The osteoblasts rapidly divide in the regions close to the new blood vessels, building spongy bone nearby. Granulation tissue develops, and in regions farther

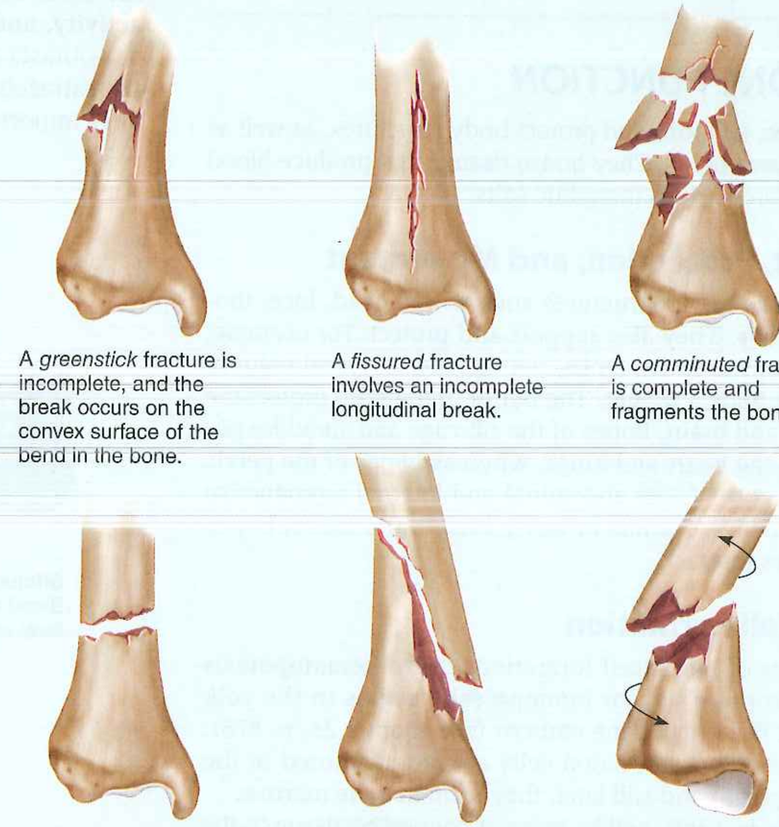


FIGURE 7A Types of fractures.

details of this homeostatic mechanism are in chapter 13, pp. 505–507.

In addition to storing calcium and phosphorus (as calcium phosphate), bone tissue contains smaller amounts of magnesium, sodium, potassium, and carbonate ions. Bones also accumulate certain harmful metallic elements such as lead, radium, and strontium, which are not normally present in the body but are sometimes accidentally ingested.

PRACTICE

13 Name the major functions of bones.

14 Distinguish between the functions of red marrow and yellow marrow.

15 Explain regulation of the concentration of blood calcium.

16 List the substances normally stored in bone tissue.

Continued—

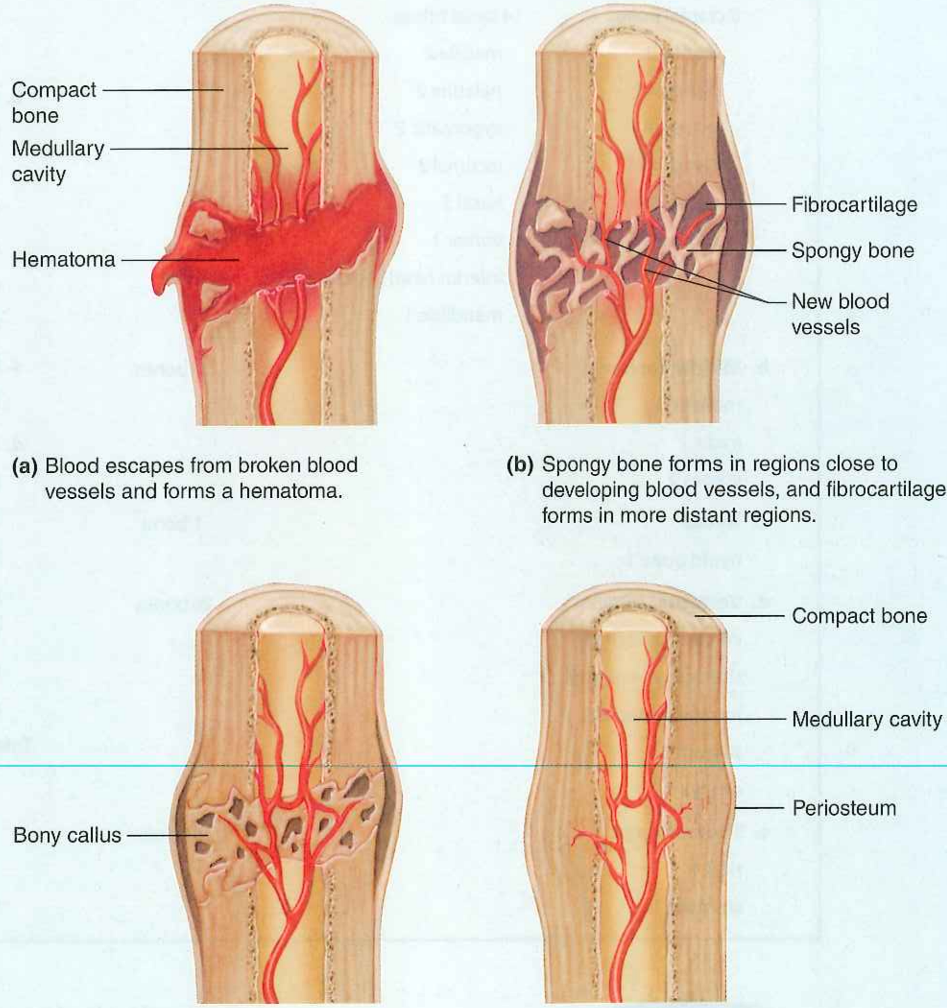
from a blood supply, fibroblasts produce masses of fibrocartilage. Meanwhile, phagocytic cells begin to remove the blood clot as well as any dead or damaged cells in the affected area. Osteoclasts also appear and resorb bone fragments, aiding in "cleaning up" debris.

In time, fibrocartilage fills the gap between the ends of the broken bone. This mass, termed a cartilaginous callus, is later replaced by bone tissue in much the same way that the hyaline cartilage of a developing endochondral bone is replaced. That is, the cartilaginous callus breaks down, blood vessels and osteoblasts invade the area, and a bony callus fills the space.

Typically, more bone is produced at the site of a healing fracture than is necessary to replace the damaged tissues. Osteoclasts remove the excess, and the result is a bone shaped much like the original. Figure 7B shows the steps in the healing of a fracture.

If the ends of a broken bone are close together, healing is faster than if they are far apart. Physicians can help the bone-healing process. The first casts to immobilize fractured bones were introduced in Philadelphia in 1876, and soon after, doctors began using screws and plates internally to align healing bone parts. Today, orthopedic surgeons also use rods, wires, and nails. These devices have become lighter and smaller; many are built of titanium. A device called a hybrid fixator treats a broken leg using metal pins internally to align bone pieces. The pins are anchored to a metal ring device worn outside the leg.

Some bones naturally heal more rapidly than others. The long bones of the upper limbs, for example, may heal in half the time required by the long bones of the lower limbs, as Jacob was unhappy to discover. However, his young age would favor quicker healing. ■



(a) Blood escapes from broken blood vessels and forms a hematoma.

(b) Spongy bone forms in regions close to developing blood vessels, and fibrocartilage forms in more distant regions.

(c) A bony callus replaces fibrocartilage.

(d) Osteoclasts remove excess bony tissue, restoring new bone structure much like the original.

FIGURE 7B Major steps (*a–d*) in the repair of a fracture.

Not only do human bones exhibit biomineralization—combining minerals with organic molecules—but they accept similar materials from other species. In 600 AD, Mayan dentists used nacre, the shiny substance inside oyster shells, to patch decayed teeth. Modern oral surgeons use nacre powder to fill in jaw defects. The body accepts nacre, and the substance even stimulates osteoblasts to produce new bone tissue. Nacre consists of hexagons of the mineral aragonite sandwiched between organic molecules. In a dental implant, the aragonite becomes hydroxyapatite, the mineral part of bone.

7.5 SKELETAL ORGANIZATION

Number of Bones

The number of bones in an adult human skeleton is often reported to be 206 (table 7.3), but the number varies because people may lack certain bones or have extra ones. For example, the flat bones of the skull usually grow together and tightly join along irregular lines called *sutures*. In some people, extra bones called sutural bones (wormian bones)

TABLE 7.3 | Bones of the Adult Skeleton

1. Axial Skeleton			**2. Appendicular Skeleton**	
a. Skull		22 bones	**a. Pectoral girdle**	4 bones
8 cranial bones	14 facial bones		scapula 2	
frontal 1	maxilla 2		clavicle 2	
parietal 2	palatine 2		**b. Upper limbs**	60 bones
occipital 1	zygomatic 2		humerus 2	
temporal 2	lacrimal 2		radius 2	
sphenoid 1	nasal 2		ulna 2	
ethmoid 1	vomer 1		carpal 16	
	inferior nasal concha 2		metacarpal 10	
	mandible 1		phalanx 28	
b. Middle ear bones		6 bones	**c. Pelvic girdle**	2 bones
malleus 2			hip bone 2	
incus 2			**d. Lower limbs**	60 bones
stapes 2			femur 2	
c. Hyoid		1 bone	tibia 2	
hyoid bone 1			fibula 2	
d. Vertebral column		26 bones	patella 2	
cervical vertebra 7			tarsal 14	
thoracic vertebra 12			metatarsal 10	
lumbar vertebra 5			phalanx 28	
sacrum 1			**Total**	206 bones
coccyx 1				
e. Thoracic cage		25 bones		
rib 24				
sternum 1				

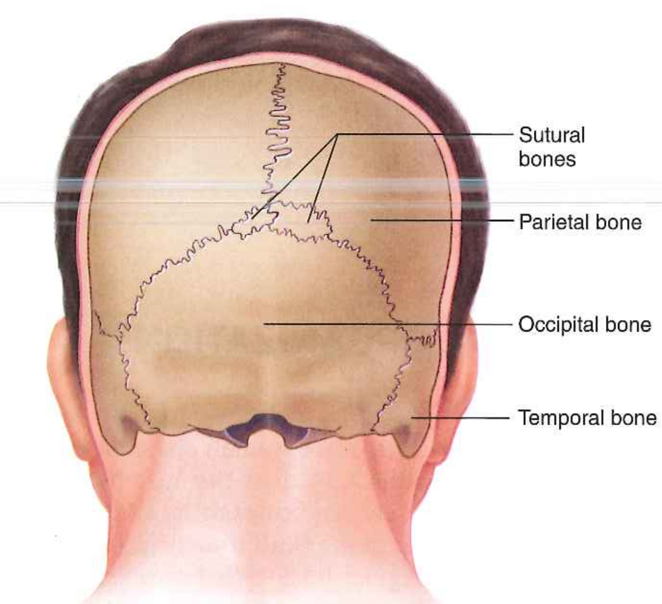


FIGURE 7.14 Sutural (wormian) bones are extra bones that sometimes develop in sutures between the flat bones of the skull.

develop in these sutures (fig. 7.14). Extra small, round sesamoid bones may develop in tendons, where they reduce friction in places where tendons pass over bony prominences.

Divisions of the Skeleton

For purposes of study, it is convenient to divide the skeleton into two major portions—an axial skeleton and an appendicular skeleton (fig. 7.15). The **axial skeleton** consists of the bony and cartilaginous parts that support and protect the organs of the head, neck, and trunk. These parts include the following:

1. The **skull** is composed of the *cranium* (brain case) and the *facial bones*.
2. The **hyoid** (hi′oid) **bone** is located in the neck between the lower jaw and the larynx (fig. 7.16). It does not articulate with any other bones but is fixed in position by muscles and ligaments. The hyoid bone supports the tongue and is an attachment for certain muscles that help move the tongue during swallowing. It can be felt approximately a finger's width above the anterior prominence of the larynx.

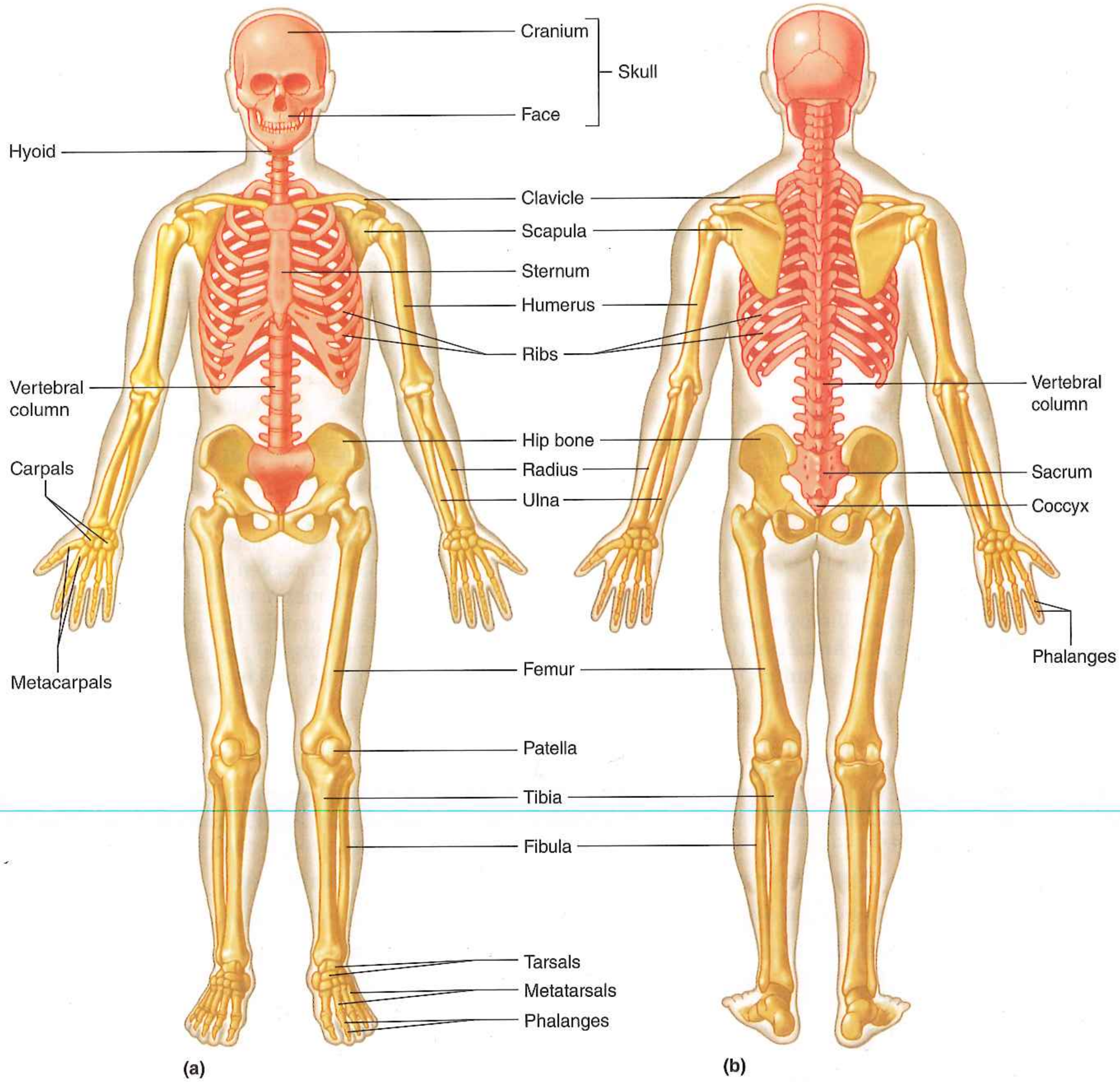


FIGURE 7.15 APR Major bones of the skeleton. (*a*) Anterior view. (*b*) Posterior view. The axial portion is shown in orange, and the appendicular portions are shown in yellow.

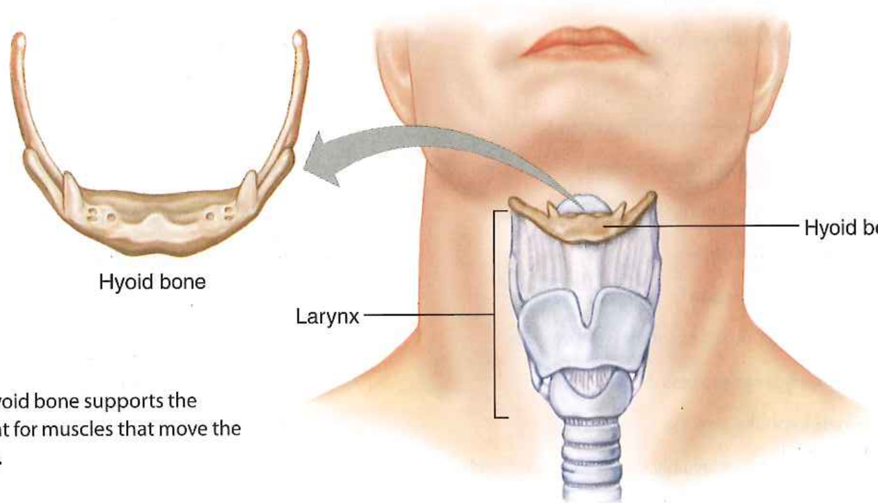


FIGURE 7.16 APR The hyoid bone supports the tongue and serves as an attachment for muscles that move the tongue and function in swallowing.

3. The **vertebral column**, or spinal column, consists of many **vertebrae** separated by cartilaginous *intervertebral discs*. This column forms the central axis of the skeleton. Near its distal end, five vertebrae fuse to form the **sacrum** (sa′krum), part of the pelvis. A small tailbone formed by the fusion of four vertebrae and called the **coccyx** (kok′siks) is attached to the end of the sacrum.
4. The **thoracic cage** protects the organs of the thoracic cavity and the upper abdominal cavity. It is composed of twelve pairs of **ribs**, which articulate posteriorly with the thoracic vertebrae. It also includes the **sternum** (ster′num), or breastbone, to which most of the ribs are attached anteriorly.

The **appendicular skeleton** consists of the bones of the upper and lower limbs and the bones that anchor the limbs to the axial skeleton. It includes the following:

1. The **pectoral girdle** is formed by a **scapula** (scap′u-lah), or shoulder blade, and a **clavicle** (klav′ĭ-k′l), or collarbone, on both sides of the body. The pectoral girdle connects the bones of the upper limbs to the axial skeleton and aids in upper limb movements.
2. Each **upper limb** consists of a **humerus** (hu′mer-us), or arm bone; two forearm bones—a **radius** (ra′de-us) and an **ulna** (ul′nah)—and a hand. The humerus, radius, and ulna articulate with each other at the elbow joint. At the distal end of the radius and ulna is the hand. There are eight **carpals** (kar′palz), or wrist bones. The five bones of the palm are called **metacarpals** (met″ah-kar′palz), and the fourteen finger bones are called **phalanges** (fah-lan′jēz; sing., *phalanx*, fa′lanks).
3. The **pelvic girdle** is formed by two hip bones attached to each other anteriorly and to the sacrum posteriorly. They connect the bones of the lower limbs to the axial skeleton and, with the sacrum and coccyx, form the **pelvis,** which protects the lower abdominal and internal reproductive organs.
4. Each **lower limb** consists of a **femur** (fe′mur), or thigh bone; two leg bones—a large **tibia** (tib′e-ah), or shin bone, and a slender **fibula** (fib′u-lah)—and a foot. The femur and tibia articulate with each other at the knee joint, where the **patella** (pah-tel′ah), or kneecap, covers the anterior surface. At the distal ends of the tibia and fibula is the foot. There are seven **tarsals** (tahr′salz), or ankle bones. The five bones of the instep are called **metatarsals** (met″ah-tar′salz), and the fourteen bones of the toes (like those of the fingers) are called **phalanges.** Table 7.4 defines some terms used to describe skeletal structures.

TABLE 7.4 | Terms Used to Describe Skeletal Structures

Term	Definition	Example
Condyle (kon′dīl)	Rounded process that usually articulates with another bone	Occipital condyle of the occipital bone (fig. 7.21)
Crest (krest)	Narrow, ridgelike projection	Iliac crest of the ilium (fig. 7.48)
Epicondyle (ep″ĭ-kon′dīl)	Projection situated above a condyle	Medial epicondyle of the humerus (fig. 7.43)
Facet (fas′et)	Small, nearly flat surface	Rib facet of a thoracic vertebra (fig. 7.36*b*)
Fissure (fish′ūr)	Cleft or groove	Inferior orbital fissure in the orbit of the eye (fig. 7.18)
Fontanel (fon″tah-nel′)	Soft spot in the skull where membranes cover the space between bones	Anterior fontanel between the frontal and parietal bones (fig. 7.31*a*)
Foramen (fo-ra′men)	Opening through a bone that usually serves as a passageway for blood vessels, nerves, or ligaments	Foramen magnum of the occipital bone (fig. 7.21)
Fossa (fos′ah)	Relatively deep pit or depression	Olecranon fossa of the humerus (fig. 7.43*b*)
Fovea (fo′ve-ah)	Tiny pit or depression	Fovea capitis of the femur (fig. 7.51*b*)
Head (hed)	Enlargement on the end of a bone	Head of the humerus (fig. 7.43)
Linea (lin′e-ah)	Narrow ridge	Linea aspera of the femur (fig. 7.51*b*)
Meatus (me-a′tus)	Tubelike passageway within a bone	External acoustic meatus of the temporal bone (fig. 7.19)
Process (pros′es)	Prominent projection on a bone	Mastoid process of the temporal bone (fig. 7.19)
Ramus (ra′mus)	Branch or similar extension	Ramus of the mandible (fig. 7.29*a*)
Sinus (si′nus)	Cavity within a bone	Frontal sinus of the frontal bone (fig. 7.20)
Spine (spīn)	Thornlike projection	Spine of the scapula (fig. 7.41*a, b*)
Suture (soo′cher)	Interlocking line of union between bones	Lambdoid suture between the occipital and parietal bones (fig. 7.19)
Trochanter (tro-kan′ter)	Relatively large process	Greater trochanter of the femur (fig. 7.51*a*)
Tubercle (tu′ber-kl)	Small, knoblike process	Tubercle of a rib (fig. 7.39)
Tuberosity (tu″bĕ-ros′ĭ-te)	Knoblike process usually larger than a tubercle	Radial tuberosity of the radius (fig. 7.44*a*)

PRACTICE

17 Distinguish between the axial and appendicular skeletons.

18 List the bones of the axial skeleton and of the appendicular skeleton.

7.6 SKULL APR

A human skull usually consists of twenty-two bones that, except for the lower jaw, are firmly interlocked along sutures. Eight of these interlocked bones make up the cranium and fourteen form the facial skeleton. The **mandible** (man′dĭ-b′l), or lower jawbone, is a movable bone held to the cranium by ligaments (figs. 7.17 and 7.19). Some facial and cranial bones together form the orbit of the eye (fig. 7.18).

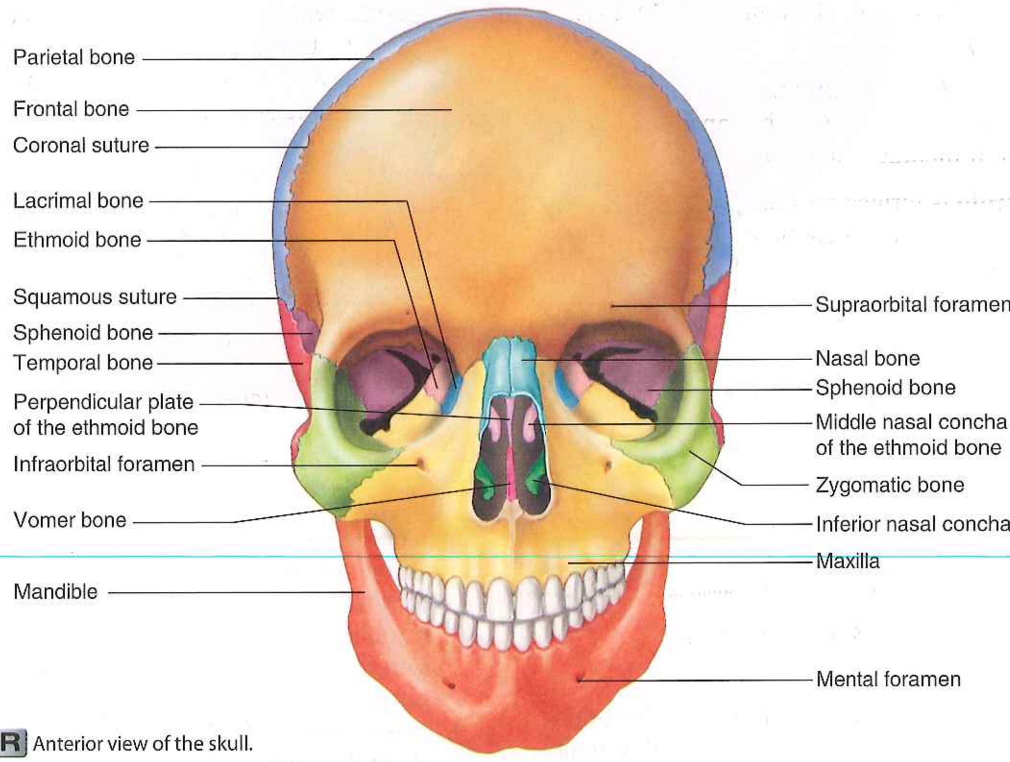


FIGURE 7.17 APR Anterior view of the skull.

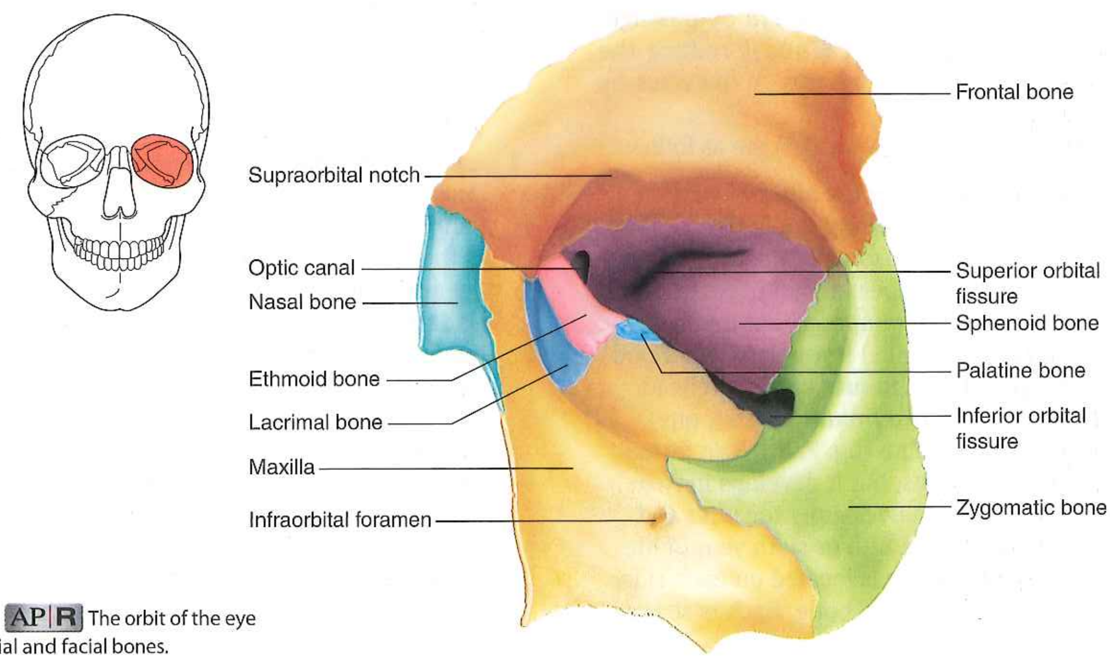


FIGURE 7.18 APR The orbit of the eye includes both cranial and facial bones.

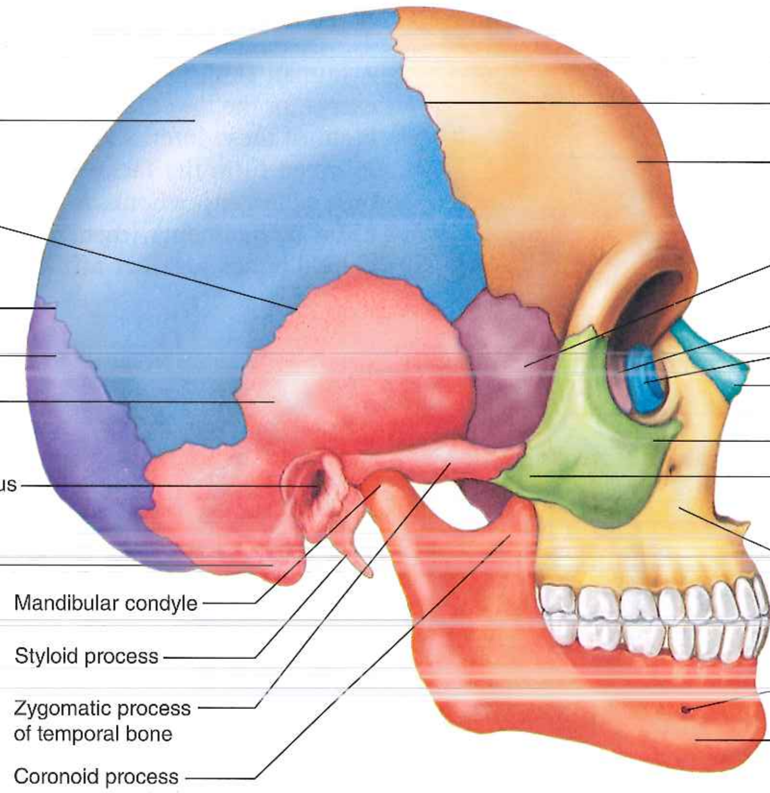


FIGURE 7.19 APR Right lateral view of the skull.

Plates 26–54 on pages 254–268 show a set of photographs of the human skull and its parts.

Cranium

The **cranium** (kra′ne-um) encloses and protects the brain, and its surface provides attachments for muscles that make chewing and head movements possible. Some of the cranial bones contain air-filled cavities called *paranasal sinuses*, lined with mucous membranes and connected by passageways to the nasal cavity (fig. 7.20). Sinuses reduce the weight of the skull and increase the intensity of the voice by serving as resonant sound chambers.

The eight bones of the cranium (table 7.5) are as follows:

1. The **frontal** (frun′tal) **bone** forms the anterior portion of the skull above the eyes, including the forehead, the roof of the nasal cavity, and the roofs of the orbits (bony sockets) of the eyes. On the upper margin of each orbit, the frontal bone is marked by a *supraorbital foramen* (or *supraorbital notch* in some skulls) through which blood vessels and nerves pass to the tissues of the forehead. Within the frontal bone are two *frontal sinuses*, one above each eye near the midline (fig. 7.20). The frontal bone is a single bone in adults, but it develops in two parts (see fig. 7.31*b*). These halves grow together and usually completely fuse by the fifth or sixth year of life.
2. One **parietal** (pah-ri′ĕ-tal) **bone** is located on each side of the skull just behind the frontal bone. Each is shaped like a curved plate and has four borders. Together, the parietal bones form the bulging sides and roof of the cranium. They are fused at the midline along the *sagittal suture*, and they meet the frontal bone along the *coronal suture*.
3. The **occipital** (ok-sip′i-tal) **bone** joins the parietal bones along the *lambdoid* (lam′doid) *suture*. It forms the back of the skull and the base of the cranium. A large opening on its lower surface is the *foramen magnum*, where the inferior part of the brainstem connects with the spinal cord. Rounded processes called *occipital condyles*, located on each side of the foramen magnum, articulate with the first vertebra (atlas) of the vertebral column.
4. A **temporal** (tem′por-al) **bone** on each side of the skull joins the parietal bone along a *squamous suture*. The temporal bones form parts of the sides and the base of the cranium. Located near the inferior margin is an opening, the *external acoustic* (auditory) *meatus*, which leads inward to parts of the ear. The temporal bones also house the internal ear structures and have depressions called the *mandibular fossae* (glenoid fossae) that articulate with condyles of the mandible. Below each external acoustic meatus are two projections—a rounded *mastoid process* and a long, pointed *styloid process* (see fig. 7.19). The mastoid process provides an attachment for certain muscles of the neck, whereas the styloid process anchors muscles associated with the tongue and pharynx. An opening near the mastoid process, the *carotid canal*,

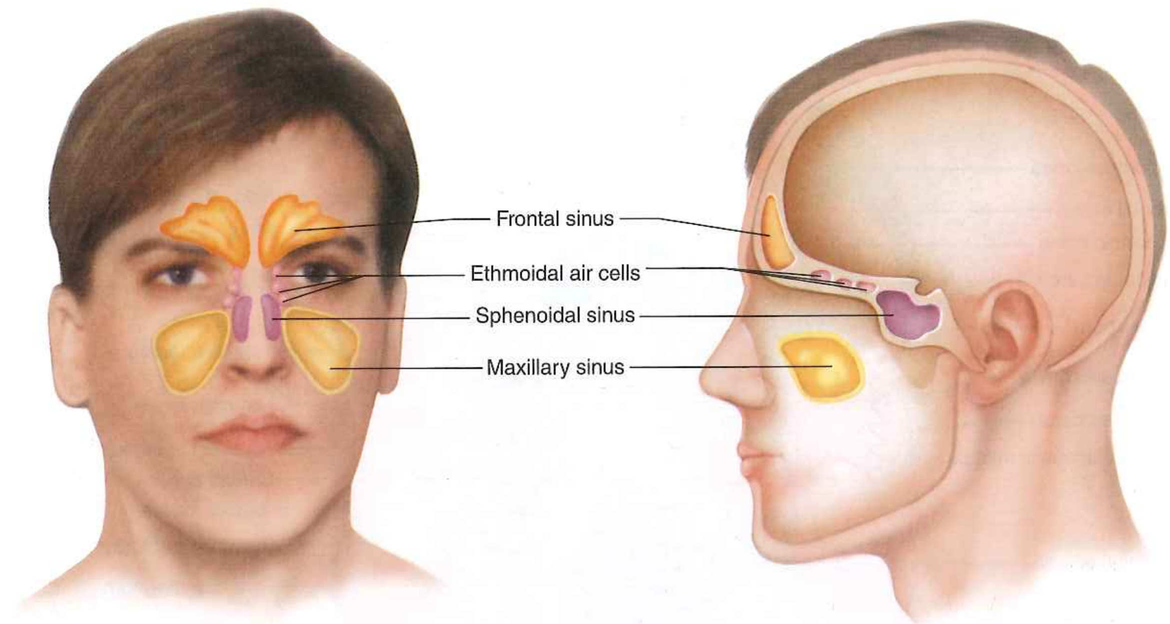


FIGURE 7.20 APIR Locations of the paranasal sinuses.

TABLE 7.5 | Cranial Bones

Name and Number	Description	Special Features
Frontal (1)	Forms forehead, roof of nasal cavity, and roofs of orbits	Supraorbital foramen, frontal sinuses
Parietal (2)	Form side walls and roof of cranium	Fused at midline along sagittal suture
Occipital (1)	Forms back of skull and base of cranium	Foramen magnum, occipital condyles
Temporal (2)	Form side walls and floor of cranium	External acoustic meatus, mandibular fossa, mastoid process, styloid process, zygomatic process
Sphenoid (1)	Forms parts of base of cranium, sides of skull, and floors and sides of orbits	Sella turcica, sphenoidal sinuses
Ethmoid (1)	Forms parts of roof and walls of nasal cavity, floor of cranium, and walls of orbits	Cribriform plates, perpendicular plate, superior and middle nasal conchae, ethmoidal air cells, crista galli

transmits the internal carotid artery. An opening between the temporal and occipital bones, the *jugular foramen,* accommodates the internal jugular vein (fig. 7.21).

The mastoid process may become infected. The tissues in this region of the temporal bone contain a number of interconnected air cells lined with mucous membranes that communicate with the middle ear. Microorganisms from an infected middle ear *(otitis media)* can spread into the air cells, causing infection and inflammation, called *mastoiditis.* The danger is that it may spread to nearby membranes that surround the brain.

A *zygomatic process* projects anteriorly from the temporal bone in the region of the external acoustic meatus. It joins the temporal process of the zygomatic bone and helps form the prominence of the cheek, the *zygomatic arch* (fig. 7.21).

5. The **sphenoid** (sfe′noid) **bone** (fig. 7.22) is wedged between several other bones in the anterior portion of the cranium. It consists of a central part and two winglike structures that extend laterally toward each side of the skull. This bone helps form the base of the cranium, the sides of the skull, and the floors and sides of the orbits. Along the midline within the cranial cavity, a portion of the sphenoid bone indents to form the saddle-shaped *sella turcica* (sel′ah tur′si-ka) (Turk's saddle). In this depression lies the pituitary gland, which hangs from the base of the brain by a stalk.

   The sphenoid bone also contains two *sphenoidal sinuses* (see fig. 7.20). These lie side by side and are separated by a bony septum that projects downward into the nasal cavity.

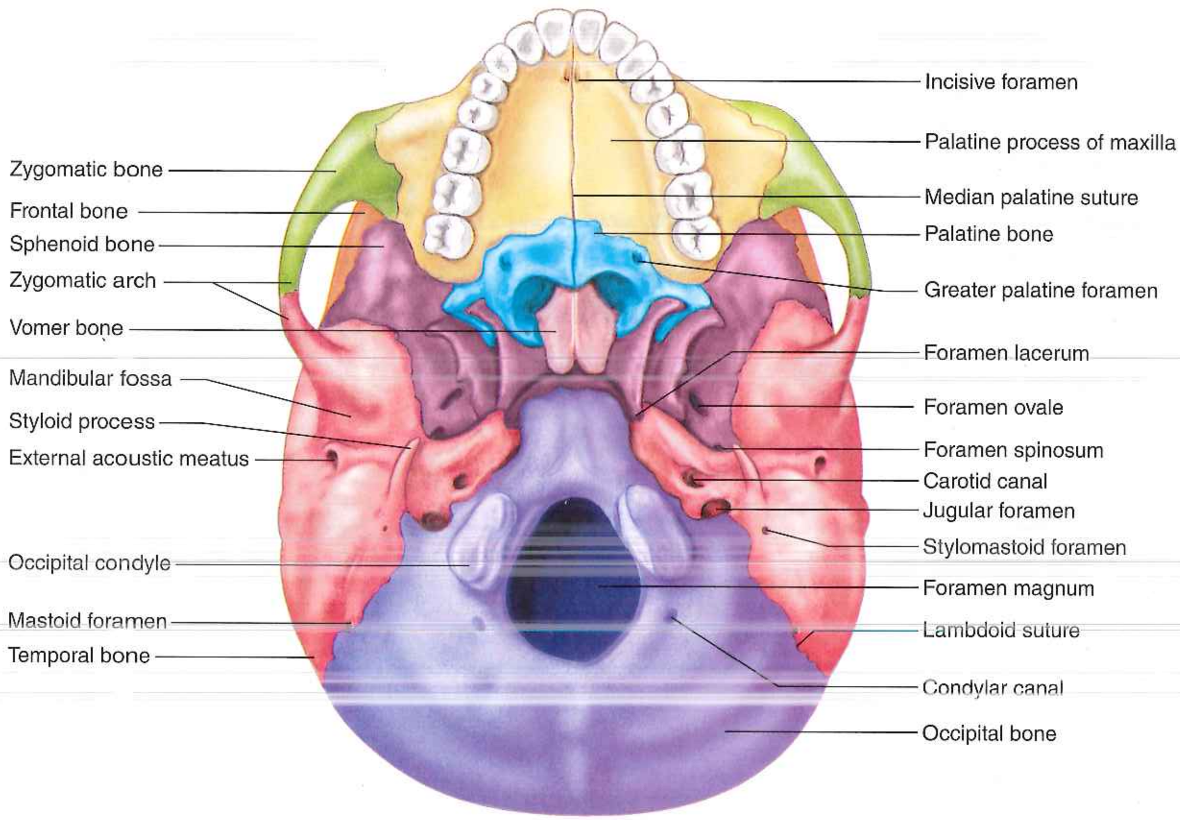


FIGURE 7.21 AP|R Inferior view of the skull.

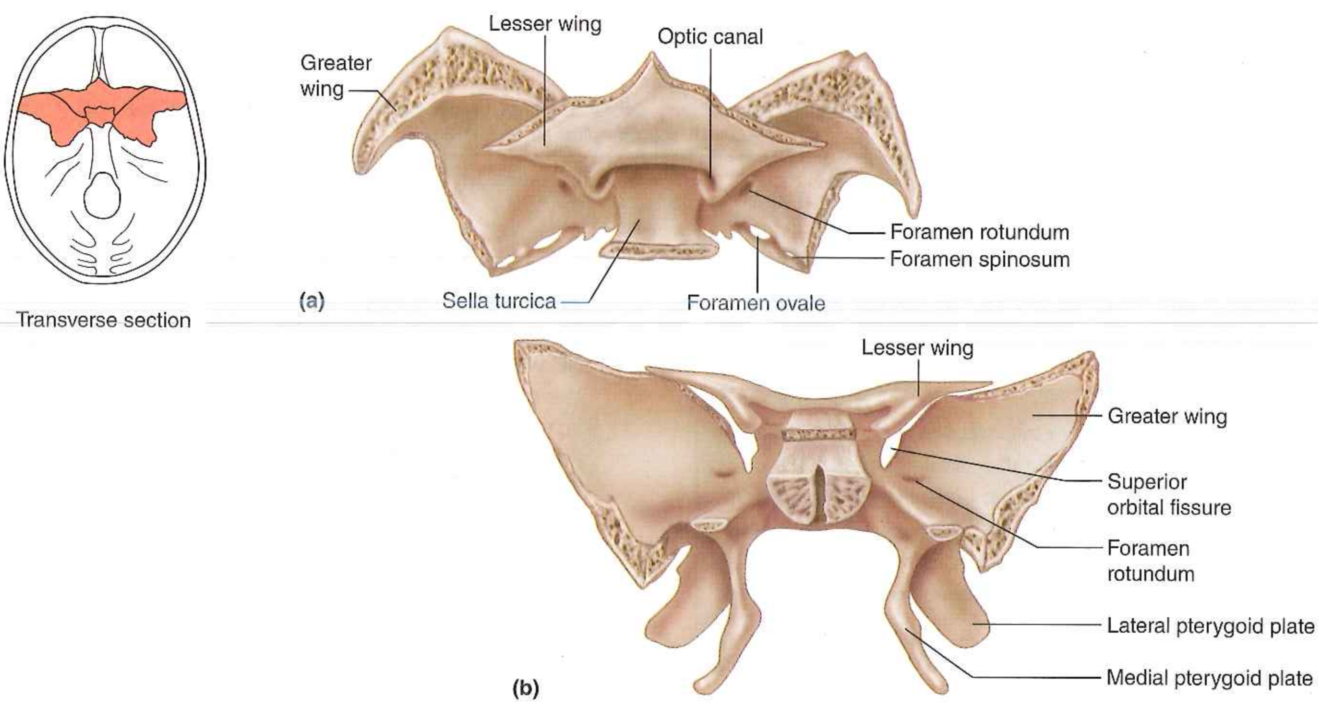


FIGURE 7.22 AP|R The sphenoid bone. (*a*) Superior view. (*b*) Posterior view.

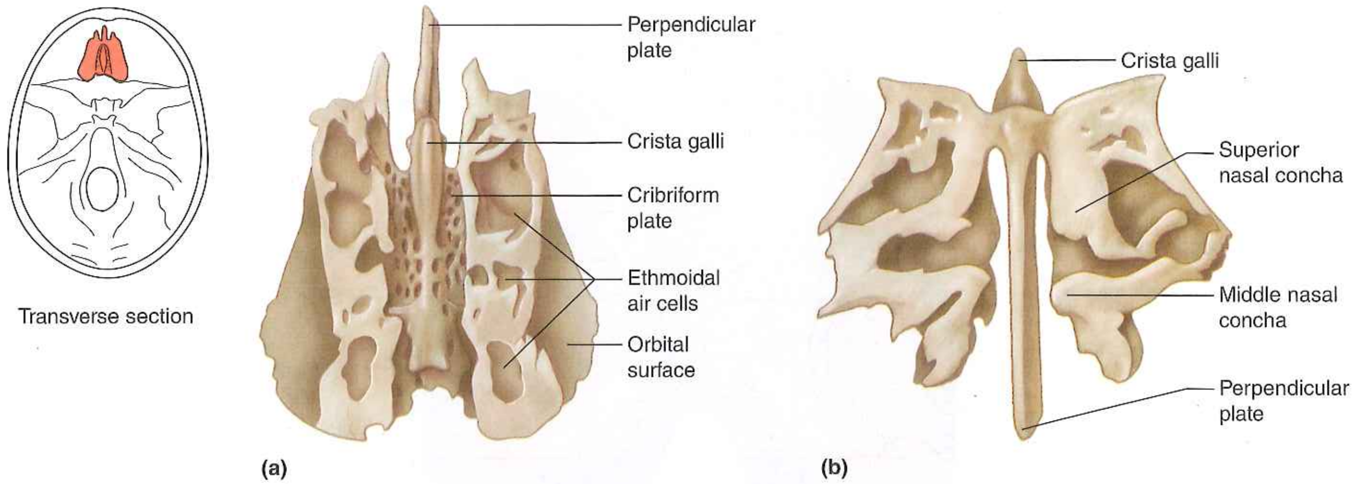


FIGURE 7.23 APR The ethmoid bone. (*a*) Superior view. (*b*) Posterior view.

6. The **ethmoid** (eth′moid) **bone** (fig. 7.23) is located in front of the sphenoid bone. It consists of two masses, one on each side of the nasal cavity, joined horizontally by thin *cribriform* (krib′rĭ-form) *plates.* These plates form part of the roof of the nasal cavity, and nerves associated with the sense of smell pass through tiny openings *(olfactory foramina)* in them. Portions of the ethmoid bone also form sections of the cranial floor, orbital walls, and nasal cavity walls. A *perpendicular plate* projects downward in the midline from the cribriform plates to form most of the nasal septum.

   Delicate, scroll-shaped plates called the *superior nasal concha* (kong′kah) and the *middle nasal concha* project inward from the lateral portions of the ethmoid bone toward the perpendicular plate. These bony plates support mucous membranes that line the nasal cavity. The mucous membranes, in turn, begin moistening, warming, and filtering air as it enters the respiratory tract. The lateral portions of the ethmoid bone contain many small spaces, the *ethmoidal air cells,* that together form the ethmoidal sinus (see fig. 7.20). Figure 7.24 shows various structures in the nasal cavity.

   Projecting upward into the cranial cavity between the cribriform plates is a triangular process of the ethmoid bone called the *crista galli* (kris′tă gal′li) (cock's comb). Membranes that enclose the brain attach to this process. Figure 7.25 shows a view of the floor of the cranial cavity.

Facial Skeleton

The **facial skeleton** consists of thirteen immovable bones and a movable lower jawbone. In addition to forming the

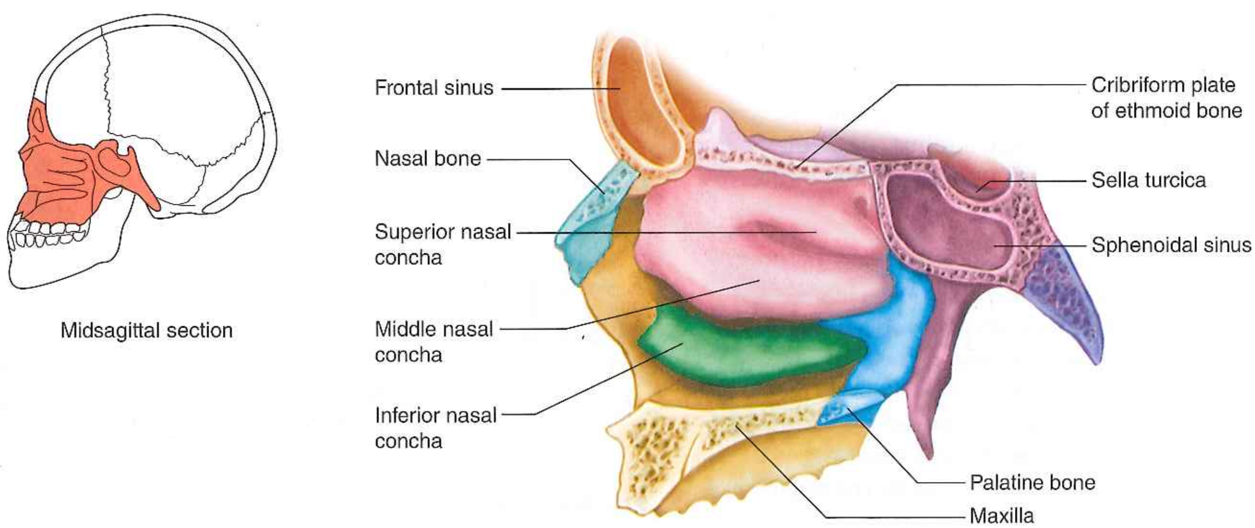


FIGURE 7.24 Lateral wall of the nasal cavity.

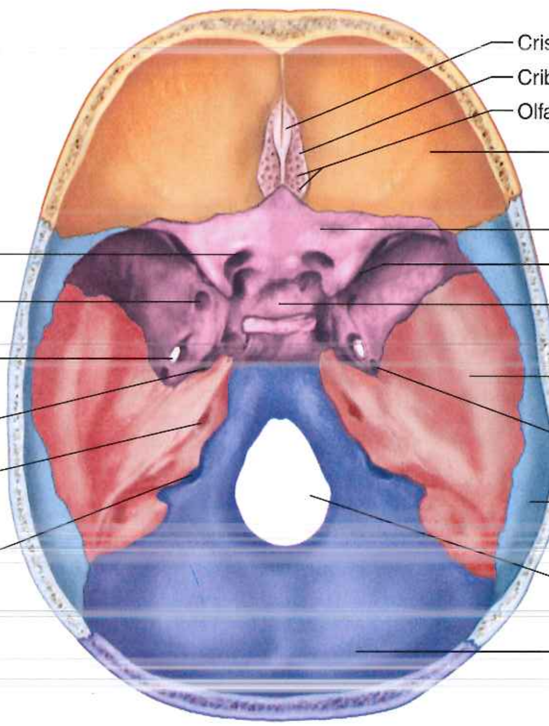


FIGURE 7.25 APR Floor of the cranial cavity, viewed from above.

basic shape of the face, these bones provide attachments for muscles that move the jaw and control facial expressions.

The bones of the facial skeleton are as follows:

1. The **maxillae** (mak-sil'e; sing., *maxilla,* mak-sil'ah) form the upper jaw; together they form the keystone of the face, because the other immovable facial bones articulate with them.

   Portions of the maxillary bones compose the anterior roof of the mouth *(hard palate),* the floors of the orbits, and the sides and floor of the nasal cavity. They also contain the sockets of the upper teeth. Inside the maxillae, lateral to the nasal cavity, are *maxillary sinuses* (see fig. 7.20). These spaces are the largest of the sinuses, and they extend from the floor of the orbits to the roots of the upper teeth During development, portions of the maxillary bones called *palatine processes* grow together and fuse along the midline, or median palatine suture. This forms the anterior section of the hard palate (see fig. 7.21).

A *cleft palate* results from incomplete fusion of the palatine processes of the maxillae by the time of birth. An infant with a cleft palate may have trouble sucking a bottle due to the opening between the oral and nasal cavities. A temporary prosthetic device (artificial palate) worn in the mouth or a special type of nipple placed on a bottle can help the child eat and drink until surgery corrects the cleft. This surgery is best performed between the ages of twelve and eighteen months.

   The inferior border of each maxillary bone projects downward, forming an *alveolar* (al-ve'o-lar) *process.* Together these processes form a horseshoe-shaped *alveolar arch* (dental arch). Teeth occupy cavities (dental alveoli) in this arch (see chapter 17, p. 655). Dense connective tissue binds teeth to the bony sockets.

2. The L-shaped **palatine** (pal'ah-tīn) **bones** are located behind the maxillae (fig. 7.26). The horizontal portions form the posterior section of the hard palate and the floor of the nasal cavity. The perpendicular portions help form the lateral walls of the nasal cavity.

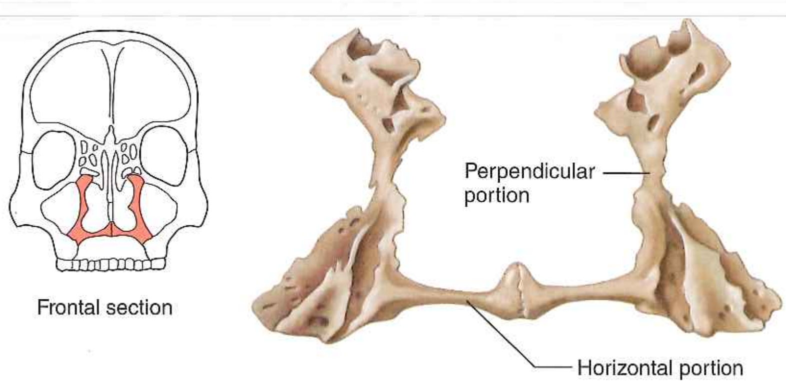


FIGURE 7.26 The horizontal portions of the palatine bones form the posterior section of the hard palate, and the perpendicular portions help form the lateral walls of the nasal cavity.

3. The **zygomatic** (zi″go-mat′ik) **bones** are responsible for the prominences of the cheeks below and to the sides of the eyes. These bones also help form the lateral walls and the floors of the orbits. Each bone has a *temporal process,* which extends posteriorly to join the zygomatic process of a temporal bone (see fig. 7.19).
4. A **lacrimal** (lak′rĭ-mal) **bone** is a thin, scalelike structure located in the medial wall of each orbit between the ethmoid bone and the maxilla (see fig. 7.19). A groove in its anterior portion leads from the orbit to the nasal cavity, providing a pathway for a channel that carries tears from the eye to the nasal cavity.
5. The **nasal** (na′zal) **bones** are long, thin, and nearly rectangular (see fig. 7.17). They lie side by side and are fused at the midline, where they form the bridge of the nose. These bones are attachments for the cartilaginous tissues that form the shape of the nose.
6. The thin, flat **vomer** (vo′mer) **bone** is located along the midline within the nasal cavity. Posteriorly, it joins the perpendicular plate of the ethmoid bone, and together they form the nasal septum (figs. 7.27 and 7.28).
7. The **inferior nasal conchae** (kong′ke) are fragile, scroll-shaped bones attached to the lateral walls of the nasal cavity. They are the largest of the conchae and are below the superior and middle nasal conchae of the ethmoid bone (see figs. 7.17 and 7.24). Like the ethmoidal conchae, the inferior conchae support mucous membranes in the nasal cavity.
8. The **mandible** (man′dĭ-bl), or lower jawbone, is a horizontal, horseshoe-shaped body with a flat *ramus* projecting upward at each end. The rami are divided into a posterior *mandibular condyle* and an anterior *coronoid* (kor′o-noid) *process* (fig. 7.29). The mandibular condyles articulate with the mandibular fossae of the temporal bones, whereas the coronoid processes provide attachments for muscles used in chewing. Other large chewing muscles are inserted on the lateral surfaces of the rami. On the superior border of the mandible, the *alveolar processes* contain the hollow sockets (dental alveoli) that bear the lower teeth.

On the medial side of the mandible, near the center of each ramus, is a *mandibular foramen.* This opening admits blood vessels and a nerve, which supply the roots of the lower teeth. Dentists inject anesthetic into the tissues near this foramen to temporarily block nerve impulse conduction and

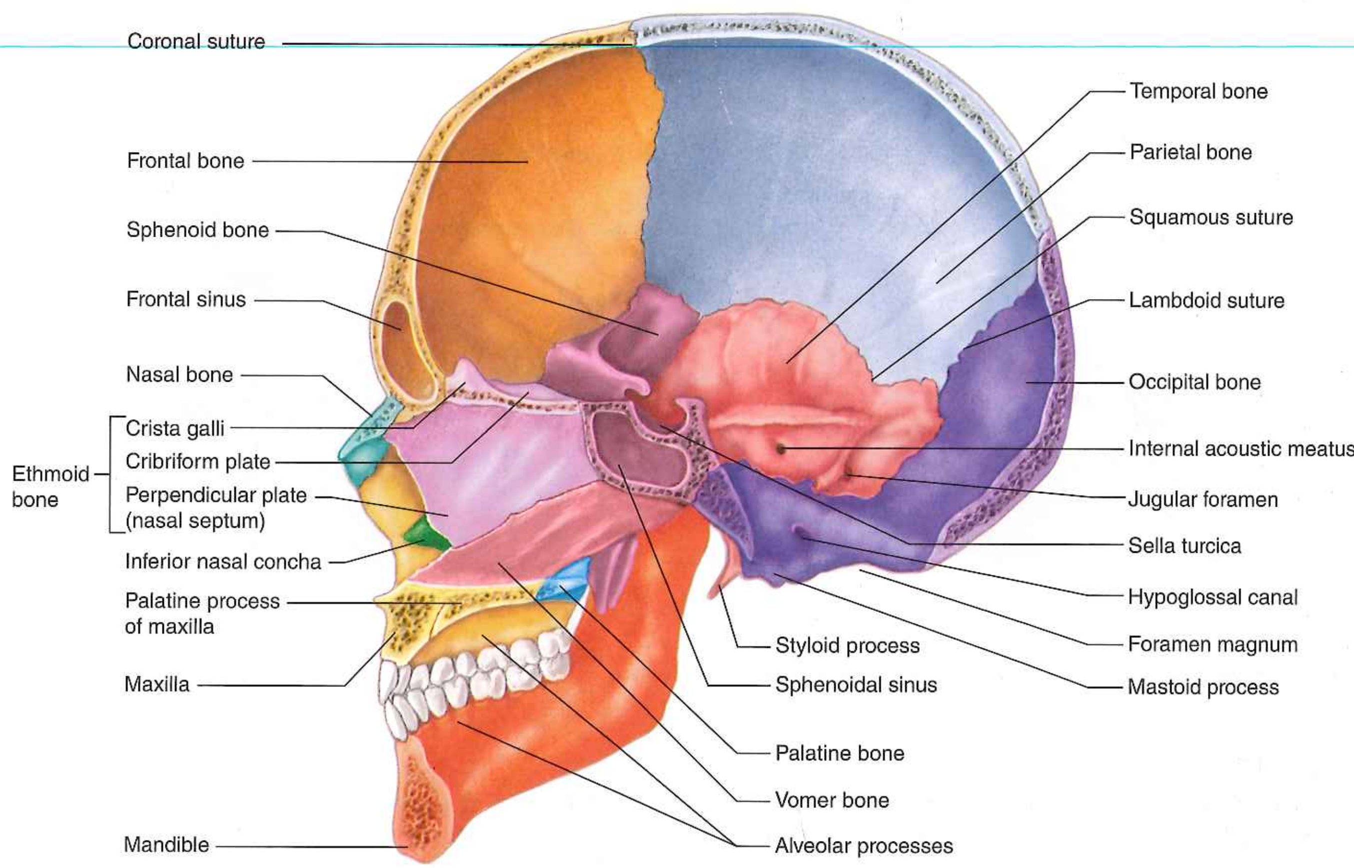


FIGURE 7.27 APIR Sagittal section of the skull.

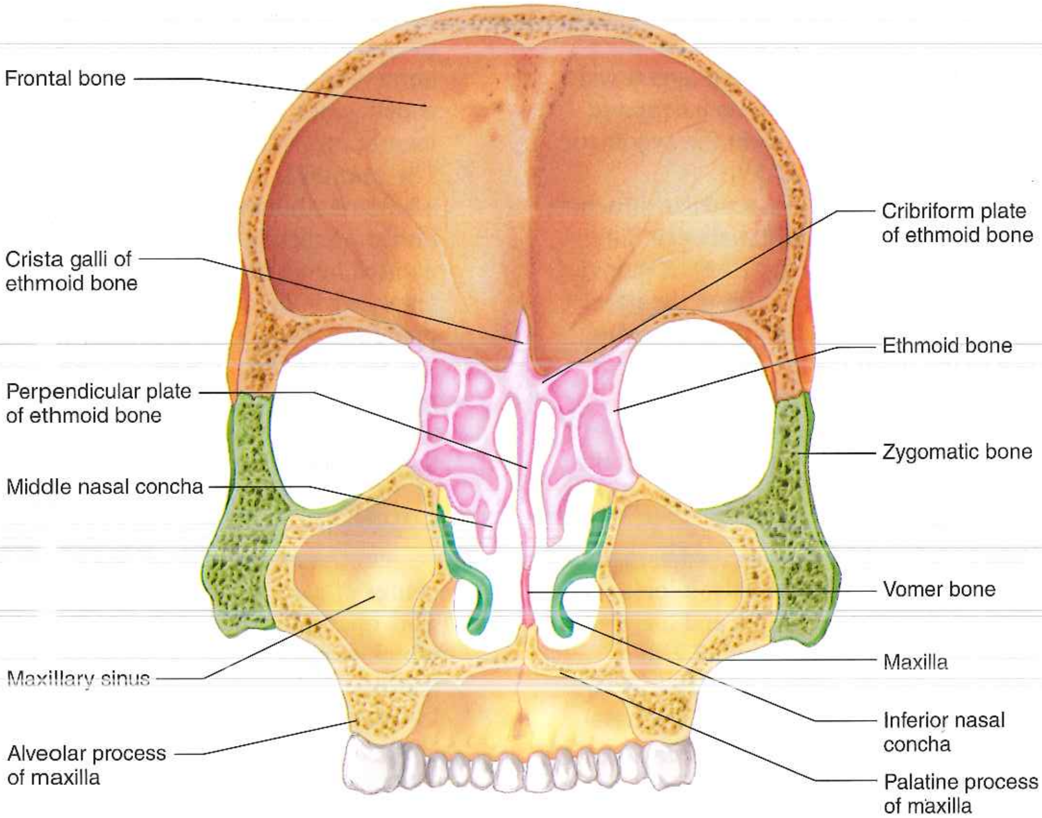


FIGURE 7.28 Frontal section of the skull (posterior view).

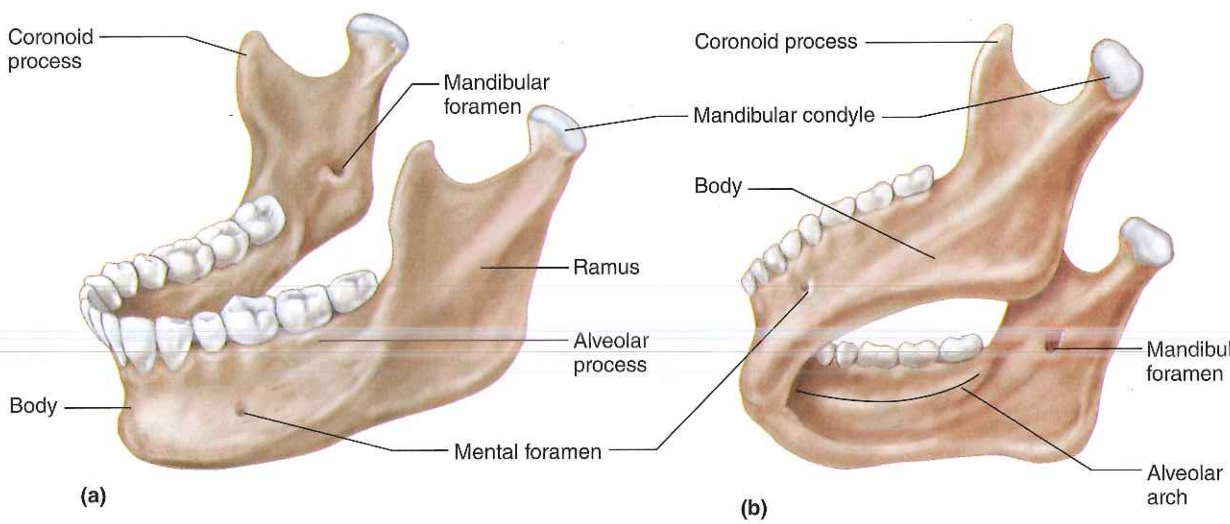


FIGURE 7.29 APR Mandible. (*a*) Left lateral view. (*b*) Inferior view.

desensitize teeth on that side of the jaw. Branches of the blood vessels and the nerve emerge from the mandible through the *mental foramen,* which opens on the outside near the point of the jaw. They supply the tissues of the chin and lower lip.

Table 7.6 describes the fourteen facial bones. Figure 7.30 shows features of these bones on radiographs. Table 7.7 lists the major openings *(foramina)* and passageways through bones of the skull, as well as their general locations and the structures that pass through them.

TABLE 7.6 | Bones of the Facial Skeleton

Name and Number	Description	Special Features
Maxillae (2)	Form upper jaw, anterior roof of mouth, floors of orbits, and sides and floor of nasal cavity	Alveolar processes, maxillary sinuses, palatine process
Palatine (2)	Form posterior roof of mouth and floor and lateral walls of nasal cavity	
Zygomatic (2)	Form prominences of cheeks and lateral walls and floors of orbits	Temporal process
Lacrimal (2)	Form part of medial walls of orbits	Groove that leads from orbit to nasal cavity
Nasal (2)	Form bridge of nose	
Vomer (1)	Forms inferior portion of nasal septum	
Inferior nasal conchae (2)	Extend into nasal cavity from its lateral walls	
Mandible (1)	Forms lower jaw	Body, ramus, mandibular condyle, coronoid process, alveolar process, mandibular foramen, mental foramen

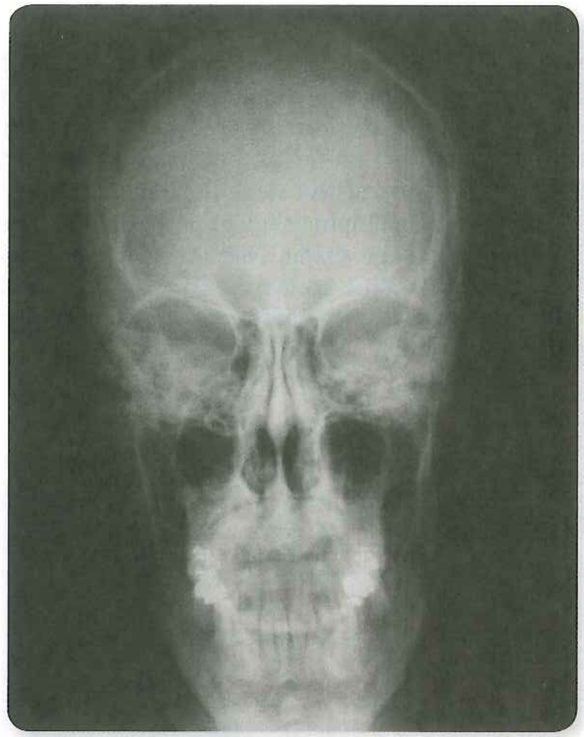


FIGURE 7.30 AP|R Radiograph of the skull. Anterior view.

TABLE 7.7 | Passageways Through Bones of the Skull

Passageway	Location	Major Structures Passing Through
Carotid canal (fig. 7.21)	Inferior surface of the temporal bone	Internal carotid artery, veins, and nerves
Foramen lacerum (fig. 7.21)	Floor of cranial cavity between temporal and sphenoid bones	Branch of pharyngeal artery (in life, opening is largely covered by fibrocartilage)
Foramen magnum (fig. 7.25)	Base of skull in occipital bone	Inferior part of brainstem connecting to spinal cord, also certain arteries
Foramen ovale (fig. 7.21)	Floor of cranial cavity in sphenoid bone	Mandibular division of trigeminal nerve and veins
Foramen rotundum (fig. 7.25)	Floor of cranial cavity in sphenoid bone	Maxillary division of trigeminal nerve
Foramen spinosum (fig. 7.25)	Floor of cranial cavity in sphenoid bone	Middle meningeal blood vessels and branch of mandibular nerve
Greater palatine foramen (fig. 7.21)	Posterior portion of hard palate in palatine bone	Palatine blood vessels and nerves
Hypoglossal canal (fig. 7.27)	Near margin of foramen magnum in occipital bone	Hypoglossal nerve
Incisive foramen (fig. 7.21)	Incisive fossa in anterior portion of hard palate	Nasopalatine nerves, openings of vomeronasal organ
Inferior orbital fissure (fig. 7.18)	Floor of the orbit	Maxillary nerve and blood vessels
Infraorbital foramen (fig. 7.18)	Below the orbit in maxillary bone	Infraorbital blood vessels and nerves
Internal acoustic meatus (fig. 7.25)	Floor of cranial cavity in temporal bone	Branches of facial and vestibulocochlear nerves and blood vessels
Jugular foramen (fig. 7.25)	Base of the skull between temporal and occipital bones	Glossopharyngeal, vagus and accessory nerves, and blood vessels
Mandibular foramen (fig. 7.29)	Inner surface of ramus of mandible	Inferior alveolar blood vessels and nerves
Mental foramen (fig. 7.29)	Near point of jaw in mandible	Mental nerve and blood vessels
Optic canal (fig. 7.18)	Posterior portion of orbit in sphenoid bone	Optic nerve and ophthalmic artery
Stylomastoid foramen (fig. 7.21)	Between styloid and mastoid processes	Facial nerve and blood vessels
Superior orbital fissure (fig. 7.18)	Posterior wall of orbit	Oculomotor, trochlear, and abducens nerves and ophthalmic division of trigeminal nerve
Supraorbital foramen (fig. 7.17)	Upper margin or orbit in frontal bone	Supraorbital blood vessels and nerves

Infantile Skull

At birth, the skull is incompletely developed, with fibrous membranes connecting the cranial bones. These membranous areas of incomplete intramembranous ossification are called **fontanels** (fon″tah-nel′z), or, more commonly, soft spots (fig. 7.31). They permit some movement between the bones so that the developing skull is partially compressible and can slightly change shape. This action, called *molding*, enables an infant's skull to more easily pass through the birth canal. Eventually, the fontanels close as the cranial bones grow together. The posterior fontanel usually closes about two months after birth; the sphenoidal fontanel closes at about three months; the mastoid fontanel closes near the end of the first year; and the anterior fontanel may not close until the middle or end of the second year.

Other characteristics of an infantile skull (fig. 7.31) include a small face with a prominent forehead and large orbits. The jaw and nasal cavity are small, the sinuses are incompletely formed, and the frontal bone is in two parts (reference plate 51, p. 267). The skull bones are thin, but

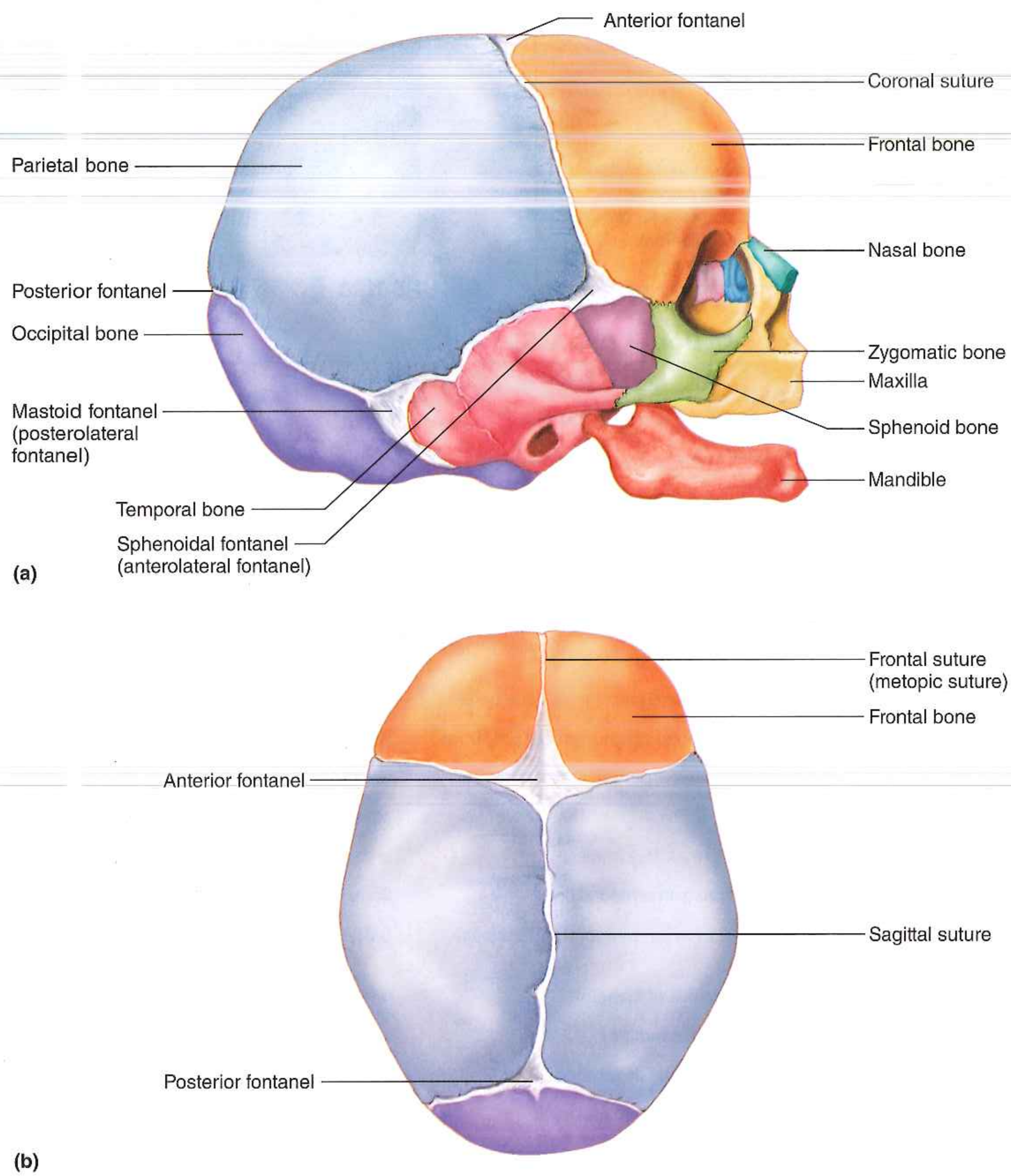


FIGURE 7.31 Fontanels. (*a*) Right lateral view and (*b*) superior view of the infantile skull.

they are also somewhat flexible and thus are less easily fractured than adult bones.

PRACTICE

19 Locate and name each of the bones of the cranium.

20 Locate and name each of the facial bones.

21 Explain how an adult skull differs from that of an infant.

7.7 VERTEBRAL COLUMN

The **vertebral column** extends from the skull to the pelvis and forms the vertical axis of the skeleton (fig. 7.32). It is composed of many bony parts called **vertebrae** (ver′tĕ-bre) separated by masses of fibrocartilage called *intervertebral discs* and connected to one another by ligaments. The vertebral column supports the head and the trunk of the body, yet is flexible enough to permit movements, such as bending

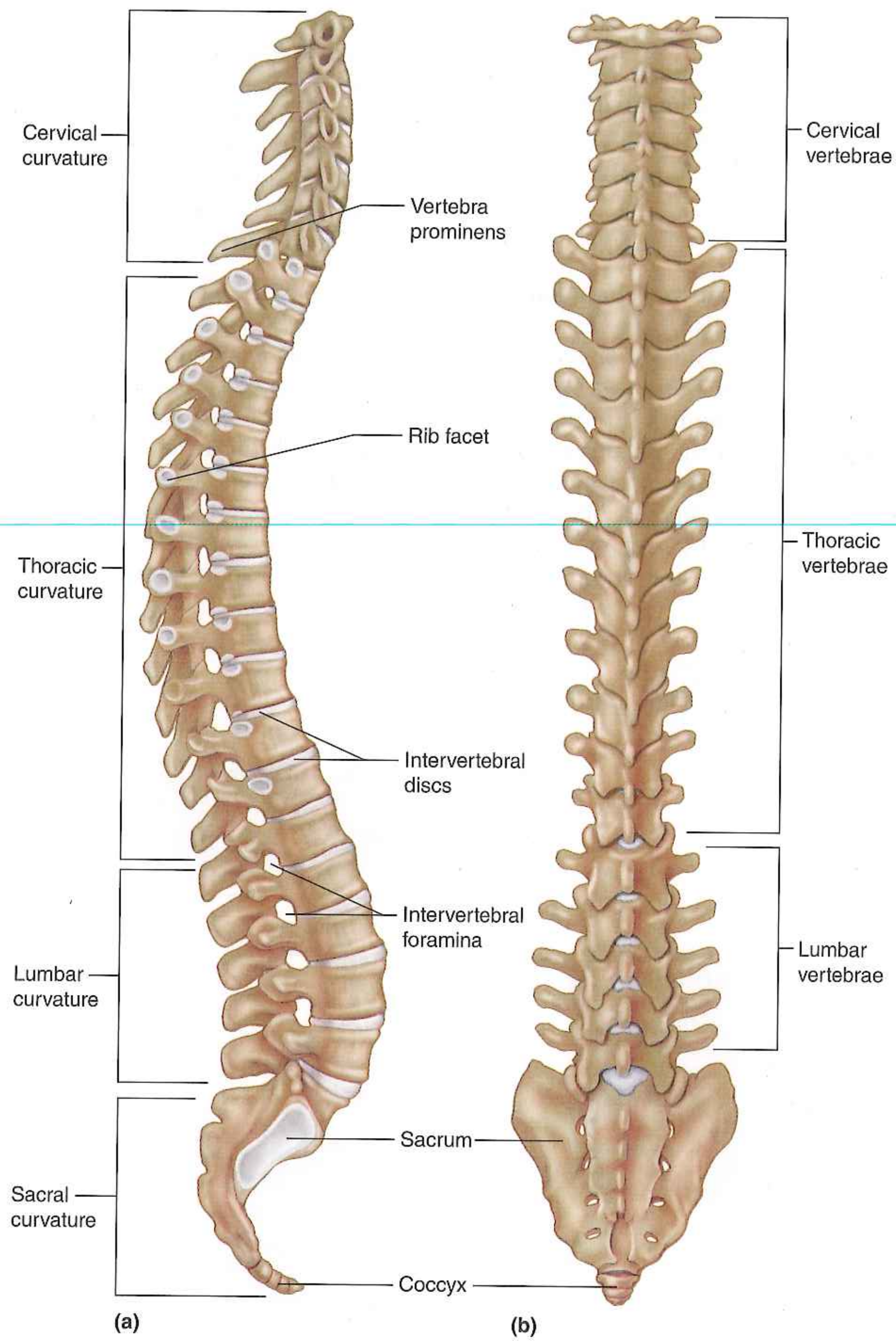


FIGURE 7.32 APR The curved vertebral column consists of many vertebrae separated by intervertebral discs. (*a*) Right lateral view. (*b*) Posterior view.

forward, backward, or to the side and turning or rotating on the central axis. It also protects the spinal cord, which passes through a *vertebral canal* formed by openings in the vertebrae.

An infant has thirty-three separate bones in the vertebral column. Five of these bones eventually fuse to form the sacrum, and four others join to become the coccyx. As a result, an adult vertebral column has twenty-six bones.

Normally, the vertebral column has four curvatures, which give it a degree of resiliency. The names of the curves correspond to the regions where they are located, as figure 7.32 shows. The *thoracic* and *sacral curvatures* are concave anteriorly and are called primary curves. The *cervical curvature* in the neck and the *lumbar curvature* in the lower back are convex anteriorly and are called secondary curves. The cervical curvature develops when a baby begins to hold up its head, and the lumbar curvature develops when the child begins to stand.

A Typical Vertebra

The vertebrae in different regions of the vertebral column have special characteristics, but they also have features in common. A typical vertebra has a drum-shaped *body,* which forms the thick, anterior portion of the bone (fig. 7.33). A longitudinal row of these vertebral bodies supports the weight of the head and trunk. The intervertebral discs, which separate adjacent vertebrae, are fastened to the roughened upper and lower surfaces of the vertebral bodies. These discs cushion and soften the forces generated by such movements as walking and jumping, which might otherwise fracture vertebrae or jar the brain. The bodies of adjacent vertebrae are joined on their anterior surfaces by *anterior longitudinal ligaments* and on their posterior surfaces by *posterior longitudinal ligaments.*

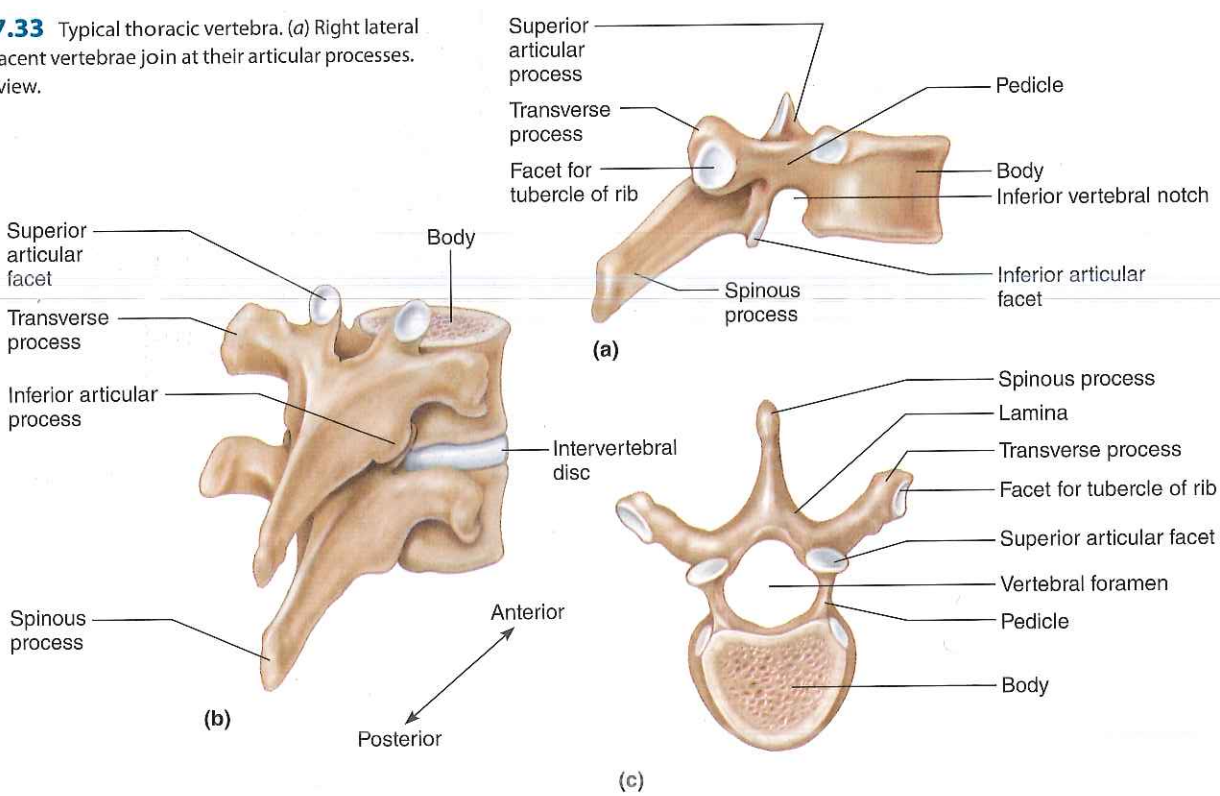
Projecting posteriorly from each vertebral body are two short stalks called *pedicles* (ped'ĭ-k'lz). They form the sides of the *vertebral foramen.* Two plates called *laminae* (lam'ĭ-ne) arise from the pedicles and fuse in the back to become a *spinous process.* The pedicles, laminae, and spinous process together complete a bony *vertebral arch* around the vertebral foramen, through which the spinal cord passes.

If the laminae of the vertebrae fail to unite during development, the vertebral arch remains incomplete, causing a condition call *spina bifida.* The contents of the vertebral canal protrude outward. This problem occurs most frequently in the lumbrosacral region. Spina bifida is associated with folic acid deficiency in certain genetically susceptible individuals.

Between the pedicles and laminae of a typical vertebra is a *transverse process,* which projects laterally and posteriorly. Various ligaments and muscles are attached to the dorsal spinous process and the transverse processes. Projecting upward and downward from each vertebral arch are *superior* and *inferior articular processes.* These processes bear cartilage-covered facets by which each vertebra is joined to the one above and the one below it.

On the lower surfaces of the vertebral pedicles are notches that align with adjacent vertebrae to help form

FIGURE 7.33 Typical thoracic vertebra. (*a*) Right lateral view. (*b*) Adjacent vertebrae join at their articular processes. (*c*) Superior view.



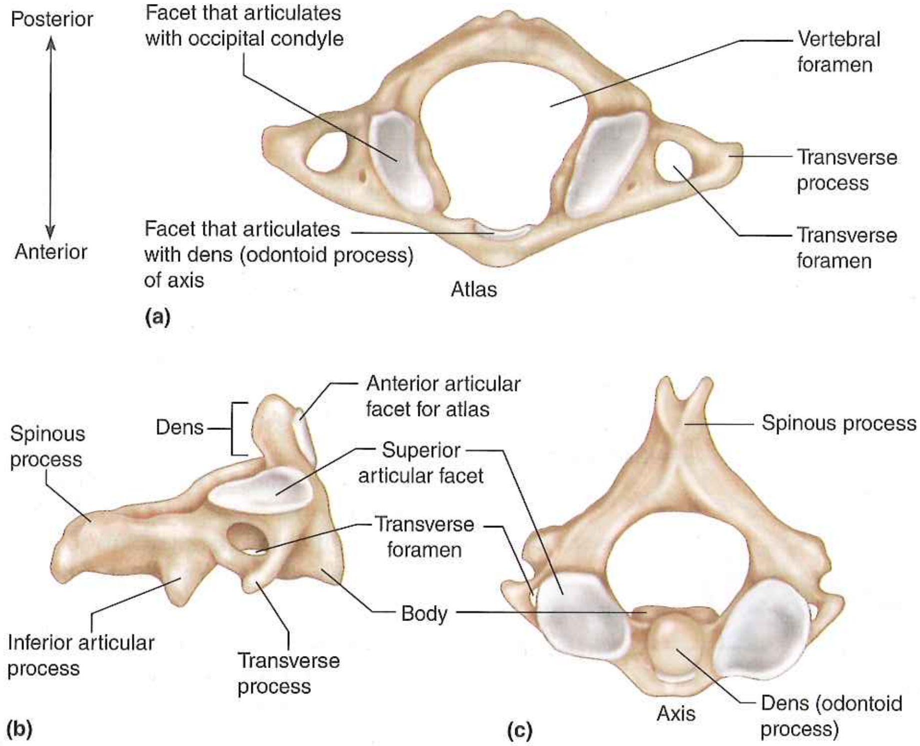


FIGURE 7.34 AP|R Atlas and axis. (*a*) Superior view of the atlas. (*b*) Right lateral view and (*c*) superior view of the axis.

openings called *intervertebral foramina* (in″ter-ver′tĕ-bral fo-ram′ĭ-nah). These openings provide passageways for spinal nerves (see fig. 7.32).

Cervical Vertebrae

Seven **cervical vertebrae** comprise the bony axis of the neck. These are the smallest vertebrae, but their bone tissues are denser than those in any other region of the vertebral column.

The transverse processes of the cervical vertebrae are distinctive because they have *transverse foramina,* which are passageways for arteries leading to the brain. Also, the spinous processes of the second through the sixth cervical vertebrae are uniquely forked (bifid). These processes provide attachments for muscles.

The spinous process of the seventh vertebra is longer and protrudes beyond the other cervical spines. It is called the *vertebra prominens,* and because it can be felt through the skin, it is a useful landmark for locating other vertebral parts (see fig. 7.32).

Two of the cervical vertebrae, shown in figure 7.34, are of special interest. The first vertebra, or **atlas** (at′las), supports the head. It has practically no body or spine and appears as a bony ring with two transverse processes. On its superior surface, the atlas has two kidney-shaped *facets,* which articulate with the occipital condyles.

The second cervical vertebra, or **axis** (ak′sis), bears a toothlike *dens* (odontoid process) on its body. This process projects upward and lies in the ring of the atlas. As the head is turned from side to side, the atlas pivots around the dens (fig. 7.34 and fig. 7.35).

FIGURE 7.35 Radiograph of the cervical vertebrae.

Thoracic Vertebrae

The twelve **thoracic vertebrae** are larger than those in the cervical region. Their transverse processes project posteriorly at sharp angles. Each vertebra has a long, pointed spinous process, which slopes downward, and a facet on each side of its body, which articulates with a rib head.

Beginning with the third thoracic vertebra and moving inferiorly, the bodies of these bones increase in size. This adapts them to bear increasing loads of body weight.

Lumbar Vertebrae

The five **lumbar vertebrae** in the small of the back (loin) support more weight than the superior vertebrae and have larger and stronger bodies. Compared to other types of vertebrae, the thinner transverse processes of these vertebrae project laterally, whereas their short, thick spinous processes are nearly horizontal where they project posteriorly. Figure 7.36 compares the structures of the cervical, thoracic, and lumbar vertebrae.

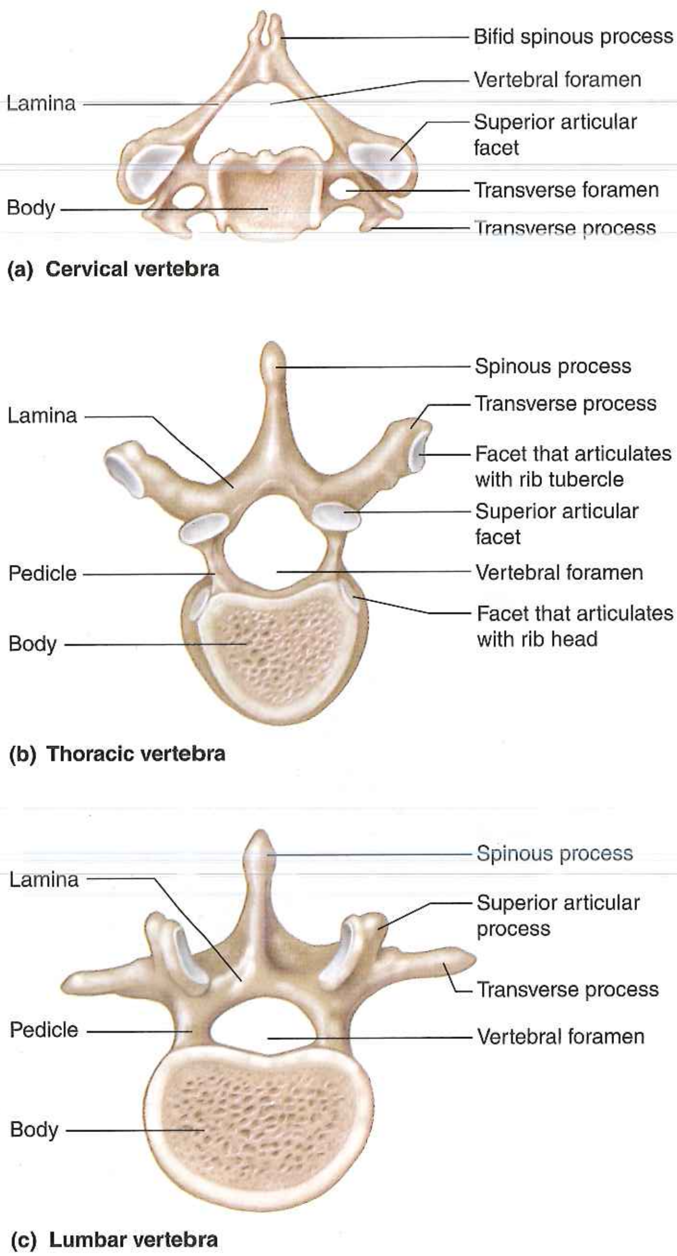


FIGURE 7.36 APR Superior view of (*a*) a cervical vertebra, (*b*) a thoracic vertebra, and (*c*) a lumbar vertebra.

Sacrum

The **sacrum** (sa'krum) is a triangular structure at the base of the vertebral column. It is composed of five vertebrae that develop separately but gradually fuse between ages eighteen and thirty (fig. 7.37). In some individuals only four vertebrae fuse to form the sacrum, and the fifth vertebra becomes a sixth lumbar vertebra. The spinous processes of these fused bones form a ridge of tubercles, called the *median sacral crest.* Nerves and blood vessels pass through rows of openings, called the *posterior sacral foramina,* located to the sides of the tubercles.

The sacrum is wedged between the hip bones of the pelvis and joins them at its *auricular surfaces* by the fibrocartilage of the *sacroiliac* (sa″kro-il'e-ak) *joints.* The pelvic girdle transmits the body's weight to the legs at these joints (see fig. 7.15).

The sacrum forms the posterior wall of the pelvic cavity. The upper anterior margin of the sacrum, which represents the body of the first sacral vertebra, is called the *sacral promontory* (sa'kral prom'on-to″re). A physician performing a vaginal examination can feel this projection and use it as a guide in determining the size of the pelvis. This measurement is helpful in estimating how easily an infant may be able to pass through a woman's pelvic cavity.

The vertebral foramina of the sacral vertebrae form the *sacral canal,* which continues through the sacrum to an opening of variable size at the tip, called the *sacral hiatus* (hi-a'tus). This foramen exists because the laminae of the last sacral vertebra are not fused. On the ventral surface of the sacrum, four pairs of *anterior sacral foramina* provide passageways for nerves and blood vessels.

> The painful condition spondylolisthesis results from a vertebra that slips out of place over the vertebra below. Most commonly the fifth lumbar vertebra slides forward over the body of the sacrum. Persons with spondylolysis who fracture a portion of the vertebra between the superior and inferior articular processes may be more likely to develop spondylolisthesis. This would include gymnasts, football players, and other athletes who flex, extend, or rotate their vertebral columns excessively and forcefully.

Coccyx

The **coccyx** (kok'siks), or tailbone, is the lowest part of the vertebral column and is usually composed of four vertebrae that fuse between the ages of twenty-five and thirty (fig. 7.37).

Variations in individuals include three to five coccygeal vertebrae with typically the last three fused. In the elderly, the coccyx may fuse to the sacrum. Ligaments attach the

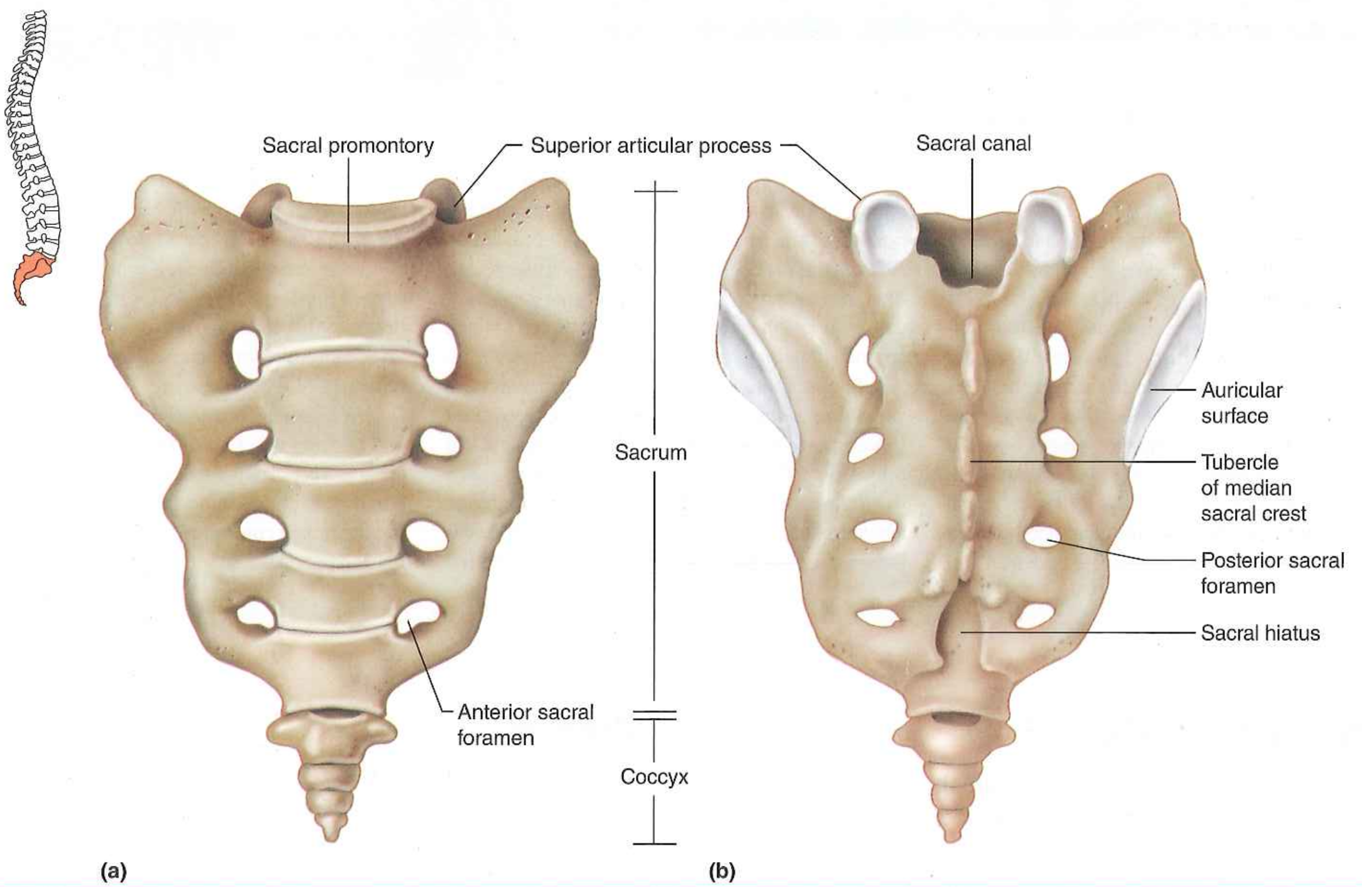


FIGURE 7.37 APIR Sacrum and coccyx. (*a*) Anterior view. (*b*) Posterior view.

TABLE 7.8 | Bones of the Vertebral Column

Bones	Number	Special Features	Bones	Number	Special Features
Cervical vertebrae	7	Transverse foramina; facets of atlas articulate with occipital condyles of skull; dens of axis articulates with atlas; spinous processes of second through sixth vertebrae are bifid	Lumbar vertebrae	5	Large bodies; thinner transverse processes that project laterally; short, thick spinous processes that project posteriorly nearly horizontal
Thoracic vertebrae	12	Transverse processes project posteriorly at sharp angles; pointed spinous processes that slope downward; facets that articulate with ribs	Sacrum	5 vertebrae fused	Posterior sacral foramina, auricular surfaces, sacral promontory, sacral canal, sacral hiatus, anterior sacral foramina
			Coccyx	4 vertebrae fused	Attached by ligaments to the margins of the sacral hiatus

coccyx to the margins of the sacral hiatus. Sitting presses on the coccyx, and it moves forward, acting like a shock absorber. Sitting down with great force, as when slipping and falling on ice, can fracture or dislocate the coccyx. The coccyx is also an attachment for the muscles of the pelvic floor. Table 7.8 summarizes the bones of the vertebral column, and Clinical Application 7.2 discusses disorders of the vertebral column.

PRACTICE

22 Describe the structure of the vertebral column.

23 Explain the difference between the vertebral column of an adult and that of an infant.

24 Describe a typical vertebra.

25 Explain how the structures of cervical, thoracic, and lumbar vertebrae differ.

7.2 CLINICAL APPLICATION

Disorders of the Vertebral Column

Changes in the intervertebral discs may cause various problems. Each disc is composed of a tough, outer layer of fibrocartilage (annulus fibrosus) and an elastic central mass (nucleus pulposus). With age, these discs degenerate. The central masses lose firmness, and the outer layers thin, weaken, and crack. A fall or lifting a heavy object can exert enough pressure to break the outer layers of the discs and squeeze out the central masses. Such a rupture may press on the spinal cord or on spinal nerves that branch from it. This condition, called a *ruptured,* or *herniated disc,* may cause back pain and numbness or loss of muscular function in the parts innervated by the affected spinal nerves.

A surgical procedure called a *laminectomy* may relieve the pain of a herniated disc by removing a portion of the posterior arch of a vertebra, which reduces the pressure on the affected nerve tissues. Alternatively, a protein-digesting enzyme (chymopapain) may be injected into the injured disc to shrink it so it no longer presses on a nerve.

Poor posture, injury, or disease can affect the curvatures of the vertebral column. An exaggerated thoracic curvature causes rounded shoulders and a hunchback. This condition, called kyphosis, is seen in adolescents who undertake strenuous athletic activities. Unless corrected before bone growth completes, the condition can permanently deform the vertebral column.

The vertebral column may develop an abnormal lateral curvature, placing one hip or shoulder lower than the other, which may displace or compress the thoracic and abdominal organs. This condition, called scoliosis, is most common in adolescent females. It may accompany poliomyelitis, rickets, or tuberculosis, or have an unknown cause. An accentuated lumbar curvature is called *lordosis,* or swayback.

As a person ages, the intervertebral discs shrink and become more rigid, and compression is more likely to fracture the vertebral bodies. Consequently, height may decrease, and the thoracic curvature of the vertebral column may become accentuated, bowing the back. ■

7.8 THORACIC CAGE

The **thoracic cage** includes the ribs, the thoracic vertebrae, the sternum, and the costal cartilages that attach the ribs to the sternum. These bones support the pectoral girdle and upper limbs, protect the viscera in the thoracic and upper abdominal cavities, and play a role in breathing (fig. 7.38).

Ribs

The usual number of **ribs** is twenty-four—one pair attached to each of the twelve thoracic vertebrae. Some individuals have extra ribs associated with their cervical or lumbar vertebrae.

The first seven rib pairs, called the *true ribs* (vertebrosternal ribs), join the sternum directly by their costal cartilages. The remaining five pairs are called *false ribs* because their cartilages do not reach the sternum directly. Instead, the cartilages of the upper three false ribs (vertebrochondral ribs) join the cartilages of the seventh rib, whereas the lower two rib pairs do not attach to the sternum. These lower two pairs (or in some individuals, the lower three pairs) are called *floating ribs* (vertebral ribs).

A typical rib (fig. 7.39) has a long, slender shaft that curves around the chest and slopes downward. On the posterior end is an enlarged *head* by which the rib articulates with a facet on the body of its own vertebra and with the body of the next higher vertebra. The neck of the rib is flattened, lateral to the head, where ligaments attach. A *tubercle,* close to the head of the rib, articulates with the transverse process of the vertebra.

The costal cartilages are composed of hyaline cartilage. They are attached to the anterior ends of the ribs and continue in line with them toward the sternum.

Sternum

The **sternum** (ster′num), or breastbone, is located along the midline in the anterior portion of the thoracic cage. It is a flat, elongated bone that develops in three parts—an upper *manubrium* (mah-nu′bre-um), a middle *body,* and a lower *xiphoid* (zif′oid) *process* that projects downward (see fig. 7.38).

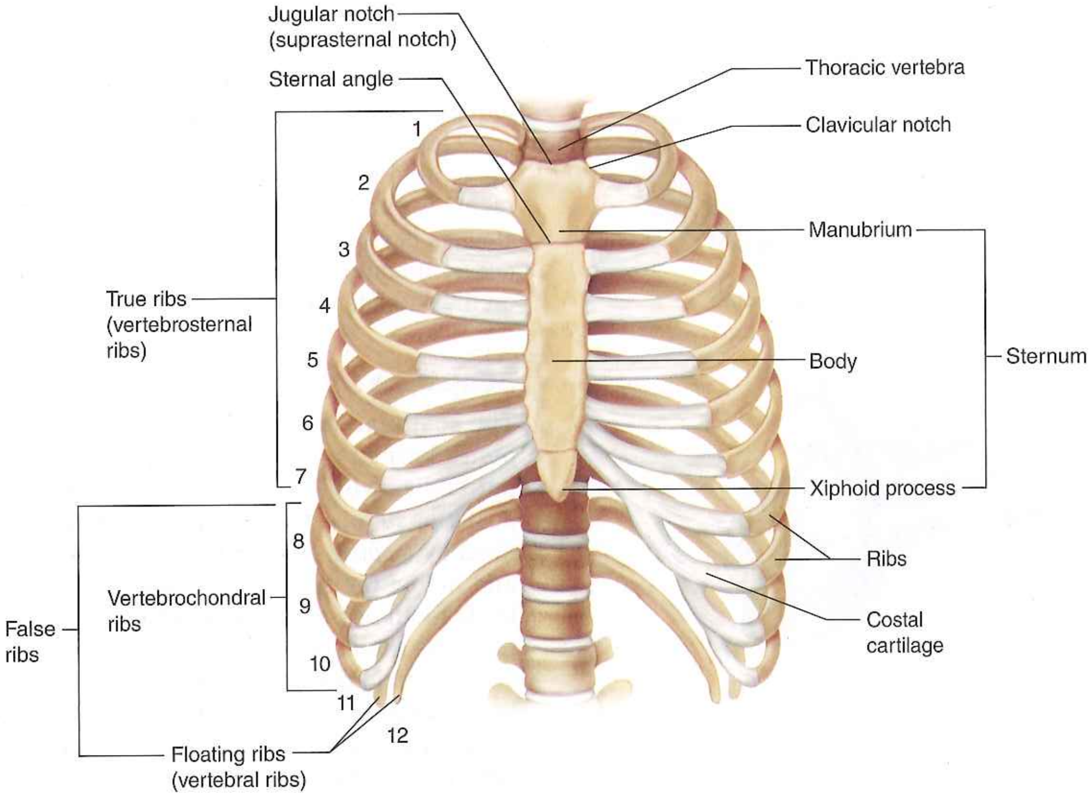
The sides of the manubrium and the body are notched where they articulate with costal cartilages. The manubrium also articulates with the clavicles by facets on its superior border. It usually remains as a separate bone until middle age or later, when it fuses to the body of the sternum.

> The manubrium and body of the sternum lie in different planes, so their line of union projects slightly forward. This projection, at the level of the second costal cartilage, is called the sternal angle (angle of Louis). It is commonly used as a clinical landmark (see fig. 7.38*a*).

The xiphoid process begins as a piece of cartilage. It slowly ossifies, and by middle age it usually fuses to the body of the sternum.

PRACTICE

26 Which bones compose the thoracic cage?
27 Describe a typical rib.
28 What are the differences among true, false, and floating ribs?
29 Name the three parts of the sternum.



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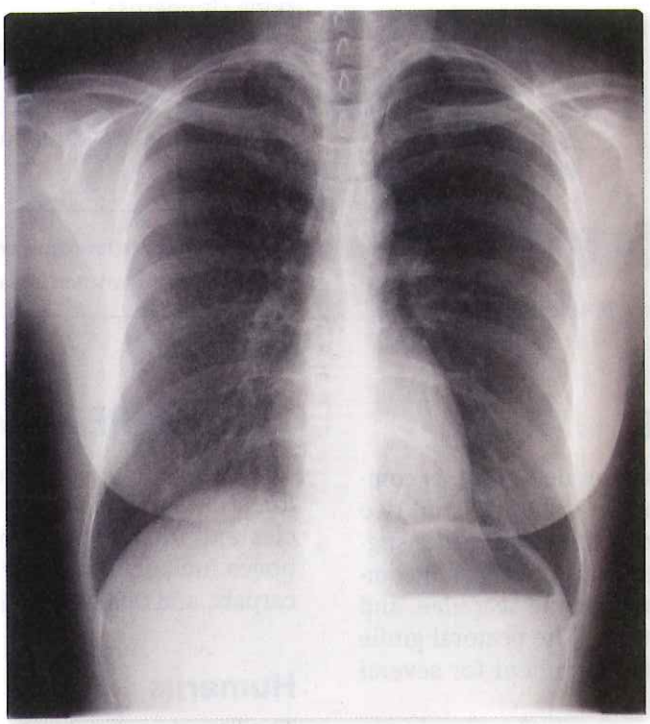


(b)

FIGURE 7.38 APR The thoracic cage includes (*a*) the thoracic vertebrae, the sternum, the ribs, and the costal cartilages that attach the ribs to the sternum. (*b*) Radiograph of the thoracic cage, anterior view. The light region behind the sternum and above the diaphragm is the heart.

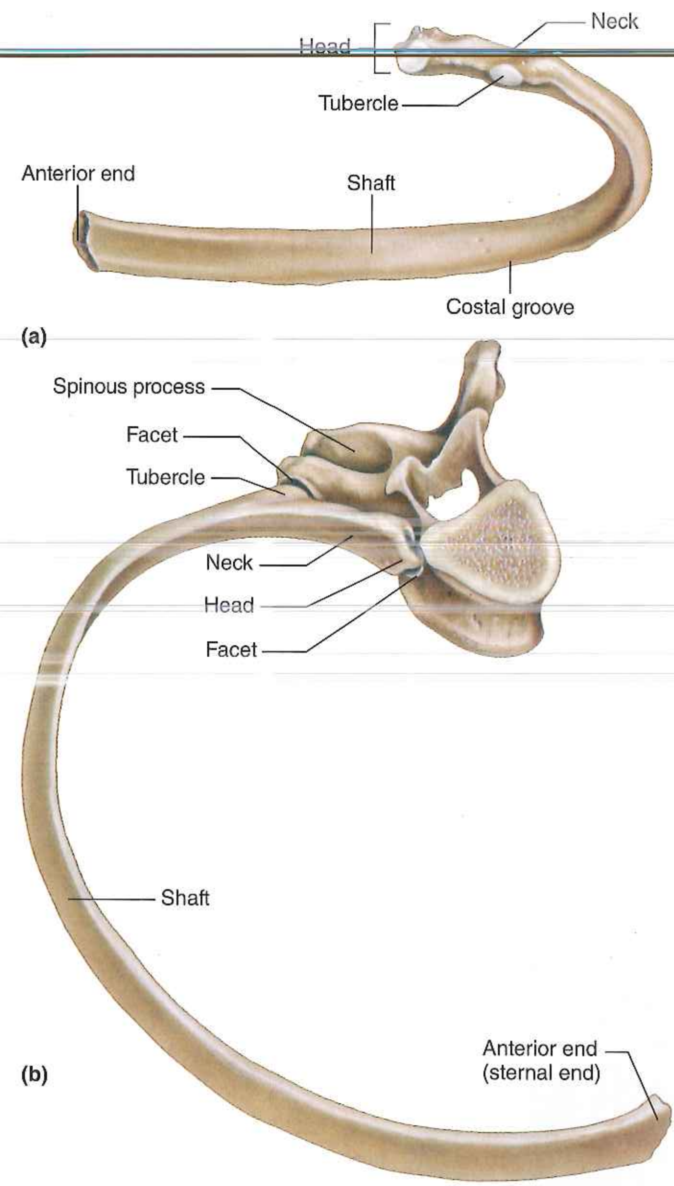


FIGURE 7.39 A typical rib. (*a*) Posterior view. (*b*) Articulations of a rib with a thoracic vertebra (superior view).

7.9 PECTORAL GIRDLE

The **pectoral** (pek'tor-al) **girdle,** or shoulder girdle, is composed of four parts—two clavicles (collarbones) and two scapulae (shoulder blades). Although the word *girdle* suggests a ring-shaped structure, the pectoral girdle is an incomplete ring. It is open in the back between the scapulae, and the sternum separates its bones in front. The pectoral girdle supports the upper limbs and is an attachment for several muscles that move them (fig. 7.40).

Clavicles

The **clavicles** (klav'ĭ-k'lz) are slender, rodlike bones with elongated S-shapes (fig. 7.40). Located at the base of the neck, they run horizontally between the manubrium and the scapulae. The sternal (or medial) ends of the clavicles articulate with the manubrium, and the acromial (or lateral) ends join processes of the scapulae.

The clavicles brace the freely movable scapulae, helping to hold the shoulders in place. They also provide attachments for muscles of the upper limbs, chest, and back. The clavicle is structurally weak because of its elongated double curve. If compressed lengthwise due to abnormal pressure on the shoulder, it is likely to fracture.

Scapulae

The **scapulae** (skap'u-le) are broad, somewhat triangular bones located on either side of the upper back. They have flat bodies with concave anterior surfaces (fig. 7.41). The posterior surface of each scapula is divided into unequal portions by a *spine.* Above the spine is the *supraspinous fossa,* and below the spine is the *infraspinous fossa.* This spine leads to an *acromion* (ah-kro'me-on) *process* that forms the tip of the shoulder. The acromion process articulates with the clavicle and provides attachments for muscles of the upper limb and chest. A *coracoid* (kor'ah-koid) *process* curves anteriorly and inferiorly to the acromion process. The coracoid process also provides attachments for upper limb and chest muscles. On the lateral surface of the scapula between the processes is a depression called the *glenoid cavity* (glenoid fossa of the scapula). It articulates with the head of the arm bone (humerus).

The scapula has three borders. The *superior border* is on the superior edge. The *axillary,* or *lateral border,* is directed toward the upper limb. The *vertebral,* or *medial border,* is closest to the vertebral column, about 5 cm away.

PRACTICE

30 Which bones form the pectoral girdle?

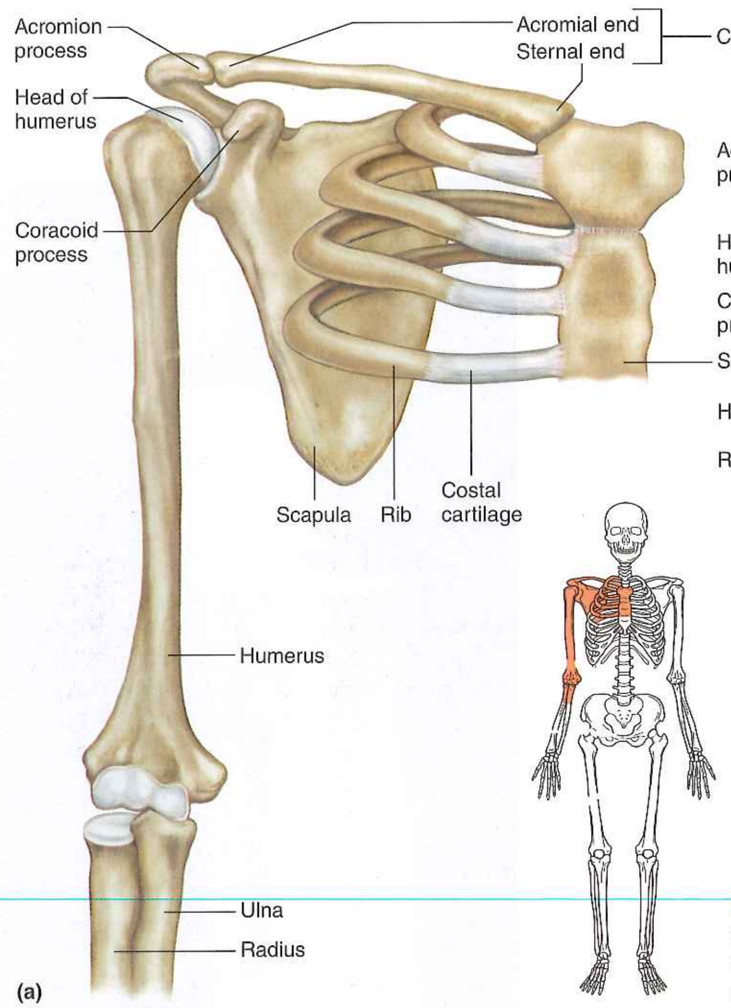
31 What is the function of the pectoral girdle?

7.10 UPPER LIMB

The bones of the upper limb form the framework of the arm, forearm, and hand. They also provide attachments for muscles and interact with muscles to move limb parts. These bones include a humerus, a radius, an ulna, carpals, metacarpals, and phalanges (fig. 7.42).

Humerus

The **humerus** is a long bone that extends from the scapula to the elbow. At its upper end is a smooth, rounded *head* that fits into the glenoid cavity of the scapula (fig. 7.43). Just below the head are two processes—a *greater tubercle* on the lateral side and a *lesser tubercle* on the anterior side. These



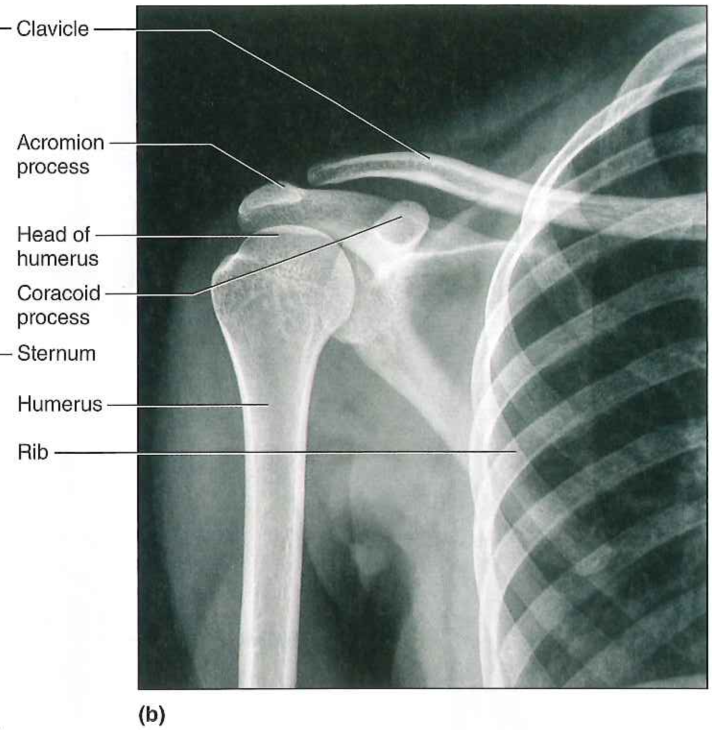


FIGURE 7.40 APR Right portion of the pectoral girdle. (*a*) The pectoral girdle, to which the upper limbs are attached, consists of a clavicle and a scapula on each side. (*b*) Radiograph of the right shoulder region, anterior view.

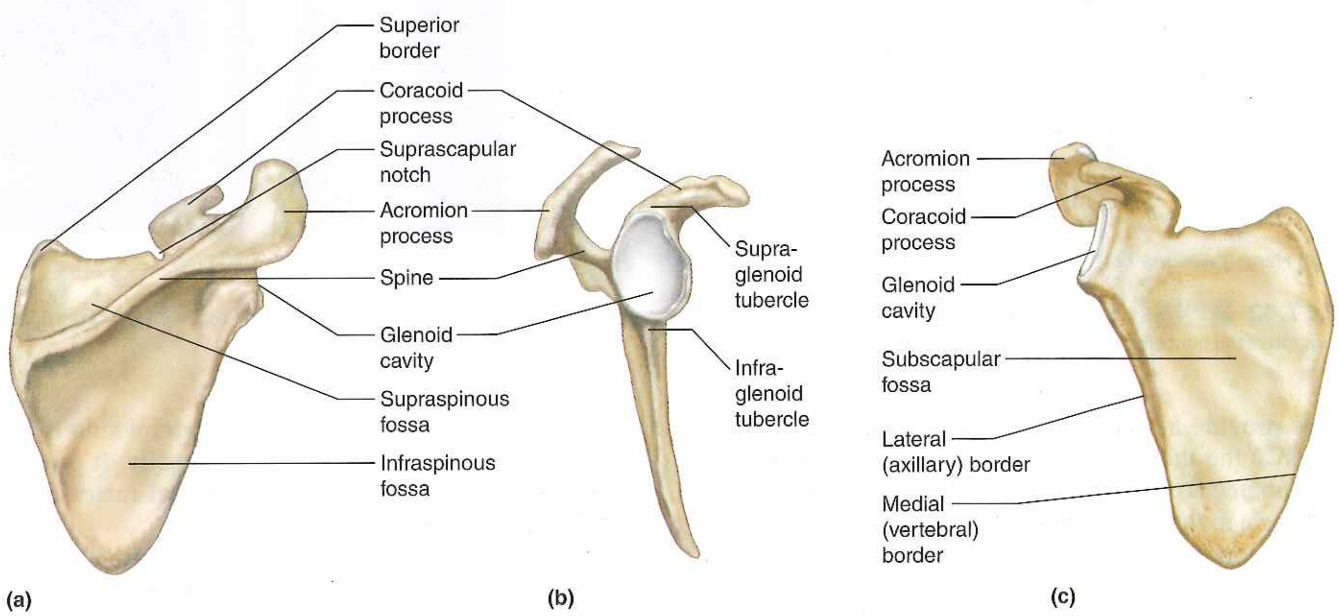


FIGURE 7.41 APR Right scapula. (*a*) Posterior surface. (*b*) Lateral view showing the glenoid cavity that articulates with the head of the humerus. (*c*) Anterior surface.

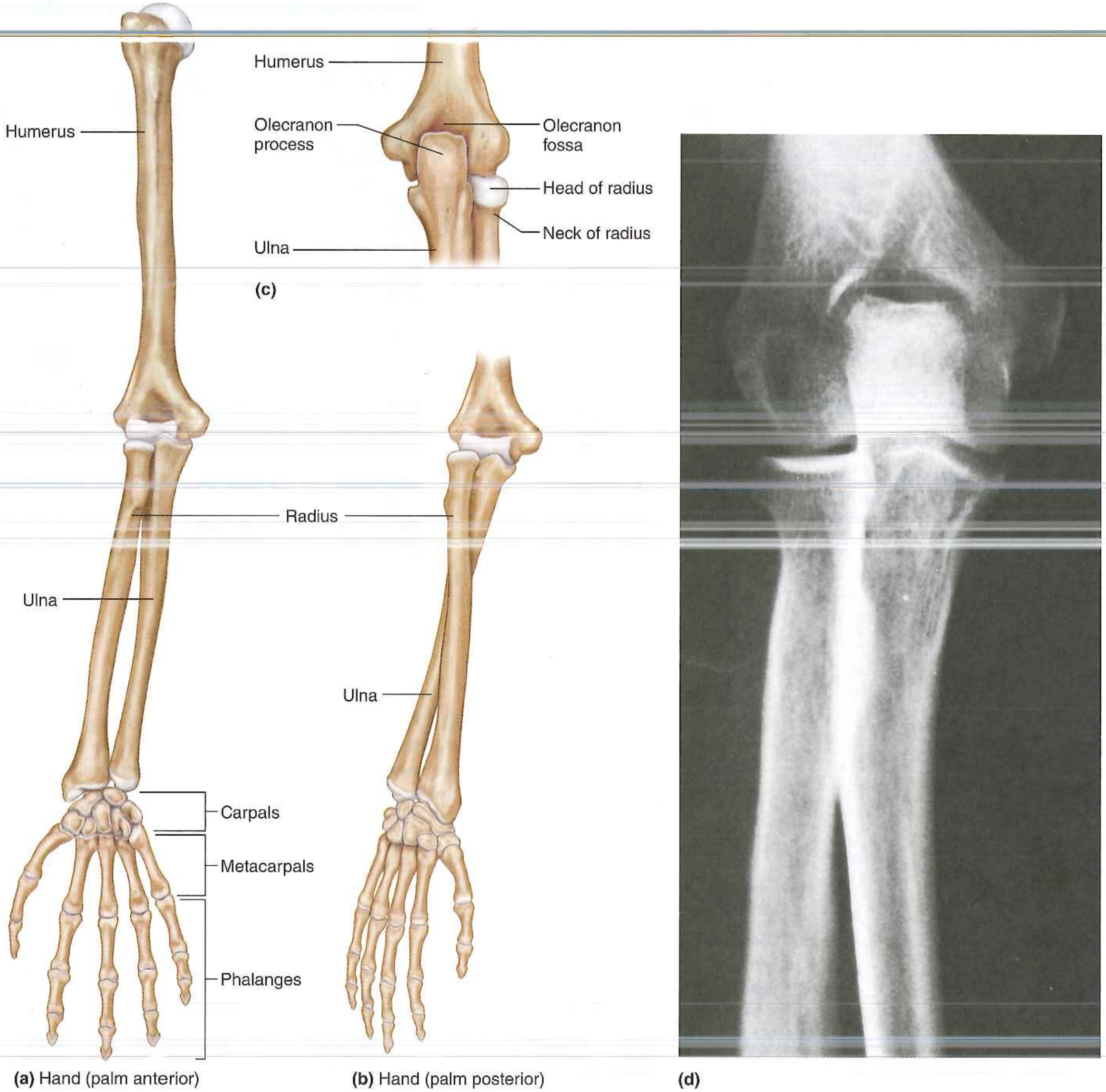


FIGURE 7.42 AP|R Right upper limb. (*a*) Anterior view with the hand, palm anterior and (*b*) with the hand, palm posterior. (*c*) Posterior view of the right elbow. (*d*) Radiograph of the right elbow and forearm, anterior view.

tubercles provide attachments for muscles that move the upper limb at the shoulder. Between them is a narrow furrow, the *intertubercular groove,* through which a tendon passes from a muscle in the arm (biceps brachii) to the shoulder.

The narrow depression along the lower margin of the head that separates it from the tubercles is called the *anatomical neck.* Just below the head and the tubercles of the humerus is a tapering region called the *surgical neck,* so named because fractures commonly occur there. Near the middle of the bony shaft on the lateral side is a rough V-shaped area called the *deltoid tuberosity.* It provides an attachment for the muscle (deltoid) that raises the upper limb horizontally to the side.

At the lower end of the humerus are two smooth *condyles*—a knoblike *capitulum* (kah-pit′u-lum) on the lateral side and a pulley-shaped *trochlea* (trok′le-ah) on the medial side. The capitulum articulates with the radius at the elbow, whereas the trochlea joins the ulna.

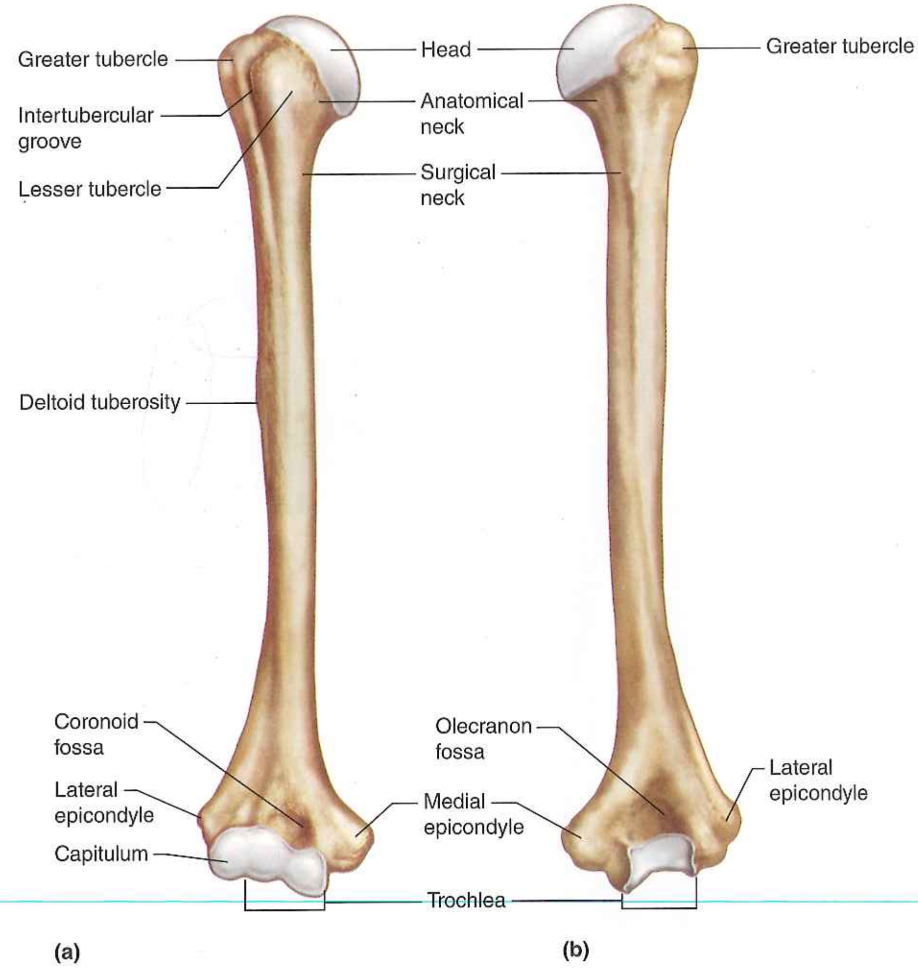


FIGURE 7.43 AP|R Right humerus. (*a*) Anterior surface. (*b*) Posterior surface.

Above the condyles on either side are *epicondyles,* which provide attachments for muscles and ligaments of the elbow. Between the epicondyles anteriorly is a depression, the *coronoid fossa,* that receives a process of the ulna (coronoid process) when the elbow bends. Another depression on the posterior surface, the *olecranon* (o″lek′ra-non) *fossa,* receives a different ulnar process (olecranon process) when the elbow straightens.

Radius

The **radius,** located on the thumb side of the forearm, is somewhat shorter than its companion, the ulna (fig. 7.44). The radius extends from the elbow to the wrist and crosses over the ulna when the hand is turned so that the palm faces backward.

A thick, disclike *head* at the upper end of the radius articulates with the capitulum of the humerus and a notch of the ulna (radial notch). This arrangement allows the radius to rotate.

On the radial shaft just below the head is a process called the *radial tuberosity.* It is an attachment for a muscle (biceps brachii) that bends the upper limb at the elbow. At the distal end of the radius, a lateral *styloid* (sti′loid) *process* provides attachments for ligaments of the wrist.

Ulna

The **ulna,** located on the medial side of the forearm, is longer than the radius and overlaps the end of the humerus posteriorly. At its proximal end, the ulna has a wrenchlike opening, the *trochlear notch* (semilunar notch), that articulates with the trochlea of the humerus. A process lies on either side of this notch. The *olecranon process,* located above the trochlear notch, provides an attachment for the muscle (triceps brachii) that straightens the upper limb at the elbow. During this movement, the olecranon process of the ulna fits into the olecranon fossa of the humerus. Similarly, the *coronoid process,* just below the trochlear notch, fits into the coronoid fossa of the humerus when the elbow bends.

At the distal end of the ulna, its knoblike *head* articulates laterally with a notch of the radius (ulnar notch) and with a disc of fibrocartilage inferiorly (fig. 7.44). This disc, in turn, joins a wrist bone (triquetrum). A medial *styloid process* at the distal end of the ulna provides attachments for ligaments of the wrist.

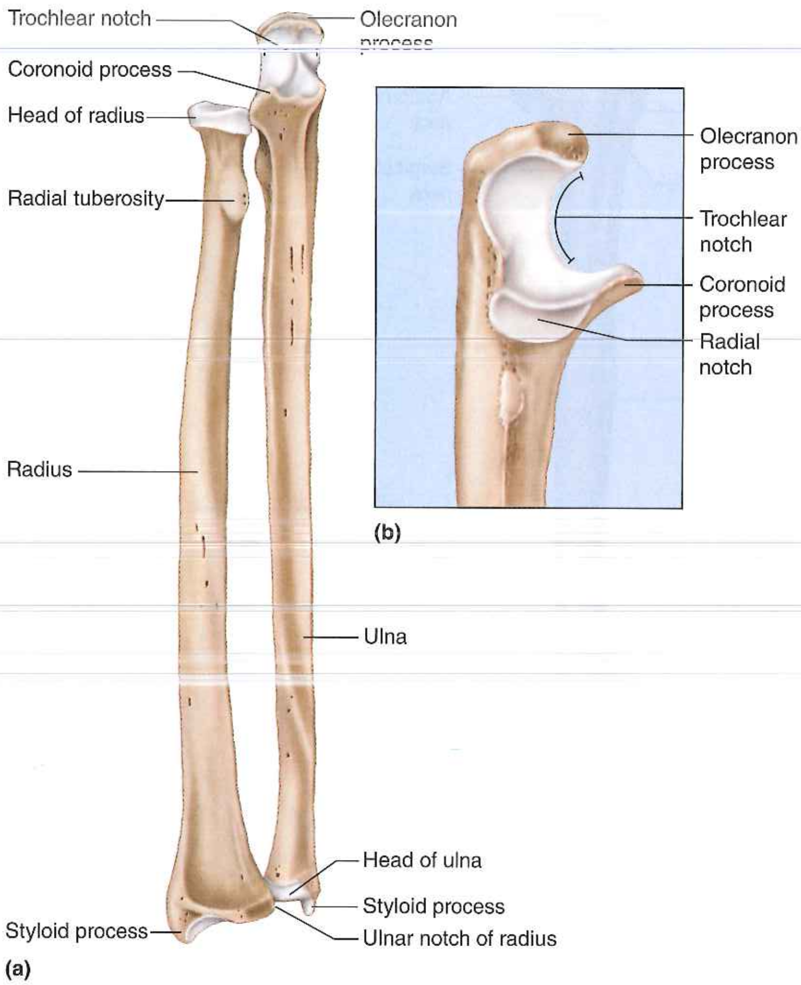


FIGURE 7.44 AP|R Right radius and ulna. (*a*) The head of the radius articulates with the radial notch of the ulna, and the head of the ulna articulates with the ulnar notch of the radius. (*b*) Lateral view of the proximal end of the ulna.

> Many a thirtyish parent of a young little leaguer or softball player becomes tempted to join in. But if he or she has not pitched in many years, sudden activity may break the forearm. Forearm pain while pitching is a signal that a fracture could happen. Medical specialists advise returning to the pitching mound gradually. Start with twenty pitches, five days a week, for two to three months before regular games begin. By the season's start, 120 pitches per daily practice session should be painless.

Hand

The hand is made up of the wrist, palm, and fingers. The skeleton of the wrist consists of eight small **carpal bones** firmly bound in two rows of four bones each. The resulting compact mass is called a *carpus* (kar'pus). The carpus is rounded on its proximal surface, where it articulates with the radius and with the fibrocartilaginous disc on the ulnar side. The carpus is concave anteriorly, forming a canal through which tendons and nerves extend to the palm. Its distal surface articulates with the metacarpal bones. Figure 7.45 names the individual bones of the carpus.

Five **metacarpal bones,** one in line with each finger, form the framework of the palm or *metacarpus* (met″ah-kar'pus) of the hand. These bones are cylindrical, with rounded distal ends that form the knuckles of a clenched fist. The metacarpals articulate proximally with the carpals and distally with the phalanges. The metacarpal on the lateral side is the most freely movable; it permits the thumb to oppose the fingers when grasping something. These bones are numbered 1 to 5, beginning with the metacarpal of the thumb (fig. 7.45).

The **phalanges** are the finger bones. Three are in each finger—a proximal, a middle, and a distal phalanx—and two are in the thumb. (The thumb lacks a middle phalanx.) Thus, each hand has fourteen finger bones. Table 7.9 summarizes the bones of the pectoral girdle and upper limbs.

> It is not uncommon for a baby to be born with an extra finger or toe, but because the extra digit is usually surgically removed early in life, hands like the ones in figure 7.46 are rare. Polydactyly ("many digits") is an inherited trait.

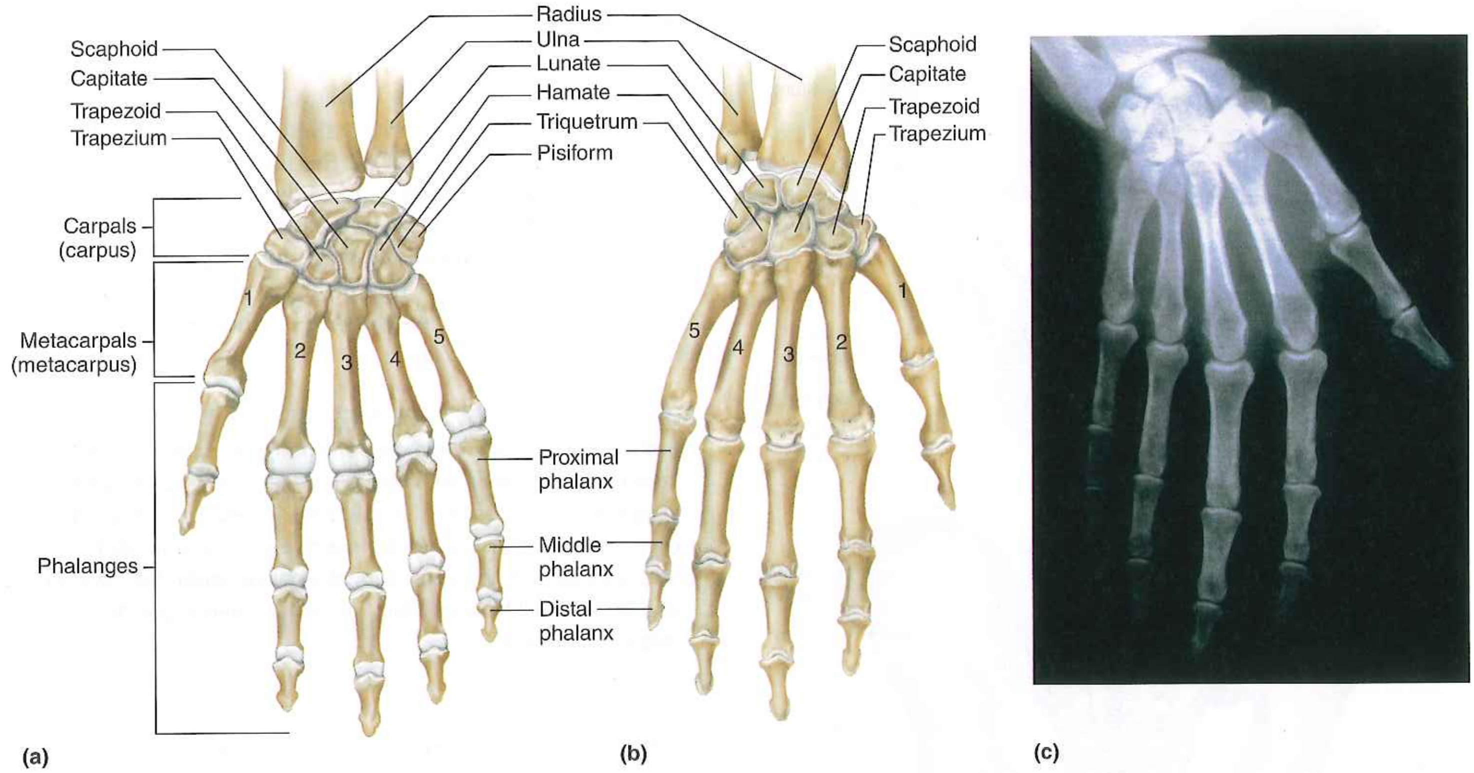


FIGURE 7.45 AP|R Right hand. (*a*) Anterior view. (*b*) Posterior view. (*c*) Radiograph, posterior view.

TABLE 7.9 | Bones of the Pectoral Girdle and Upper Limbs

Name and Number	Location	Special Features
Clavicle (2)	Base of neck between sternum and scapula	Sternal end, acromial end
Scapula (2)	Upper back, forming part of shoulder	Body, spine, acromion process, coracoid process, glenoid cavity
Humerus (2)	Arm, between scapula and elbow	Head, greater tubercle, lesser tubercle, intertubercular groove, anatomical neck, surgical neck, deltoid tuberosity, capitulum, trochlea, medial epicondyle, lateral epicondyle, coronoid fossa, olecranon fossa
Radius (2)	Lateral side of forearm, between elbow and wrist	Head, radial tuberosity, styloid process, ulnar notch
Ulna (2)	Medial side of forearm, between elbow and wrist	Trochlear notch, olecranon process, coronoid process, head, styloid process, radial notch
Carpal (16)	Wrist	Two rows of four bones each
Metacarpal (10)	Palm	One bone in line with each finger and thumb
Phalanx (28)	Finger	Three phalanges in each finger; two phalanges in each thumb

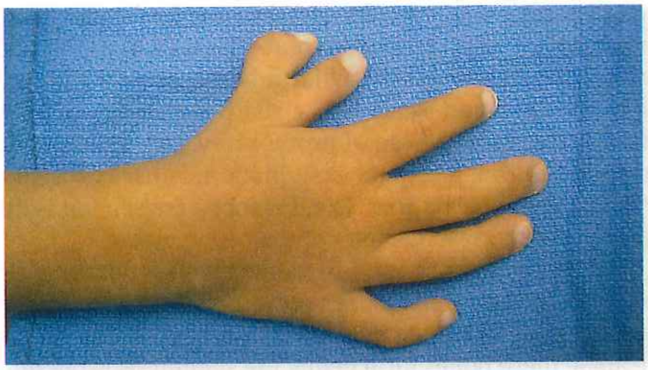


FIGURE 7.46 A person with polydactyly has extra digits.

PRACTICE

32 Locate and name each of the bones of the upper limb.

33 Explain how the bones of the upper limb articulate.

7.11 PELVIC GIRDLE

The **pelvic girdle** consists of the two hip bones, also known as coxal bones (ossa coxae), pelvic bones or innominate bones, which articulate with each other anteriorly and with the sacrum posteriorly (fig. 7.47). The sacrum, coccyx, and pelvic girdle form the bowl-shaped *pelvis*. The pelvic girdle

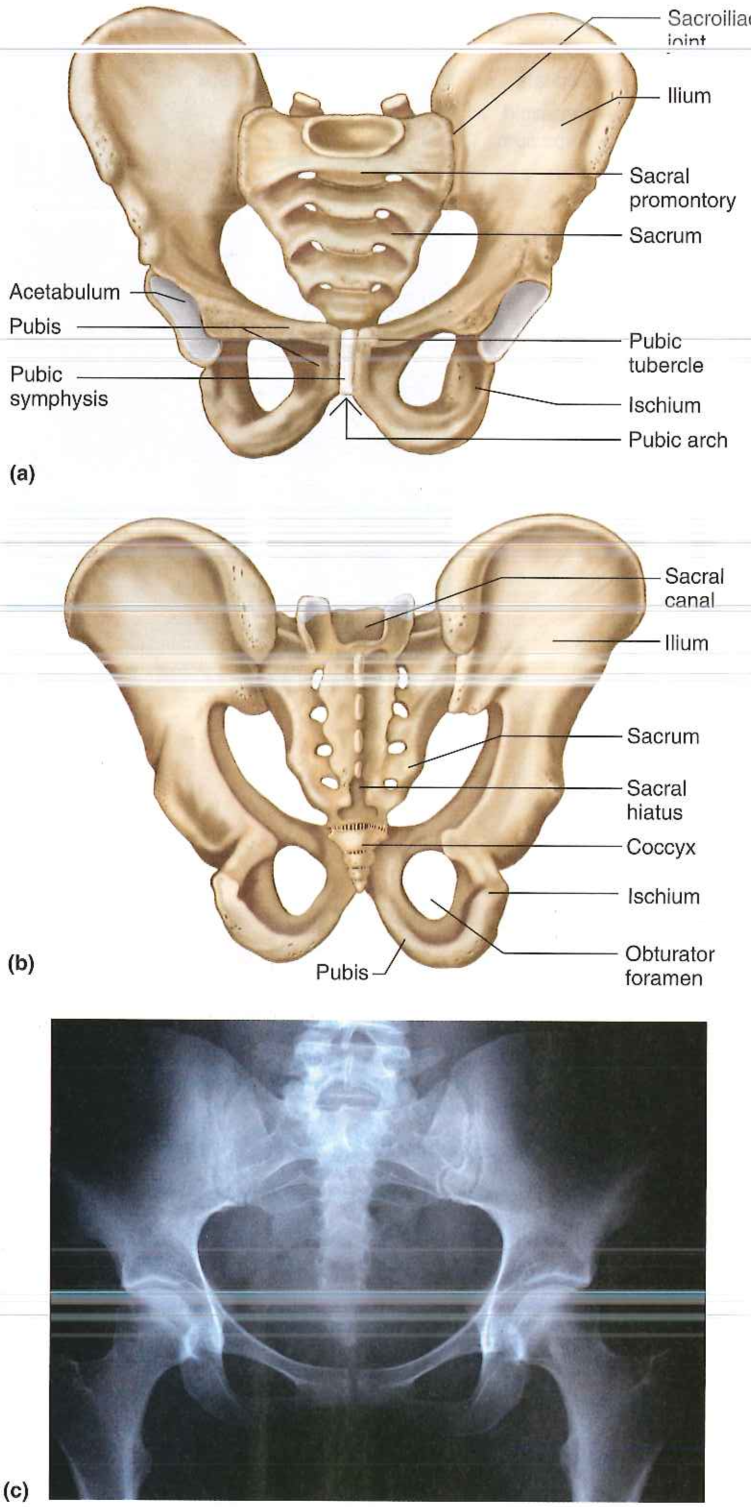


FIGURE 7.47 APR Pelvic girdle. (*a*) Anterior view. (*b*) Posterior view. The pelvic girdle provides an attachment for the lower limbs and together with the sacrum and coccyx forms the pelvis. (*c*) Radiograph of the pelvic girdle.

supports the trunk of the body; provides attachments for the lower limbs; and protects the urinary bladder, the distal end of the large intestine, and the internal reproductive organs. The body's weight is transmitted through the pelvic girdle to the lower limbs and then onto the ground.

Hip Bones

Each hip bone develops from three parts—an ilium, an ischium, and a pubis (fig. 7.48). These parts fuse in the region of a cup-shaped cavity called the *acetabulum* (as″ĕ-tab′u-lum). This depression, on the lateral surface of the hip bone, receives the rounded head of the femur or thigh bone.

The **ilium** (il′e-um), the largest and most superior portion of the hip bone, flares outward, forming the prominence of the hip. The margin of this prominence is called the *iliac crest*. The smooth, concave surface on the anterior aspect of the ilium is the *iliac fossa*.

Red marrow within the spongy bone of the iliac crests of the hip bones produces blood cells into adulthood. It may be sampled to diagnose certain diseases through the iliac crest, which has a thin covering of compact bone and is easy to reach. This procedure suctions (aspirates) some marrow through a hollow needle. Marrow may also be removed from the sternum, called a sternal puncture, for diagnostic purposes.

Posteriorly, the ilium joins the sacrum at the *sacroiliac joint*. Anteriorly, a projection of the ilium, the *anterior superior iliac spine*, can be felt lateral to the groin. This spine provides attachments for ligaments and muscles and is an important surgical landmark.

A common injury in contact sports such as football is bruising the soft tissues and bone associated with the anterior superior iliac spine. Wearing protective padding can prevent this painful injury, called a *hip pointer*.

On the posterior border of the ilium is a *posterior superior iliac spine*. Below this spine is a deep indentation, the *greater sciatic notch*, through which a number of nerves and blood vessels pass.

The **ischium** (is′ke-um), which forms the lowest portion of the hip bone, is L-shaped, with its angle, the *ischial tuberosity*, pointing posteriorly and downward. This tuberosity has a rough surface that provides attachments for ligaments and lower limb muscles. It also supports the weight of the body during sitting. Above the ischial tuberosity, near the junction of the ilium and ischium, is a sharp projection called the *ischial spine*. Like the sacral promontory, this spine, which can be felt during a vaginal examination, is used as a guide for determining pelvis size. The distance between the ischial spines is the shortest diameter of the pelvic outlet.

The **pubis** (pu′bis) constitutes the anterior portion of the hip bone. The two pubic bones come together at the midline to form a joint called the *pubic symphysis* (pu′bik sim′fĭ-sis). The angle these bones form below the symphysis is the *pubic arch* (fig. 7.49).

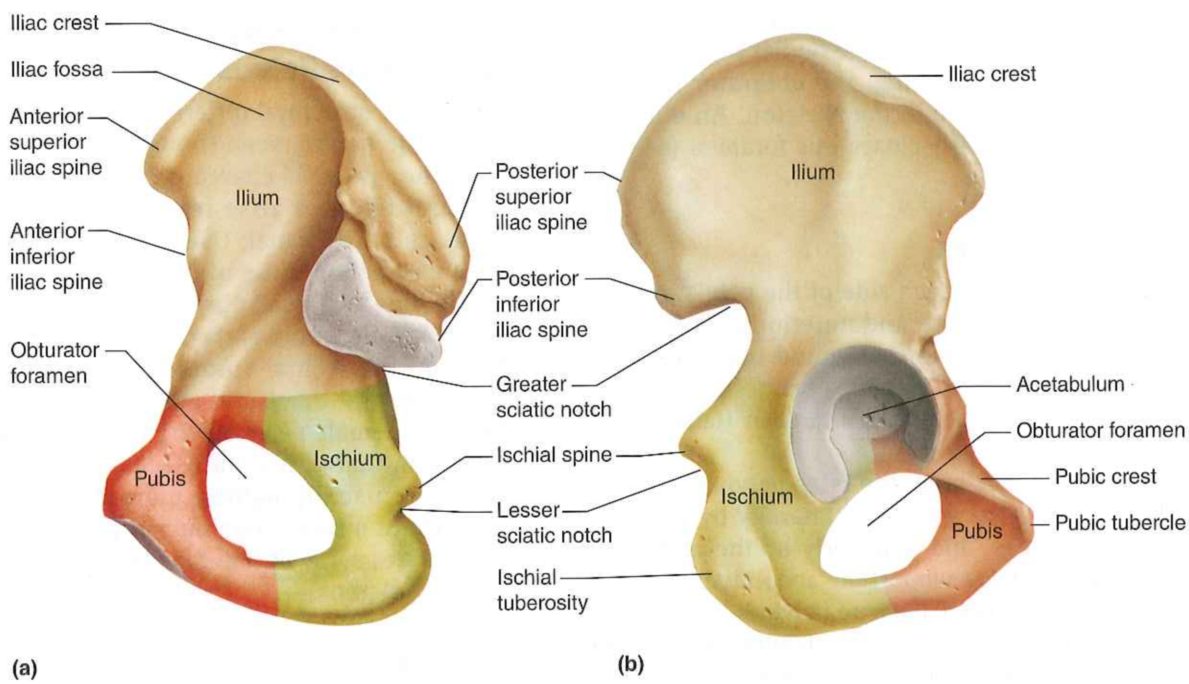


FIGURE 7.48 AP|R Right hip bone. (*a*) Medial surface. (*b*) Lateral view.

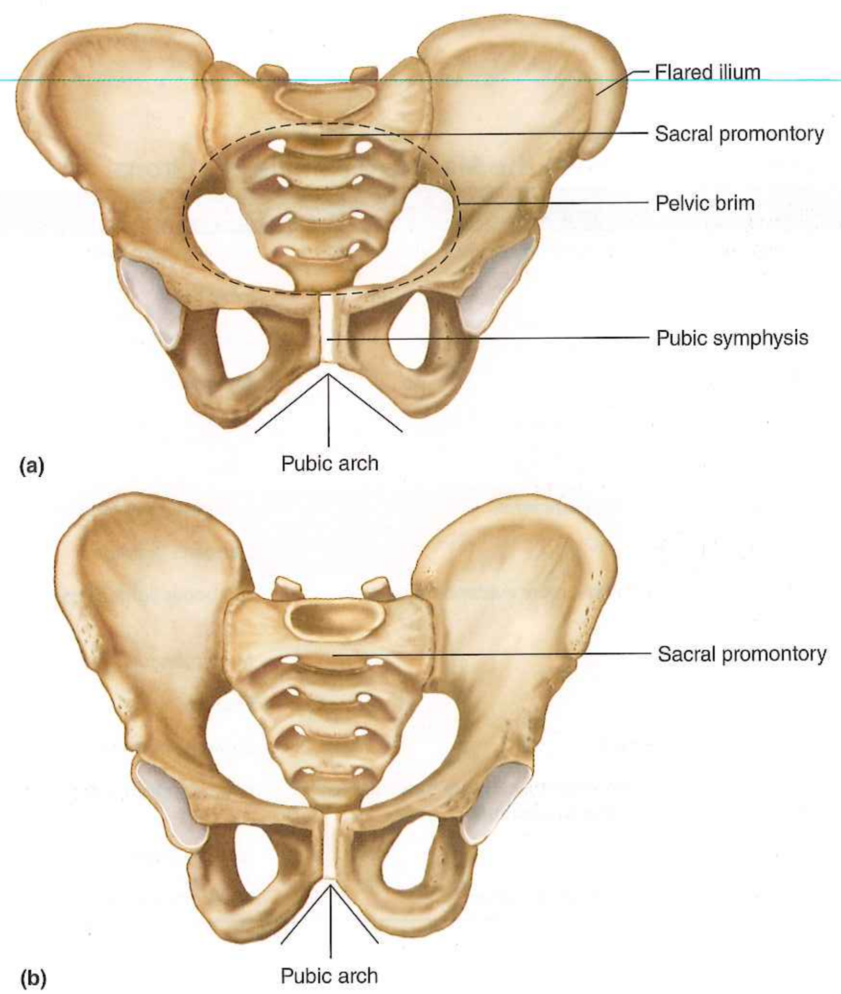


FIGURE 7.49 AP|R The female pelvis is usually wider in all diameters and roomier than that of the male. (*a*) Female pelvis. (*b*) Male pelvis.

Q: *Is the radiograph in fig. 7.47c taken of a male or female?*

Answer can be found in Appendix G on page 938.

A portion of each pubis passes posteriorly and downward to join an ischium. Between the bodies of these bones on either side is a large opening, the *obturator foramen,* which is the largest foramen in the skeleton. An obturator membrane covers and nearly closes this foramen (see figs. 7.47 and 7.48).

True and False Pelves

If a line were drawn along each side of the pelvis from the sacral promontory downward and anteriorly to the upper margin of the symphysis pubis, it would mark the *pelvic brim* (linea terminalis). This margin separates the lower, or lesser (true), pelvis from the upper, or greater (false), pelvis (see fig. 7.49).

Superior to the pelvic brim, the **false pelvis** is bounded posteriorly by the lumbar vertebrae, laterally by the flared parts of the iliac bones, and anteriorly by the abdominal wall. The false pelvis helps support the abdominal organs.

Inferior to the pelvic brim, the **true pelvis** is bounded posteriorly by the sacrum and coccyx and laterally and anteriorly by the lower ilium, ischium, and pubis bones. This portion of the pelvis surrounds a short, canal-like cavity. The superior opening of the cavity, the *pelvic inlet,* is at the boundary between the true and false pelves. The inferior opening of the cavity is the *pelvic outlet.* An infant passes through this cavity during childbirth.

Differences Between Male and Female Pelves

Some basic structural differences distinguish the male and the female pelves, even though it may be difficult to find all of the "typical" characteristics in any one individual. These differences arise from the function of the female pelvis as a birth canal. Usually, the female iliac bones are more flared than those of the male, and consequently, the female hips are usually broader than the male's. The angle of the female pubic arch is usually greater, the distance between the ischial spines and the ischial tuberosities is greater, and the sacral curvature is shorter and flatter. Thus, the female pelvic cavity is usually wider in all diameters than that of the male. Also, the bones of the female pelvis are usually lighter, more delicate, and show less evidence of muscle attachments (see fig. 7.49). Table 7.10 summarizes some of the differences between the male and female skeletons.

PRACTICE

34 Locate and name each bone that forms the pelvis.

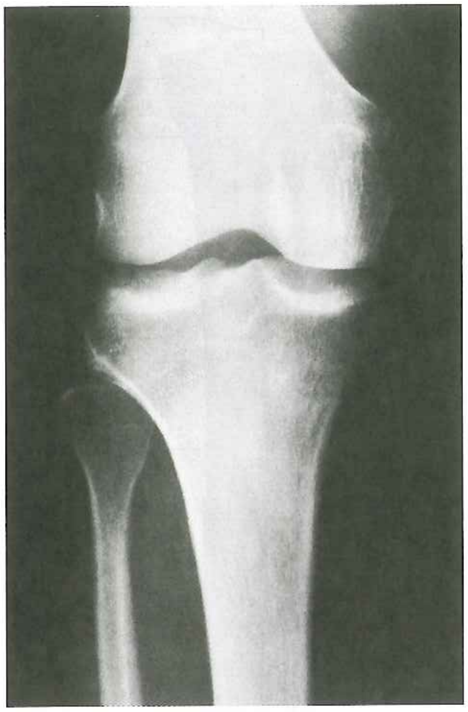
35 Name the bones that fuse to form a hip bone.

36 Distinguish between the false pelvis and the true pelvis.

37 How are male and female pelves different?

TABLE 7.10 | Differences Between the Male and Female Skeletons

Part	Male Differences	Female Differences
Skull	Larger, heavier, more conspicuous muscle attachment	Smaller, more delicate, less evidence of muscle attachment
mastoid process	Larger	Smaller
supraorbital ridge	More prominent	Less prominent
chin	More squared	More pointed
jaw angle	Angle of ramus about 90 degrees	Angle of ramus greater than 125 degrees
forehead	Shorter	Taller
orbit	Superior border thicker, blunt edge	Superior border thinner, sharp edge
palate	Wider U-shape	Narrower U-shape
Pelvis	Hip bones heavier, thicker, more evidence of muscle attachment	Hip bones lighter, less evidence of muscle attachment
obturator foramen	More oval	More triangular
acetabulum	Larger	Smaller
pubic arch	Narrow, more V-shaped	Broader, more convex
sacrum	Narrow, sacral promontory projects more forward, sacral curvature bends less sharply posteriorly	Wide, sacral curvature bends sharply posteriorly
coccyx	Less movable	More movable
cavity	Narrow and long, more funnel-shaped	Wide, distance between ischial spines and ischial tuberosities is greater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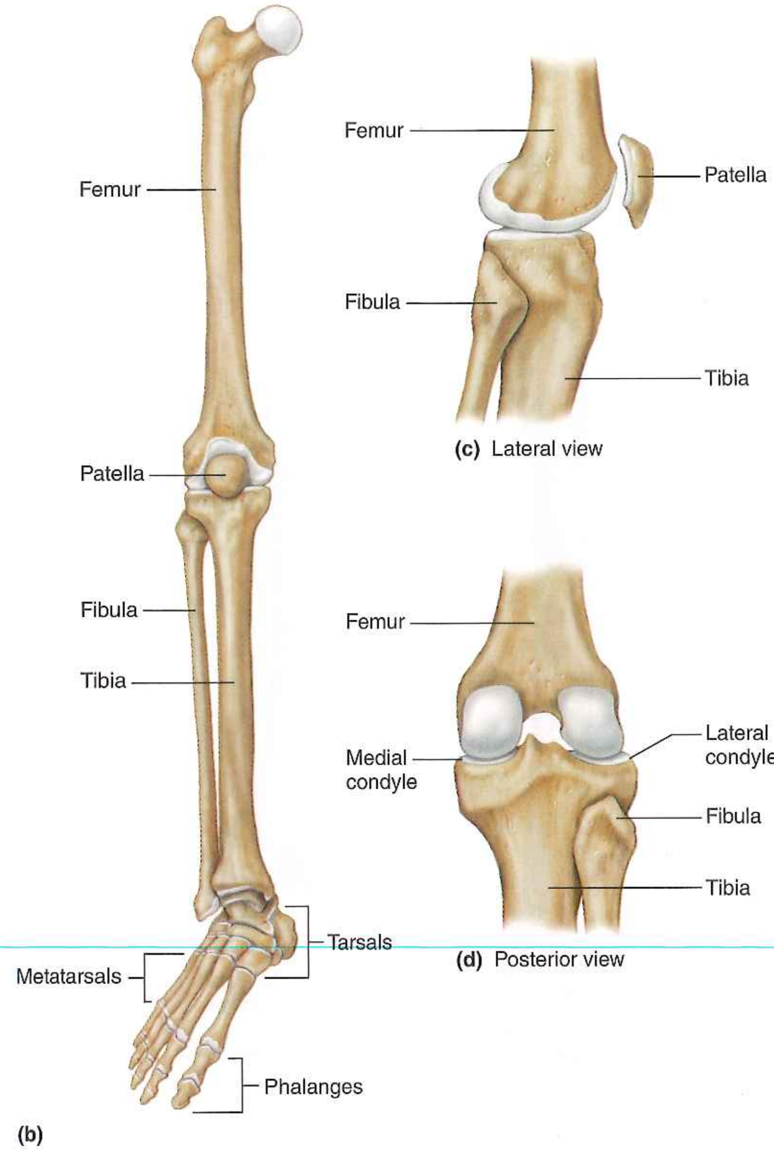


FIGURE 7.50 AP|R Parts of the right lower limb. (*a*) Radiograph of the knee (anterior view), showing the ends of the femur, tibia, and fibula. Thinner areas of bone, such as part of the head of the fibula and the patella, barely show in this radiograph. (*b*) Anterior view of the lower limb. (*c*) Lateral view of the knee. (*d*) Posterior view of the knee.

7.12 LOWER LIMB

The bones of the lower limb form the frameworks of the thigh, leg, and foot. They include a femur, a tibia, a fibula, tarsals, metatarsals, and phalanges (fig. 7.50).

Femur

The **femur,** or thigh bone, is the longest bone in the body and extends from the hip to the knee. A large, rounded *head* at its proximal end projects medially into the acetabulum of the hip bone (fig. 7.51). On the head, a pit called the *fovea capitis* marks the attachment of a ligament. Just below the head are a constriction, or *neck,* and two large processes—a superior, lateral *greater trochanter* and an inferior, medial *lesser trochanter.* These processes provide attachments for muscles of the lower limbs and buttocks. On the posterior surface in the middle third of the shaft is a longitudinal crest called the *linea aspera.* This rough strip is an attachment for several muscles.

At the distal end of the femur, two rounded processes, the *lateral* and *medial condyles,* articulate with the tibia of the leg. A patella also articulates with the femur on its distal anterior surface.

On the medial surface at its distal end is a prominent *medial epicondyle,* and on the lateral surface is a *lateral epicondyle.* These projections provide attachments for muscles and ligaments.

Patella

The **patella,** or kneecap, is a flat sesamoid bone located in a tendon that passes anteriorly over the knee (see fig. 7.50). The patella, because of its position, controls the angle at which

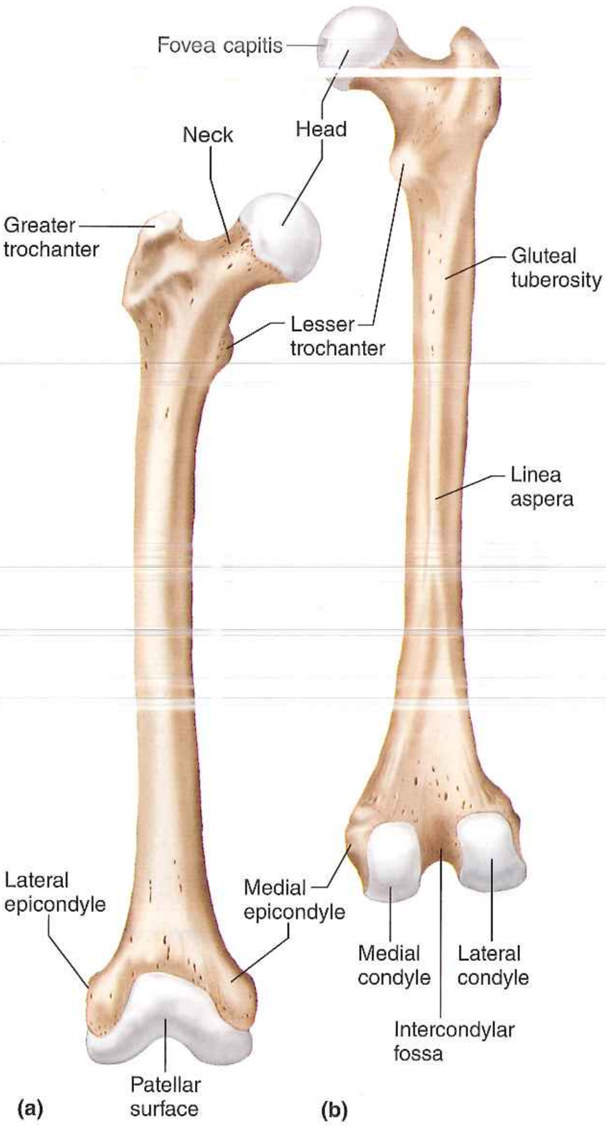


FIGURE 7.51 AP|R Right femur. (*a*) Anterior surface. (*b*) Posterior surface.

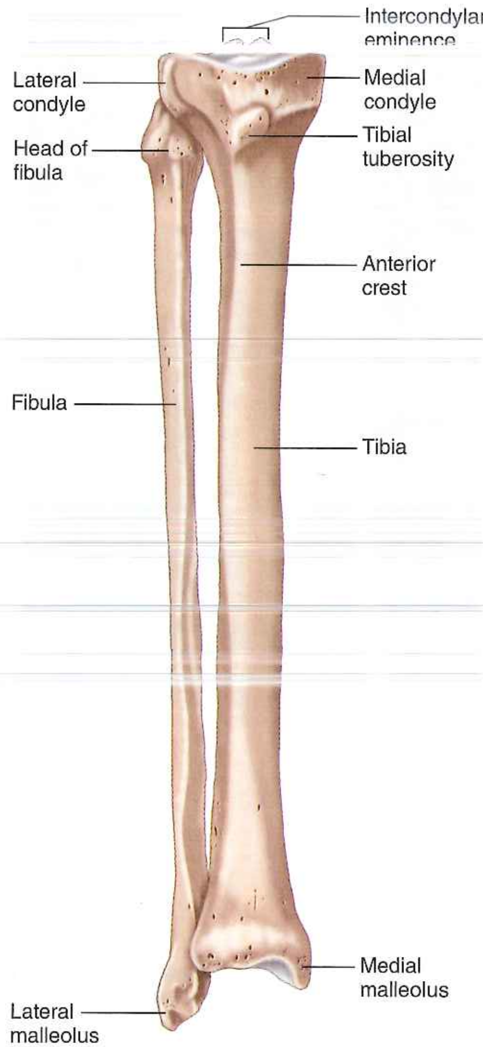


FIGURE 7.52 AP|R Bones of the right leg, anterior view.

this tendon continues toward the tibia. Therefore it functions in lever actions associated with lower limb movements.

> The patella can slip to one side as a result of a blow to the knee or a forceful unnatural movement of the leg. This painful condition is called a *patellar dislocation.* Doing exercises that strengthen muscles associated with the knee and wearing protective padding can prevent knee displacement. Unfortunately, once the soft tissues that hold the patella in place are stretched, patellar dislocation tends to recur.

Tibia

The **tibia,** or shin bone, is the larger of the two leg bones and is located on the medial side. Its proximal end is expanded into *medial* and *lateral condyles,* which have concave surfaces and articulate with the condyles of the femur (fig. 7.52). Below the condyles, on the anterior surface, is a process called the *tibial tuberosity,* which provides an attachment for the *patellar ligament* (a continuation of the patella-bearing tendon). A prominent *anterior crest* extends downward from the tuberosity and attaches connective tissues in the leg.

At its distal end, the tibia expands to form a prominence on the inner ankle called the *medial malleolus* (mah-le′o-lus), which is an attachment for ligaments. On its lateral side is a depression that articulates with the fibula. The inferior surface of the tibia's distal end articulates with a large bone (the talus) in the ankle.

> The skeleton is particularly vulnerable to injury during adolescence, when bones grow rapidly. Athletic teens can develop Osgood-Schlatter disease, which is a painful swelling of a bony projection of the tibia below the knee. Overusing the thigh muscles to straighten the lower limb irritates the area, causing the swelling. Usually a few months of rest and no athletic activity allows the bone to heal on its own. Rarely, a cast must be used to immobilize the knee.

Fibula

The **fibula** is a long, slender bone located on the lateral side of the tibia. Its ends are slightly enlarged into a proximal *head* and a distal *lateral malleolus* (fig. 7.52). The head articulates with the tibia just below the lateral condyle, but it does not enter into the knee joint and does not bear any body weight. The lateral malleolus articulates with the ankle and protrudes on the lateral side.

Foot

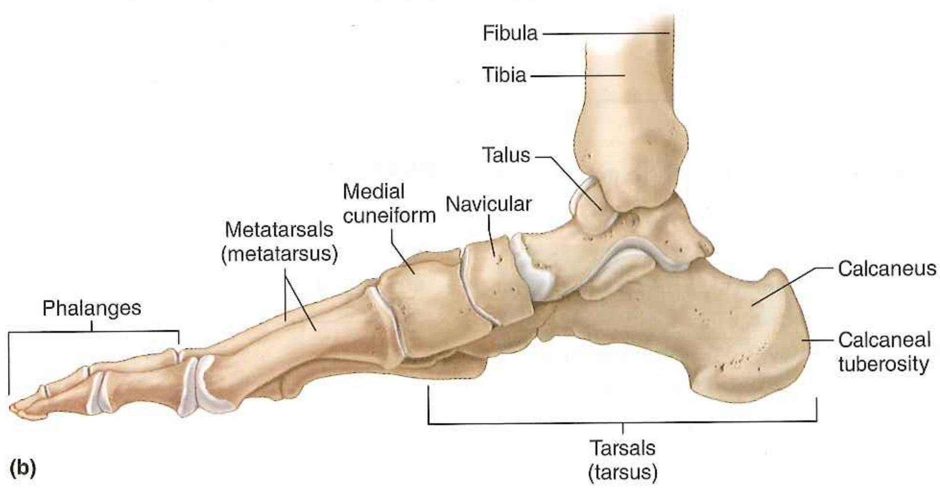
The foot is made up of the ankle, the instep, and the toes. The ankle or *tarsus* (tahr'sus) is composed of seven **tarsal bones.** One of these bones, the **talus** (ta'lus), can move freely where it joins the tibia and fibula, forming the ankle. The other tarsal bones are firmly bound, supporting the talus. Figures 7.53 and 7.54 name the bones of the tarsus.

The largest of the tarsals, the **calcaneus** (kal-ka'ne-us), or heel bone, is below the talus where it projects backward to form the base of the heel. The calcaneus helps support body weight and provides an attachment, the *calcaneal tuberosity,* for muscles that move the foot.

The instep or *metatarsus* (met″ah-tahr'sus) consists of five elongated **metatarsal bones,** which articulate with the tarsus. They are numbered 1 to 5, beginning on the medial side (fig. 7.54). The heads at the distal ends of these bones form the ball of the foot. The tarsals and metatarsals are bound by ligaments, forming the arches of the foot. A longitudinal arch extends from the heel to the toe, and a transverse arch stretches across the foot. These arches provide a stable, springy base for the body. Sometimes, however, the tissues that bind the metatarsals weaken, producing fallen arches, or flat feet.

The **phalanges** of the toes are shorter but otherwise similar to those of the fingers and align and articulate with the metatarsals. Each toe has three phalanges—a proximal, a middle, and a distal phalanx—except the great toe, which has only two because it lacks the middle phalanx (fig. 7.54).

(a)



(b)

FIGURE 7.53 AP|R Right foot. (*a*) Radiograph view from the medial side. (*b*) The talus moves freely where it articulates with the tibia and fibula.

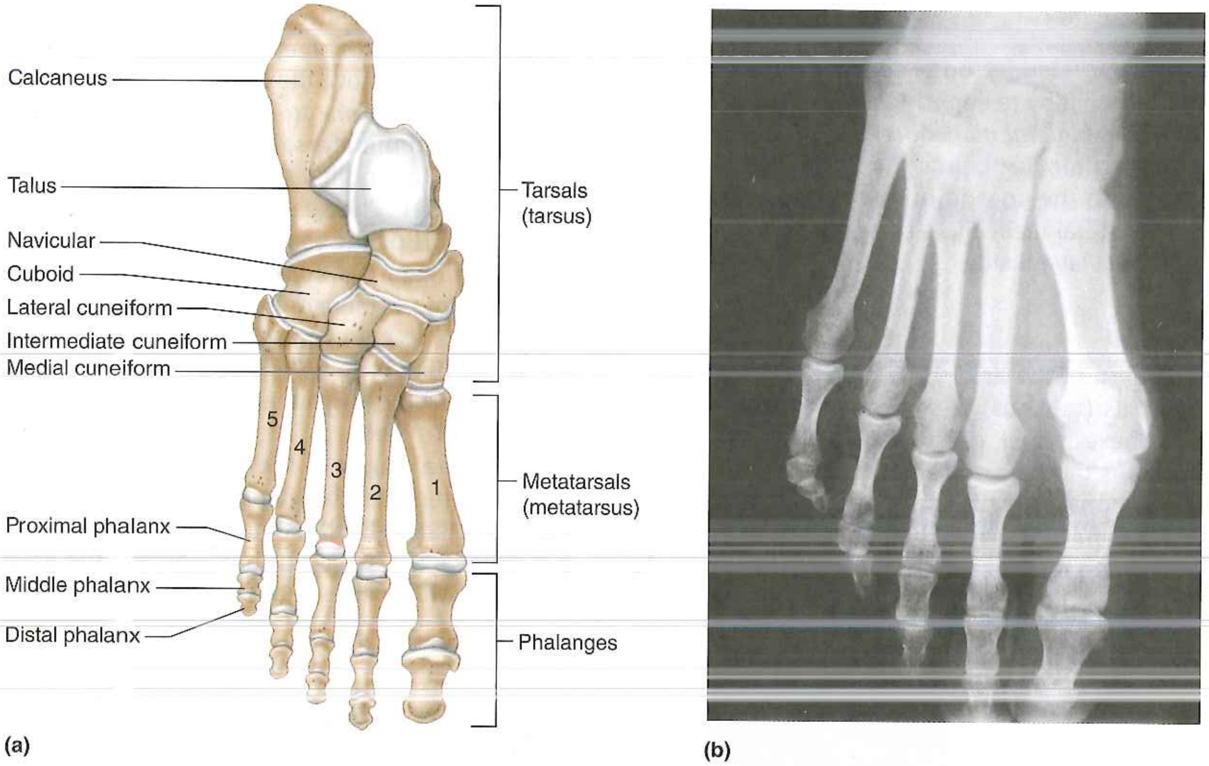


FIGURE 7.54 APIR Right foot. *(a)* Viewed superiorly. *(b)* Radiograph of the foot viewed superiorly. Note: Sesamoid bone under first metatarsal in radiograph.

TABLE 7.11 | Bones of the Pelvic Girdle and Lower Limbs

Name and Number	Location	Special Features
Hip bone (2)	Hip, articulating with the other hip bone anteriorly and with the sacrum posteriorly	Ilium, iliac crest, anterior superior iliac spine, ischium, ischial tuberosity, ischial spine, obturator foramen, acetabulum, pubis
Femur (2)	Thigh, between hip and knee	Head, fovea capitis, neck, greater trochanter, lesser trochanter, linea aspera, lateral condyle, medial condyle, gluteal tuberosity, intercondylar fossa
Patella (2)	Anterior surface of knee	A flat sesamoid bone located within a tendon
Tibia (2)	Medial side of leg, between knee and ankle	Medial condyle, lateral condyle, tibial tuberosity, anterior crest, medial malleolus, intercondylar eminence
Fibula (2)	Lateral side of leg, between knee and ankle	Head, lateral malleolus
Tarsal (14)	Ankle	Freely movable talus that articulates with leg bones; calcaneus that forms the base of the heel; five other tarsal bones bound firmly together
Metatarsal (10)	Instep	One bone in line with each toe, bound by ligaments to form arches
Phalanx (28)	Toe	Three phalanges in each toe, two phalanges in great toe

Table 7.11 summarizes the bones of the pelvic girdle and lower limbs.

An infant with two casts on her feet is probably being treated for clubfoot, a common birth defect in which the foot twists out of its normal position. Clubfoot probably results from arrested development during fetal existence, but the precise cause is not known.

PRACTICE

38 Locate and name each of the bones of the lower limb.

39 Explain how the bones of the lower limb articulate.

40 Describe how the foot is adapted to support the body.

7.13 LIFE-SPAN CHANGES

Aging-associated changes in the skeletal system are apparent at the cellular and whole-body levels. Most obvious is the incremental decrease in height that begins at about age thirty, with a loss of about 1/16 of an inch a year. In the later years, compression fractures in the vertebrae may contribute significantly to loss of height (fig. 7.55). Overall, as calcium levels fall and bone material gradually vanishes, the skeleton loses strength, and the bones become brittle and increasingly prone to fracture. However, the continued ability of fractures to heal reveals that the bone tissue is still alive and functional.

Components of the skeletal system and individual bones change to different degrees and at different rates over a lifetime. Gradually, osteoclasts come to outnumber osteoblasts, which means that bone is eaten away in the remodeling process at a faster rate than it is replaced. The result is more spaces in bones. The bone thins, its strength waning. Bone matrix changes, with the ratio of mineral to protein increasing, making bones more brittle and prone to fracture. Beginning in the third decade of life, bone matrix is removed faster than it is laid down. By age thirty-five, we start to lose bone mass.

Trabecular bone, due to its spongy, less compact nature, shows the changes of aging first. It thins, increasing in porosity and weakening the overall structure. The vertebrae consist mostly of trabecular bone. It is also found in the upper part of the femur, whereas the shaft is more compact bone. The fact that trabecular bone weakens sooner than compact bone destabilizes the femur, which is why it is a commonly broken bone among the elderly.

Compact bone loss begins at around age forty and continues at about half the rate of loss of trabecular bone. As remodeling continues throughout life, older osteons disappear as new ones are built next to them. With age, the osteons may coalesce, further weakening the overall structures as gaps form.

Bone loss is slow and steady in men, but in women it is clearly linked to changing hormone levels. In the first decade following menopause, 15% to 20% of trabecular bone is lost, which is two to three times the rate of loss in men and premenopausal women. During the same time, compact bone loss is 10% to 15%, which is three to four times the rate of loss in men and premenopausal women. By about age seventy, both sexes are losing bone at about the same rate. By very old age, a woman may have only half the trabecular and compact bone mass as she did in her twenties, whereas a very elderly man may have one-third less bone mass.

Falls among the elderly are common and have many causes (see table 7.12). The most common fractures, after vertebral compression and hip fracture, are of the wrist, leg, and pelvis. Aging-related increased risk of fracture usually begins at about age fifty. Healing slows, and pain from a broken bone may persist for months. Recommendations for preserving skeletal health include avoiding falls, taking calcium supplements, getting enough vitamin D, avoiding carbonated beverages (phosphates deplete bone), and getting regular exercise.

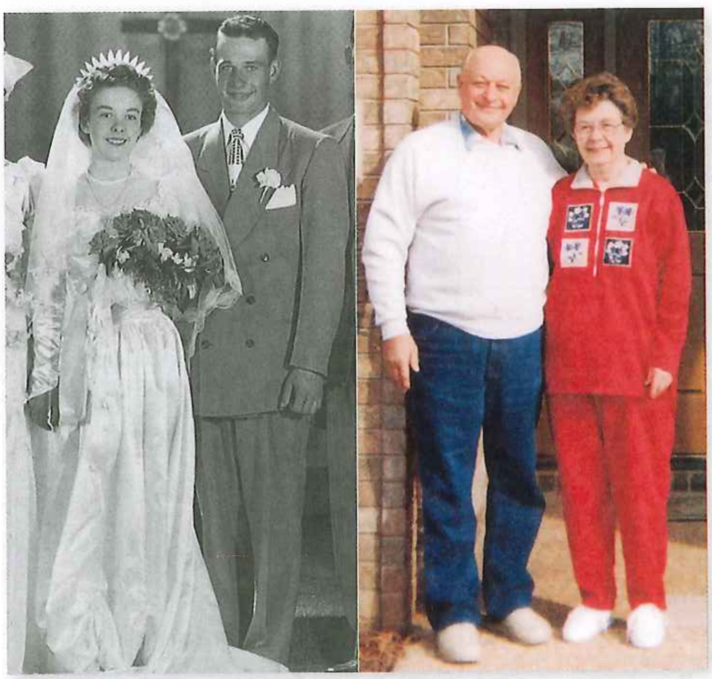


FIGURE 7.55 The bones change to different degrees and at different rates over a lifetime.

PRACTICE

41 Why is bone lost faster with aging than it is replaced?

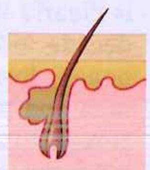
42 Which bones most commonly fracture in the elderly?

TABLE 7.12 | Possible Reasons for Falls Among the Elderly

Overall frailty
Decreased muscle strength
Decreased coordination
Side effects of medication
Slowed reaction time due to stiffening joints
Poor vision and/or hearing
Disease (cancer, infection, arthritis)

INNERCONNECTIONS Skeletal System

Integumentary System

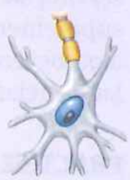


Vitamin D, production of which begins in the skin, plays a role in calcium absorption and availability for bone matrix.

Muscular System

Muscles pull on bones to cause movement.

Nervous System



Proprioceptors sense the position of body parts. Pain receptors warn of trauma to bone. Bones protect the brain and spinal cord.

Endocrine System

Some hormones act on bone to help regulate blood calcium levels.

Cardiovascular System

Blood transports nutrients to bone cells. Bone helps regulate plasma calcium levels, important to heart function.

Lymphatic System

Cells of the immune system originate in the bone marrow.

Digestive System

Absorption of dietary calcium provides material for bone matrix.

Respiratory System

Ribs and muscles work together in breathing.

Urinary System

The kidneys and bones work together to help regulate blood calcium levels.

Reproductive System

The pelvis helps support the uterus during pregnancy. Bones provide a source of calcium during lactation.

Skeletal System

Bones provide support, protection, and movement and also play a role in calcium balance.

CHAPTER SUMMARY

7.1 INTRODUCTION (PAGE 202)

1. Individual bones are the organs of the skeletal system.
   a. A bone contains active tissues.
   b. Bones support and protect soft tissues, provide attachment for muscles, house blood-producing cells, and store inorganic salts.
2. Bone classification
   Bones are grouped according to their shapes—long, short, flat, or irregular.

7.2 BONE STRUCTURE (PAGE 203)

1. Parts of a long bone
   a. Epiphyses at each end are covered with articular cartilage and articulate with other bones.
   b. The shaft of a bone is called the diaphysis.
   c. The region between the epiphysis and diaphysis is the metaphysis.
   d. Except for the articular cartilage, a bone is covered by a periosteum.
   e. Compact bone has a continuous extracellular matrix with no gaps.
   f. Spongy bone has irregular interconnecting spaces between bony plates called trabeculae.
   g. Both compact and spongy bone are strong and resist bending.
   h. The diaphysis contains a medullary cavity filled with marrow.
2. Microscopic structure
   a. Compact bone contains osteons held together by bone matrix.
   b. Central canals contain blood vessels that nourish the cells of osteons.
   c. Perforating canals connect central canals transversely and communicate with the bone's surface and the medullary cavity.
   d. Diffusion from the surface of thin bony plates nourishes cells of spongy bones.

7.3 BONE DEVELOPMENT AND GROWTH (PAGE 204)

1. Intramembranous bones
   a. Flat bones of the skull, the clavicles, the sternum, and some facial bones are intramembranous bones.
   b. They develop from sheetlike layers of connective tissues.
   c. Osteoblasts within the membranous layers form bone tissue.
   d. Osteoblasts surrounded by extracellular matrix are called osteocytes.
   e. Cells of connective tissue outside the developing bone give rise to the periosteum.
2. Endochondral bones
   a. Most of the bones of the skeleton are endochondral.
   b. They develop as hyaline cartilage that bone tissue later replaces.
   c. The primary ossification center appears in the diaphysis, whereas secondary ossification centers appear in the epiphyses.
   d. An epiphyseal plate remains between the primary and secondary ossification centers.
3. Growth at the epiphyseal plate
   a. An epiphyseal plate consists of layers of cells: zone of resting cartilage, zone of proliferating cartilage, zone of hypertrophic cartilage, and zone of calcified cartilage.
   b. The epiphyseal plates are responsible for bone lengthening.
   c. Long bones continue to lengthen until the epiphyseal plates are ossified.
   d. Growth in bone thickness is due to ossification beneath the periosteum.
   e. The action of osteoclasts forms the medullary cavity.
4. Homeostasis of bone tissue
   a. Osteoclasts and osteoblasts continually remodel bone.
   b. The total mass of bone remains nearly constant.
5. Factors affecting bone development, growth, and repair
   a. Deficiencies of vitamin A, C, or D result in abnormal bone development.
   b. Insufficient secretion of pituitary growth hormone may result in dwarfism; excessive secretion may result in gigantism.
   c. Deficiency of thyroid hormone delays bone growth.
   d. Male and female sex hormones promote bone formation and stimulate ossification of the epiphyseal plates.
   e. Physical stress stimulates bone growth.

7.4 BONE FUNCTION (PAGE 211)

1. Support, protection, and movement
   a. Bones shape and form body structures.
   b. Bones support and protect softer, underlying tissues.
   c. Bones and muscles interact, producing movement.
2. Blood cell formation
   a. At different stages in life, hematopoiesis occurs in the yolk sac, the liver, the spleen, and the red bone marrow.
   b. Red marrow houses developing red blood cells, white blood cells, and blood platelets.
3. Inorganic salt storage
   a. The extracellular matrix of bone tissue contains abundant calcium phosphate in the form of hydroxyapatite.
   b. When blood calcium ion concentration is low, osteoclasts resorb bone, releasing calcium salts.
   c. When blood calcium ion concentration is high, osteoblasts are stimulated to form bone tissue and store calcium salts.
   d. Bone stores small amounts of sodium, magnesium, potassium, and carbonate ions.
   e. Bone tissues may accumulate lead, radium, or strontium.

7.5 SKELETAL ORGANIZATION (PAGE 213)

1. Number of bones
   a. Usually an adult human skeleton has 206 bones, but the number may vary.
   b. Extra bones include sutural bones and sesamoid bones.
2. Divisions of the skeleton
   a. The skeleton can be divided into axial and appendicular portions.
   b. The axial skeleton consists of the skull, hyoid bone, vertebral column, and thoracic cage.
   c. The appendicular skeleton consists of the pectoral girdle, upper limbs, pelvic girdle, and lower limbs.

7.6 SKULL (PAGE 217)

The skull consists of twenty-two bones, which include eight cranial bones and fourteen facial bones.

1. Cranium
   a. The cranium encloses and protects the brain and provides attachments for muscles.
   b. Some cranial bones contain air-filled paranasal sinuses that help reduce the weight of the skull.
   c. Cranial bones include the frontal bone, parietal bones, occipital bone, temporal bones, sphenoid bone, and ethmoid bone.
2. Facial skeleton
   a. Facial bones form the basic shape of the face and provide attachments for muscles.
   b. Facial bones include the maxillae, palatine bones, zygomatic bones, lacrimal bones, nasal bones, vomer bone, inferior nasal conchae, and mandible.
3. Infantile skull
   a. Incompletely developed bones, connected by fontanels, enable the infantile skull to change shape slightly during childbirth.
   b. Infantile skull bones are thin, somewhat flexible, and less easily fractured.

7.7 VERTEBRAL COLUMN (PAGE 227)

The vertebral column extends from the skull to the pelvis and protects the spinal cord. It is composed of vertebrae separated by intervertebral discs. An infant has thirty-three vertebral bones and an adult has twenty-six. The vertebral column has four curvatures—cervical, thoracic, lumbar, and sacral.

1. A typical vertebra
   a. A typical vertebra consists of a body, pedicles, laminae, spinous process, transverse processes, and superior and inferior articular processes.
   b. Notches on the upper and lower surfaces of the pedicles on adjacent vertebrae form intervertebral foramina through which spinal nerves pass.
2. Cervical vertebrae
   a. Cervical vertebrae comprise the bones of the neck.
   b. Transverse processes have transverse foramina.
   c. The atlas (first vertebra) supports the head.
   d. The dens of the axis (second vertebra) provides a pivot for the atlas that allows the head to turn from side to side.
3. Thoracic vertebrae
   a. Thoracic vertebrae are larger than cervical vertebrae.
   b. Their transverse processes project posteriorly at sharp angles.
   c. Their long spinous processes slope downward, and facets on the sides of the vertebral bodies articulate with the heads of ribs.
4. Lumbar vertebrae
   a. Vertebral bodies of lumbar vertebrae are large and strong.
   b. Their transverse processes project laterally, and their spinous processes project posteriorly nearly horizontally.
5. Sacrum
   a. The sacrum, formed of five fused vertebrae, is a triangular structure that has rows of dorsal sacral foramina.
   b. It is united with the hip bones at the sacroiliac joints.
   c. The sacral promontory provides a guide for determining the size of the pelvis.
6. Coccyx
   a. The coccyx, composed of four fused vertebrae, forms the lowest part of the vertebral column.
   b. It acts as a shock absorber when a person sits and is an attachment for muscles of the pelvic floor.

7.8 THORACIC CAGE (PAGE 232)

The thoracic cage includes the ribs, thoracic vertebrae, sternum, and costal cartilages. It supports the pectoral girdle and upper limbs, protects viscera, and functions in breathing.

1. Ribs
   a. Twelve pairs of ribs are attached to the twelve thoracic vertebrae.
   b. Costal cartilages of the true ribs join the sternum directly; those of the false ribs join indirectly or not at all.
   c. A typical rib has a shaft, head, and tubercles that articulate with the thoracic vertebrae.
2. Sternum
   a. The sternum consists of a manubrium, body, and xiphoid process.
   b. It articulates with costal cartilages and the clavicles.

7.9 PECTORAL GIRDLE (PAGE 234)

The pectoral girdle is composed of two clavicles and two scapulae. It forms an incomplete ring that supports the upper limbs and provides attachments for muscles that move the upper limbs.

1. Clavicles
   a. Clavicles are rodlike bones that run horizontally between the sternum and shoulders.
   b. They help hold the shoulders in place and provide attachments for muscles.

2. Scapulae
   a. The scapulae are broad, triangular bones each with a body, spine, acromion process, coracoid process, glenoid cavity, supraspinous and infraspinous fossae, superior border, axillary border, and vertebral border.
   b. Each articulates with the humerus of each upper limb and provide attachments for muscles of the upper limbs and chest.

7.10 UPPER LIMB (PAGE 234)

Bones of the upper limb provide the framework for the limb and provide the attachments for muscles that move the limb.

1. Humerus
   a. The humerus extends from the scapula to the elbow.
   b. It has a head, greater tubercle, lesser tubercle, intertubercular groove, anatomical neck, surgical neck, deltoid tuberosity, capitulum, trochlea, epicondyles, coronoid fossa, and olecranon fossa.
2. Radius
   a. The radius is on the thumb side of the forearm between the elbow and wrist.
   b. It has a head, radial tuberosity, styloid process, and ulnar notch.
3. Ulna
   a. The ulna, on the medial side of the forearm, is longer than the radius and overlaps the humerus posteriorly.
   b. It has a trochlear notch, olecranon process, coronoid process, head, styloid process, and radial notch.
4. Hand
   a. The wrist has eight carpals.
   b. The palm has five metacarpals.
   c. The five fingers have fourteen phalanges.

7.11 PELVIC GIRDLE (PAGE 240)

The pelvic girdle consists of two hip bones that articulate with each other anteriorly and with the sacrum posteriorly. The sacrum, coccyx, and pelvic girdle form the pelvis. The girdle provides support for body weight and attachments for muscles and protects visceral organs.

1. Hip bones
   Each hip bone consists of an ilium, ischium, and pubis, fused in the region of the acetabulum.
   a. Ilium
      (1) The ilium, the largest portion of the hip bone, joins the sacrum at the sacroiliac joint.
      (2) It has an iliac crest with anterior and posterior superior iliac spines and iliac fossae.
   b. Ischium
      (1) The ischium is the lowest portion of the hip bone.
      (2) It has an ischial tuberosity and ischial spine.
   c. Pubis
      (1) The pubis is the anterior portion of the hip bone.
      (2) Pubic bones are joined anteriorly at the pubic symphysis.
2. True and false pelves
   a. The false pelvis is superior to the pelvic brim; the true pelvis is inferior to the pelvic brim.
   b. The false pelvis helps support abdominal organs; the true pelvis functions as a birth canal.
3. Differences between male and female pelves
   a. Differences between male and female pelves reflect the function of the female pelvis as a birth canal.
   b. Usually the female pelvis is more flared; pubic arch is broader; distance between the ischial spines and the ischial tuberosities is greater; and sacral curvature is shorter.

7.12 LOWER LIMB (PAGE 243)

Bones of the lower limb provide the framework for the limb and provide the attachments for muscles that move the limb.

1. Femur
   a. The femur extends from the hip to the knee.
   b. It has a head, fovea capitis, neck, greater trochanter, lesser trochanter, linea aspera, lateral condyle, and medial condyle.
2. Patella
   a. The patella is a sesamoid bone in the tendon that passes anteriorly over the knee.
   b. It controls the angle of this tendon and functions in lever actions associated with lower limb movements.
3. Tibia
   a. The tibia is located on the medial side of the leg.
   b. It has medial and lateral condyles, tibial tuberosity, anterior crest, and medial malleolus.
   c. It articulates with the talus of the ankle.
4. Fibula
   a. The fibula is located on the lateral side of the tibia.
   b. It has a head and lateral malleolus that articulates with the ankle but does not bear body weight.
5. Foot
   a. The ankle includes the talus, the calcaneus, and five other tarsals.
   b. The instep has five metatarsals.
   c. The five toes have fourteen phalanges.

7.13 LIFE-SPAN CHANGES (PAGE 247)

Aging-associated changes in the skeleton are apparent at the cellular and whole-body levels.

1. Incremental decrease in height begins at about age thirty.
2. Gradually, bone loss exceeds bone replacement.
   a. In the first decade following menopause, bone loss occurs more rapidly in women than in men or premenopausal women. By age seventy, both sexes are losing bone at about the same rate.
   b. Aging increases risk of bone fractures.

CHAPTER ASSESSMENTS

7.1 Introduction

1 Active, living tissues found in bone include ____________________. (p. 202)
   a. blood
   b. nervous tissue
   c. dense connective tissue
   d. bone tissue
   e. all of the above

2 Functions of the skeletal system include all of the following except ____________________. (p. 202)
   a. providing support
   b. protecting softer tissues
   c. digesting proteins
   d. producing blood cells
   e. storing inorganic salts

3 List four groups of bones based on their shapes, and give an example from each group. (p. 202)

7.2 Bone Structure

4 Sketch a typical long bone, and label its epiphyses, diaphysis, medullary cavity, periosteum, and articular cartilages. Designate the locations of compact and spongy bone. (p. 203)

5 Discuss the functions of the parts labeled in the sketch you made for question 4. (p. 203)

6 Distinguish between the microscopic structure of compact bone and spongy bone. (p. 203)

7 Explain how central canals and perforating canals are related. (p. 204)

7.3 Bone Development and Growth

8 Explain how the development of intramembranous bone differs from that of endochondral bone. (p. 204)

9 ____________________ are bone cells in lacunae, whereas ____________________ are bone-forming cells and ____________________ are bone-resorbing cells. (p. 206)

10 Explain the function of an epiphyseal plate. (p. 208)

11 Place the zones of cartilage in an epiphyseal plate in order (1–4), with the first zone attached to the epiphysis. (p. 208)
   __________ zone of hypertrophic cartilage
   __________ zone of calcified cartilage
   __________ zone of resting cartilage
   __________ zone of perforating cartilage

12 Explain how osteoblasts and osteoclasts regulate bone mass. (p. 208)

13 Describe the effects of vitamin deficiencies on bone development and growth. (p. 209)

14 Explain the causes of pituitary dwarfism and gigantism. (p. 210)

15 Describe the effects of thyroid and sex hormones on bone development and growth. (p. 210)

16 Physical exercise pulling on muscular attachments to bone stimulates ____________________. (p. 210)

7.4 Bone Function

17 Provide several examples to illustrate how bones support and protect body parts. (p. 211)

18 Describe the functions of red and yellow bone marrow. (p. 211)

19 Explain the mechanism that regulates the concentration of blood calcium ions. (p. 211)

20 List three metallic elements that may be abnormally stored in bone. (p. 212)

7.5 Skeletal Organization

21 Bones of the head, neck, and trunk compose the ____________ skeleton; bones of the limbs and their attachments compose the ____________ skeleton. (p. 214)

7.6 Skull–7.12 Lower Limb

22 Name the bones of the cranium and the facial skeleton. (p. 218)

23 Explain the importance of fontanels. (p. 226)

24 Describe a typical vertebra, and distinguish among the cervical, thoracic, and lumbar vertebrae. (p. 228)

25 Describe the locations of the sacroiliac joint, the sacral promontory, and the sacral hiatus. (p. 230)

26 Name the bones that comprise the thoracic cage. (p. 232)

27 The clavicle and scapula form the ________________ girdle, whereas the hip bones and sacrum form the ________________ girdle. (pp. 234 and 240)

28 Name the bones of the upper limb, and describe their locations. (p. 236)

29 Name the bones that comprise the hip bone. (p. 240)

30 Explain the major differences between the male and female skeletons. (p. 242)

31 Name the bones of the lower limb, and describe their locations. (p. 243)

32 Match the parts listed on the left with the bones listed on the right. (pp. 218–245)

(1) coronoid process	A. ethmoid bone
(2) cribriform plate	B. frontal bone
(3) foramen magnum	C. mandible
(4) mastoid process	D. maxilla
(5) palatine process	E. occipital bone
(6) sella turcica	F. temporal bone
(7) supraorbital notch	G. sphenoid bone
(8) temporal process	H. zygomatic bone
(9) acromion process	I. femur
(10) deltoid tuberosity	J. fibula
(11) greater trochanter	K. humerus
(12) lateral malleolus	L. radius
(13) medial malleolus	M. scapula
(14) olecranon process	N. sternum
(15) radial tuberosity	O. tibia
(16) xiphoid process	P. ulna

7.13 Life-Span Changes

33 Describe the changes brought about by aging in trabecular bone. (p. 247)

INTEGRATIVE ASSESSMENTS/CRITICAL THINKING

OUTCOMES 1.6, 7.3, 7.4, 7.6

1. How might the condition of an infant's fontanels be used to evaluate skeletal development? How might the fontanels be used to estimate intracranial pressure (pressure in the cranial cavity)?

OUTCOMES 1.8, 7.2, 7.3

2. Why are incomplete, longitudinal fractures of bone shafts (greenstick fractures) more common in children than in adults?

OUTCOMES 5.3, 7.2, 7.6

3. How does the structure of a bone make it strong yet lightweight?

OUTCOMES 5.3, 7.3

4. If a young patient's forearm and elbow are immobilized by a cast for several weeks, what changes would you expect to occur in the bones of the upper limb?

OUTCOMES 7.3, 7.4, 7.10, 7.12

5. When a child's bone is fractured, growth may be stimulated at the epiphyseal plate. What problems might this extra growth cause in an upper or lower limb before the growth of the other limb compensates for the difference in length?

OUTCOMES 7.3, 7.11, 7.13

6. Suppose archeologists discover human skeletal remains in Ethiopia. Examination of the bones suggests that the remains represent four types of individuals. Two of the skeletons have bone densities that are 30% less than those of the other two skeletons. The skeletons with the lower bone mass also have broader front pelvic bones. Within the two groups defined by bone mass, smaller skeletons have bones with evidence of epiphyseal plates, but larger bones have only a thin line where the epiphyseal plates should be. Give the age group and gender of the individuals in this find.

OUTCOMES 7.7, 7.13

7. Why do elderly persons often develop bowed backs and appear to lose height?