Homeostasis of Bone Tissue

After the intramembranous and endochondral bones form, the actions of osteoclasts and osteoblasts continually remodel them. Throughout life, osteoclasts resorb bone matrix and osteoblasts replace it. Hormones that regulate blood calcium help control these opposing processes of *resorption* and *deposition* of matrix (see chapter 11, pp. 312–313). As a result, the total mass of bone tissue of an adult skeleton normally remains nearly constant, even though 3–5% of bone calcium is exchanged each year.

Factors Affecting Bone Development, Growth, and Repair APR

A number of factors influence bone development, growth, and repair. These include nutrition, hormonal secretions, and physical exercise. For example, vitamin D is necessary for proper absorption of calcium in the small intestine. In the absence of this vitamin, dietary calcium is poorly absorbed, and the inorganic salt portion of bone matrix will lack calcium, softening and thereby deforming bones. Growth hormone secreted by the pituitary gland stimulates division of the cartilage cells in the epiphyseal plates. Sex hormones stimulate ossification of the epiphyseal plates. Physical exercise pulling on muscular attachments to bones stresses the bones, stimulating the bone tissue to thicken and strengthen. Clinical Application 7.1 describes repair of a fractured bone.

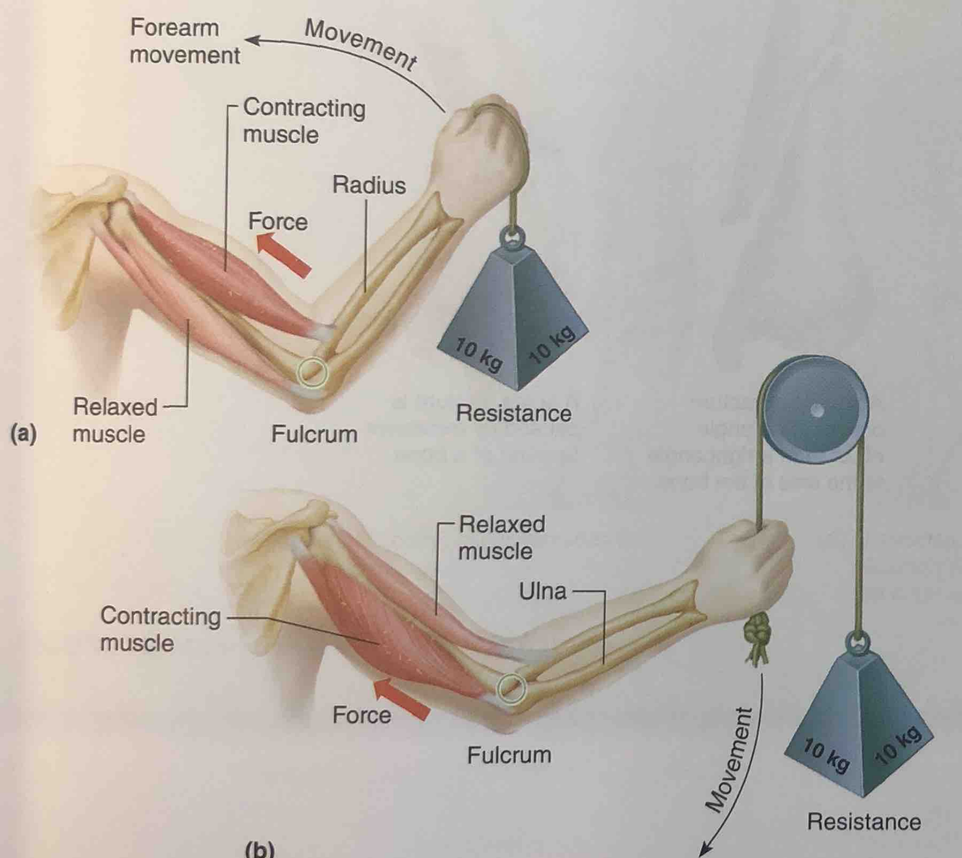


FIGURE 7.7 Levers and movement. **(a)** When the forearm bends at the elbow or **(b)** when the forearm straightens at the elbow, the bones and muscles function as a lever.

Support and Protection

Bones give shape to structures such as the head, face, thorax, and limbs. They also provide support and protection. For example, the bones of the lower limbs, pelvis, and backbone 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 the bones of the pelvic girdle protect the lower abdominal and internal reproductive organs.

Body Movement

Whenever limbs or other body parts move, bones and muscles interact as simple mechanical devices called **levers** (lev′erz). A lever has four basic components: (1) a rigid bar or rod, (2) a fulcrum or pivot on which the bar turns, (3) an object moved against resistance, and (4) a force that supplies energy for the movement of the bar.

The actions of bending and straightening the upper limb at the elbow illustrate bones and muscles functioning as levers. When the upper limb bends, the forearm bones represent the rigid bar, the elbow joint is the fulcrum, the hand is moved against the resistance provided by the weight, and the force is supplied by muscles on the anterior side of the arm (fig. 7.7*a*). One of these muscles, the *biceps brachii,* is attached by a tendon to a projection on a bone (radius) in the forearm, a short distance distal to the elbow.

When the upper limb straightens at the elbow, the forearm bones again serve as the rigid bar, the elbow joint serves as the fulcrum, and the hand moves against the resistance by pulling on the rope to raise the weight (fig. 7.7*b*). However, in this case the *triceps brachii,* a muscle located on the posterior side of the arm, supplies the force. A tendon of this muscle attaches to a projection on a forearm bone (ulna) at the point of the elbow.

Blood Cell Formation

The process of blood cell formation, called **hematopoiesis** (he″mă-to-poi-e′sis), begins in the *yolk sac,* which lies outside the human embryo (see chapter 20, p. 557). 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 within the medullary cavities of long bones, in the irregular spaces of spongy bone, and in the larger central canals of compact bone tissue. It is of two kinds: red and yellow. *Red marrow* functions in the formation of red blood cells (erythrocytes), white blood cells (leukocytes), and blood platelets. The color comes from the oxygen-carrying pigment **hemoglobin** in the red blood cells.

In an infant, red marrow occupies the cavities of most bones. With increasing age, yellow marrow replaces much of it. *Yellow marrow* stores fat; it is not active in blood cell production. In an adult, red marrow is primarily found in the spongy bone of the skull, ribs, sternum, clavicles, vertebrae, and hip bones. If the supply of blood cells is deficient, some yellow marrow may become red marrow, which then reverts to yellow marrow when the deficiency is corrected. Chapter 12 (pp. 329, 334, and 336) describes blood cell formation in more detail.

CLINICAL APPLICATION 7.1

Bone Fractures

A *fracture* is a break in a bone. A fracture is classified by its cause as a traumatic, spontaneous, or pathologic fracture and by the nature of the break as a greenstick, fissured, comminuted, transverse, oblique, or spiral fracture (fig. 7A). A broken bone exposed to the outside by an opening in the skin is termed a compound (open) fracture.

When a bone breaks, blood vessels in it rupture, and the periosteum is likely to tear. Blood from the broken vessels spreads through the damaged area and soon forms a blood clot, or *hematoma*. Vessels in surrounding tissues dilate, swelling and inflaming the tissues.

Within days or weeks, developing blood vessels and large numbers of osteoblasts originating in 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 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, a *cartilaginous soft callus*, is later

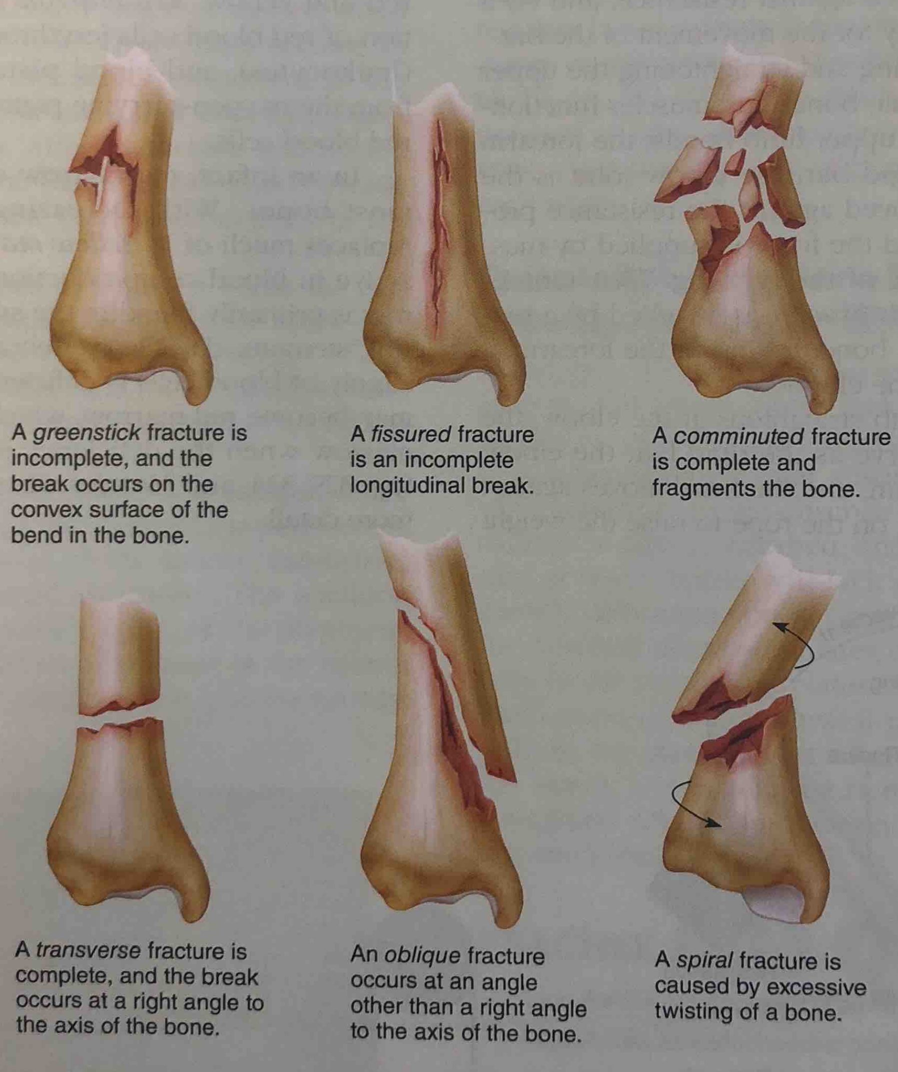
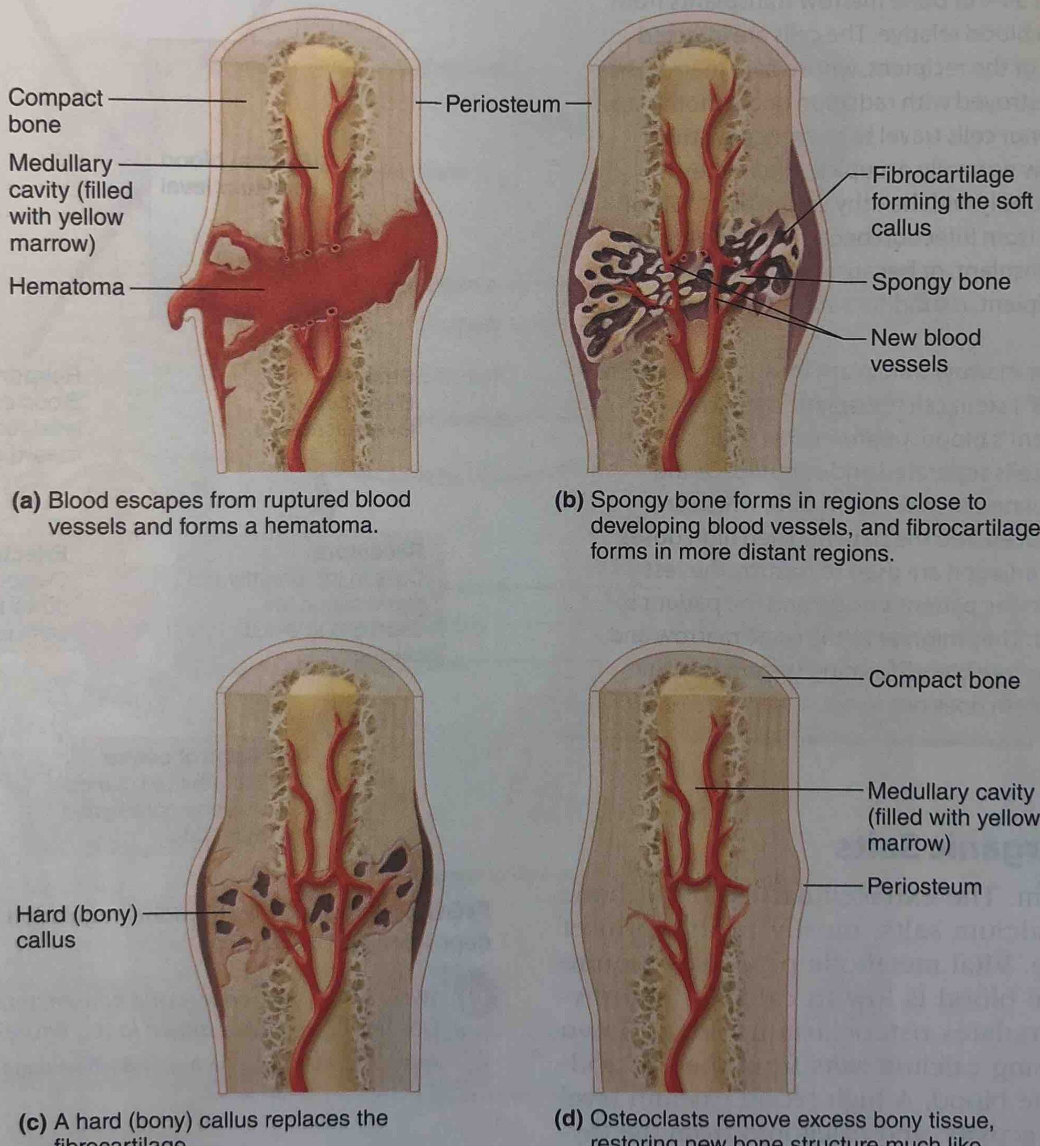


FIGURE 7A Various types of fractures.

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 *hard 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 (fig. 7B).

Several techniques are used to help the bone-healing process. The first casts to immobilize fractured bones were introduced 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. Experimental approaches to helping bones heal include cartilage grafts and infusions of stem cells taken from a patient's own bone marrow.



(a) Blood escapes from ruptured 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 hard (bony) callus replaces the fibrocartilage.

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

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

Bone marrow transplants have been used for more than half a century to enable people with certain cancers to tolerate high levels of chemotherapy drugs. Replacing bone marrow is also a way to treat an inherited disorder of blood cells (such as sickle cell disease) or a disease of the descendants of these cells that function outside the circulation (such as the brain disease adrenoleukodystrophy).

In a bone marrow transplant, a hollow needle and syringe remove normal red marrow cells from the spongy bone of a donor, or stem cells (which can give rise to specialized blood cells) are separated out from the donor's bloodstream. Stem cells from the umbilical cord of a newborn can be used in place of bone marrow.

Donors are selected based on their cells having a pattern of molecules on their surfaces that closely matches that of the recipient's cells. In 30% of bone marrow transplants from donors, the donor is a blood relative. The cells are injected into the bloodstream of the recipient, whose own marrow has been intentionally destroyed with radiation or chemotherapy. If all goes well, the donor cells travel to the spaces within bones that red marrow normally occupies, where they replenish the blood supply with healthy cells. About 15% of the time, patients die from infection because their immune systems reject the transplant, or because the transplanted tissue attacks the recipient, a condition called graft-versus-host disease.

Safer than a bone marrow transplant for some conditions is an autologous ("self") stem cell transplant. Stem cells are taken from a patient's bloodstream, and a mutation corrected or healthy cells separated and cultured. Or the bone marrow is stimulated to make stem cells, which are isolated and reintroduced into the patient. Then high doses of chemotherapy or radiation are used to destroy the rest of the bone marrow in the patient's body, and the patient's stem cells are infused. They migrate to the bone marrow and reconstitute a disease-free blood-forming system that the patient's immune system does not reject.

Storage of Inorganic Salts

Bones store calcium. The extracellular matrix of bone tissue is rich in calcium salts, mostly in the form of calcium phosphate. Vital metabolic processes require calcium. 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. A high blood calcium level inhibits osteoclast activity, and calcitonin from the thyroid gland stimulates osteoblasts to form bone tissue, storing excess calcium in the extracellular matrix (fig. 7.8). Chapter 11 (pp. 312–313) describes the details of this homeostatic mechanism. Maintaining sufficient blood calcium levels is important in muscle contraction, nerve cell function, blood clotting, and other physiological processes.

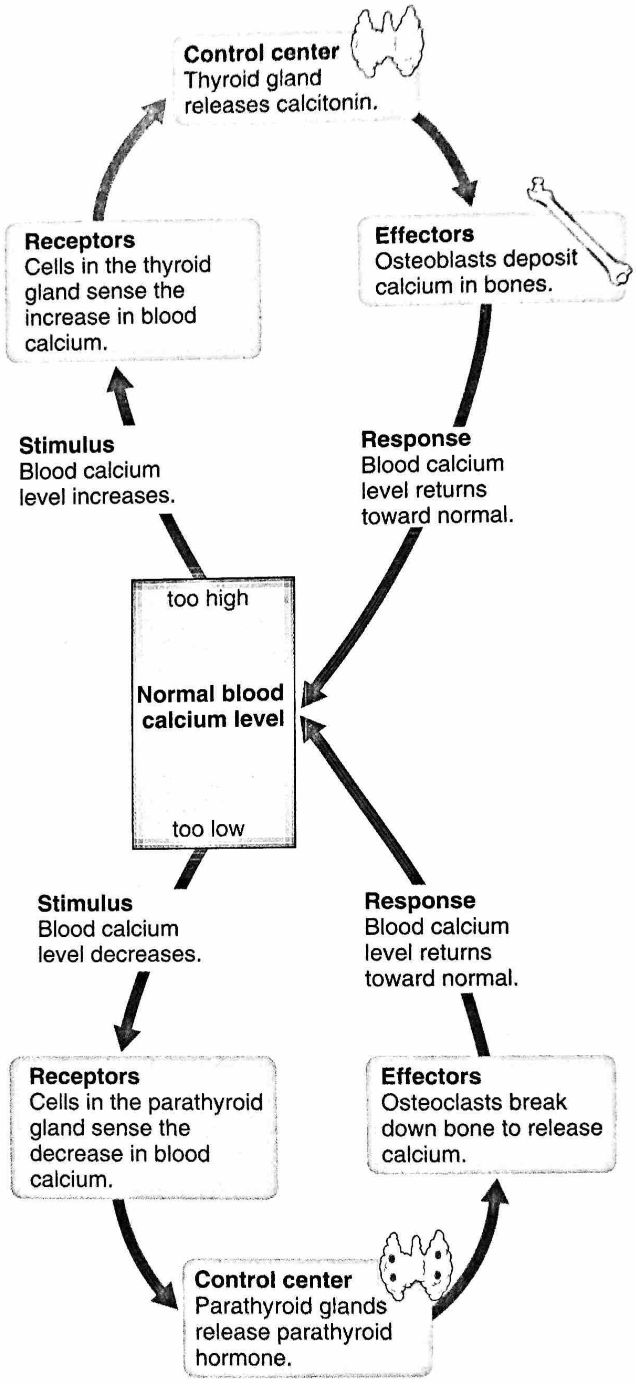


FIGURE 7.8 APR Hormonal regulation of bone calcium deposition and resorption.

What three components of a homeostatic mechanism (see fig. 1.5, p. 14) are shown in this figure?

Answer can be found in Appendix F on page 582.

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

PRACTICE

10. Name the major functions of bones.
11. Distinguish between the functions of red marrow and yellow marrow.
12. List the substances normally stored in bone tissue.

7.5 | Skeletal Organization

For purposes of study, it is convenient to divide the skeleton into two major portions—an axial skeleton and an appendicular skeleton (fig. 7.9). 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:

1. **Skull.** The skull is composed of the **cranium** (kra′ne-um), or brain case, and the *facial bones.*
2. **Hyoid bone.** The hyoid (hi′oid) bone is located in the neck between the lower jaw and the larynx. It supports the tongue and is an attachment for certain muscles that help move the tongue during swallowing.
3. **Vertebral column.** The vertebral column, or spinal column (backbone), consists of many vertebrae separated by cartilaginous *intervertebral discs.* Near its distal end, five vertebrae fuse to form the **sacrum** (sa′krum), part of the pelvis. The

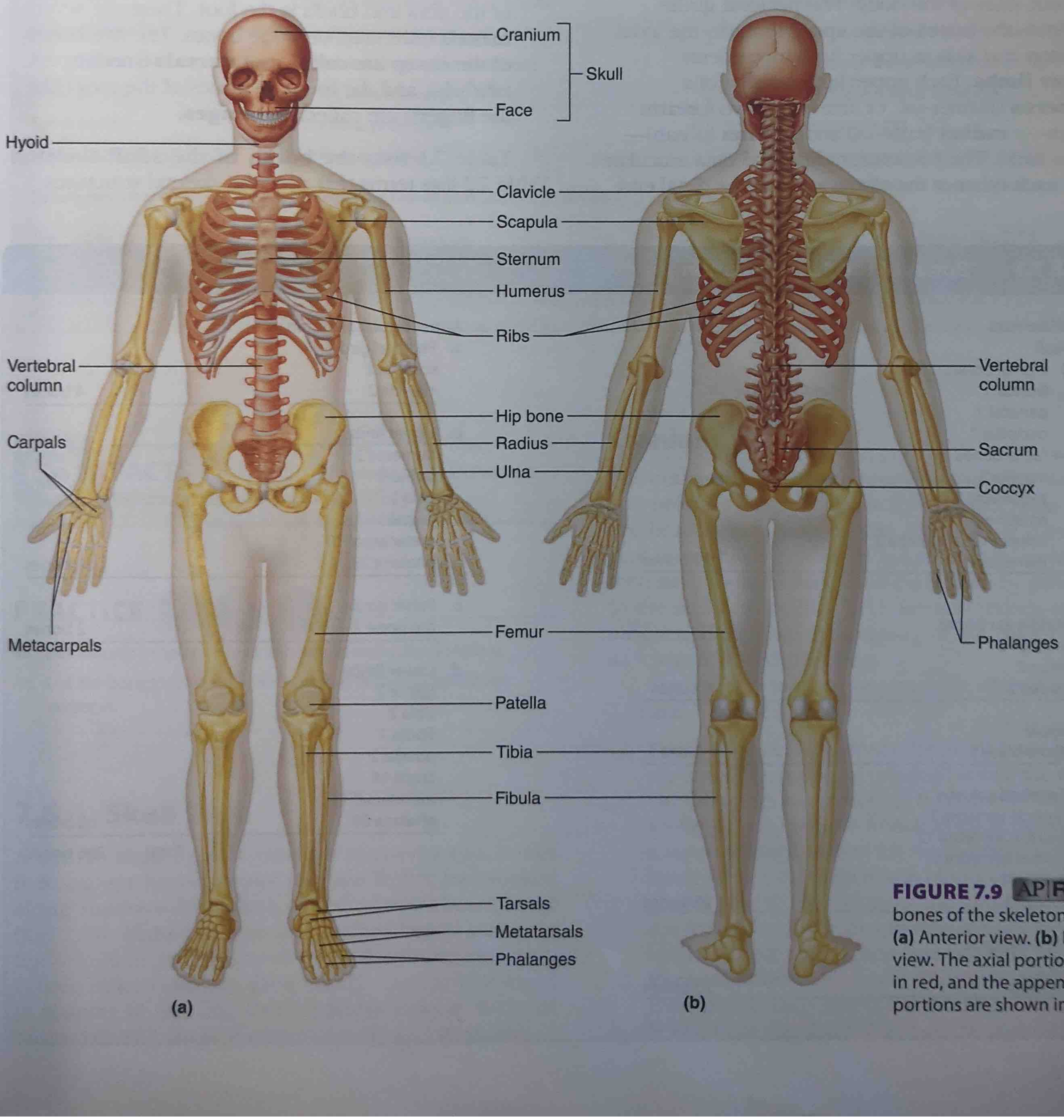


FIGURE 7.9 APR Major bones of the skeleton. **(a)** Anterior view. **(b)** Posterior view. The axial portion is shown in red, and the appendicular portions are shown in yellow.

coccyx (kok′siks), a small, rudimentary tailbone composed of four fused vertebrae, is attached to the end of the sacrum.

4. **Thoracic cage.** 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 thoracic vertebrae. The thoracic cage also includes the **sternum** (ster′num), or breastbone, to which most of the ribs attach 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:

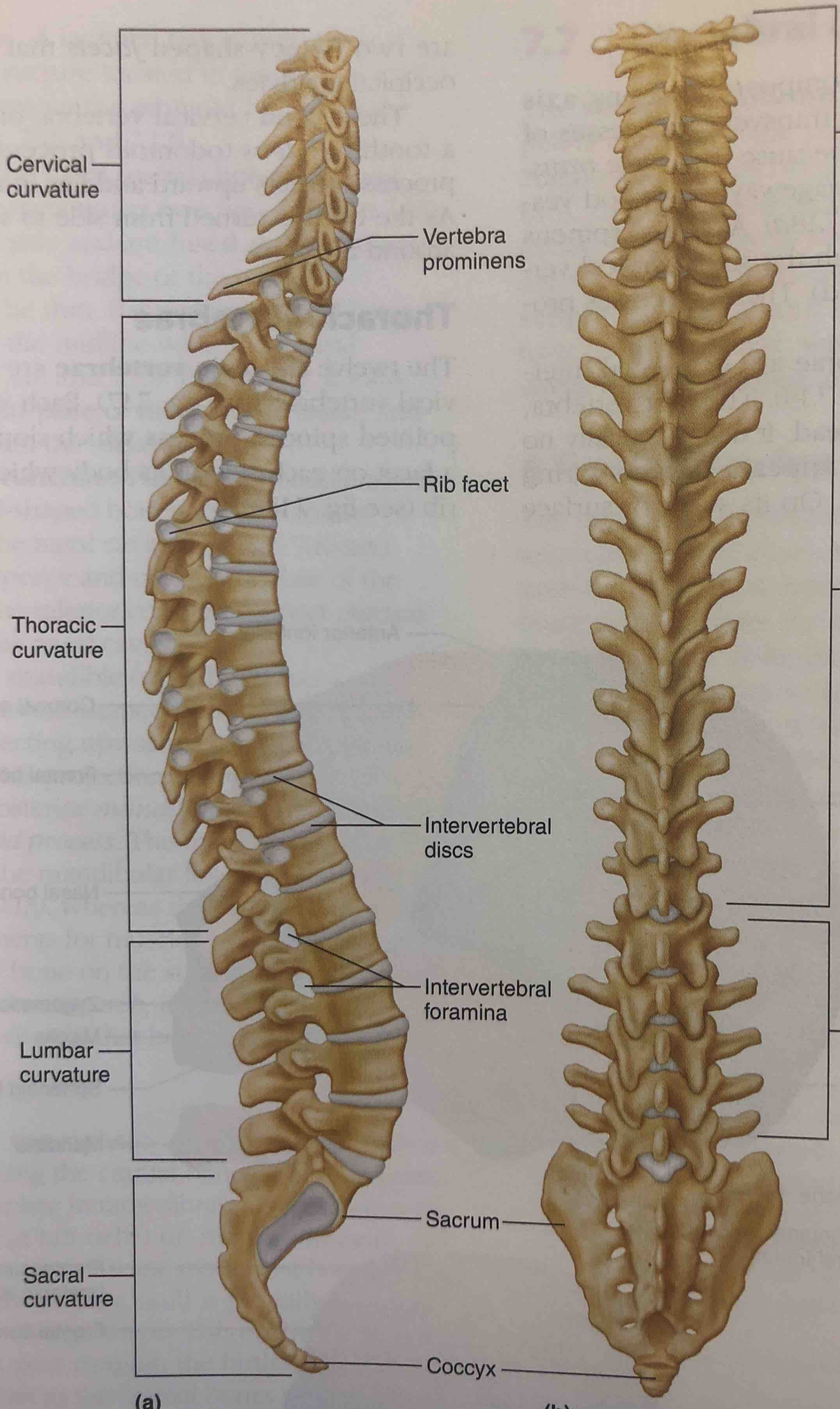
1. **Pectoral girdle.** The pectoral (pek′to-ral) girdle is formed by a **scapula** (scap′u-lah), or shoulder blade, and a **clavicle** (klav′ĭ-k′l), or collarbone, on both sides of the body. The pectoral girdle connects the bones of the upper limbs to the axial skeleton and aids in upper limb movements.
2. **Upper limbs.** 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′pals), or wrist bones. The five bones of the palm are called **metacarpals** (met″ah-kar′pals), and the fourteen finger bones are called **phalanges** (fah-lan′jēz; singular, *phalanx,* fa′lanks).
3. **Pelvic girdle.** 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.**
4. **Lower limbs.** Each lower limb consists of a **femur** (fe′mur), or thigh bone, two leg bones—a large **tibia** (tib′e-ah) 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) covers the anterior surface. At the distal ends of the tibia and fibula is the foot. There are seven **tarsals** (tahr′sals), or ankle bones. The five bones of the instep are called **metatarsals** (met″ah-tahr′sals), and the fourteen bones of the toes (like the fingers) are called **phalanges.**

Table 7.1 lists the bones of the adult skeleton. Table 7.2 lists terms that describe skeletal structures.

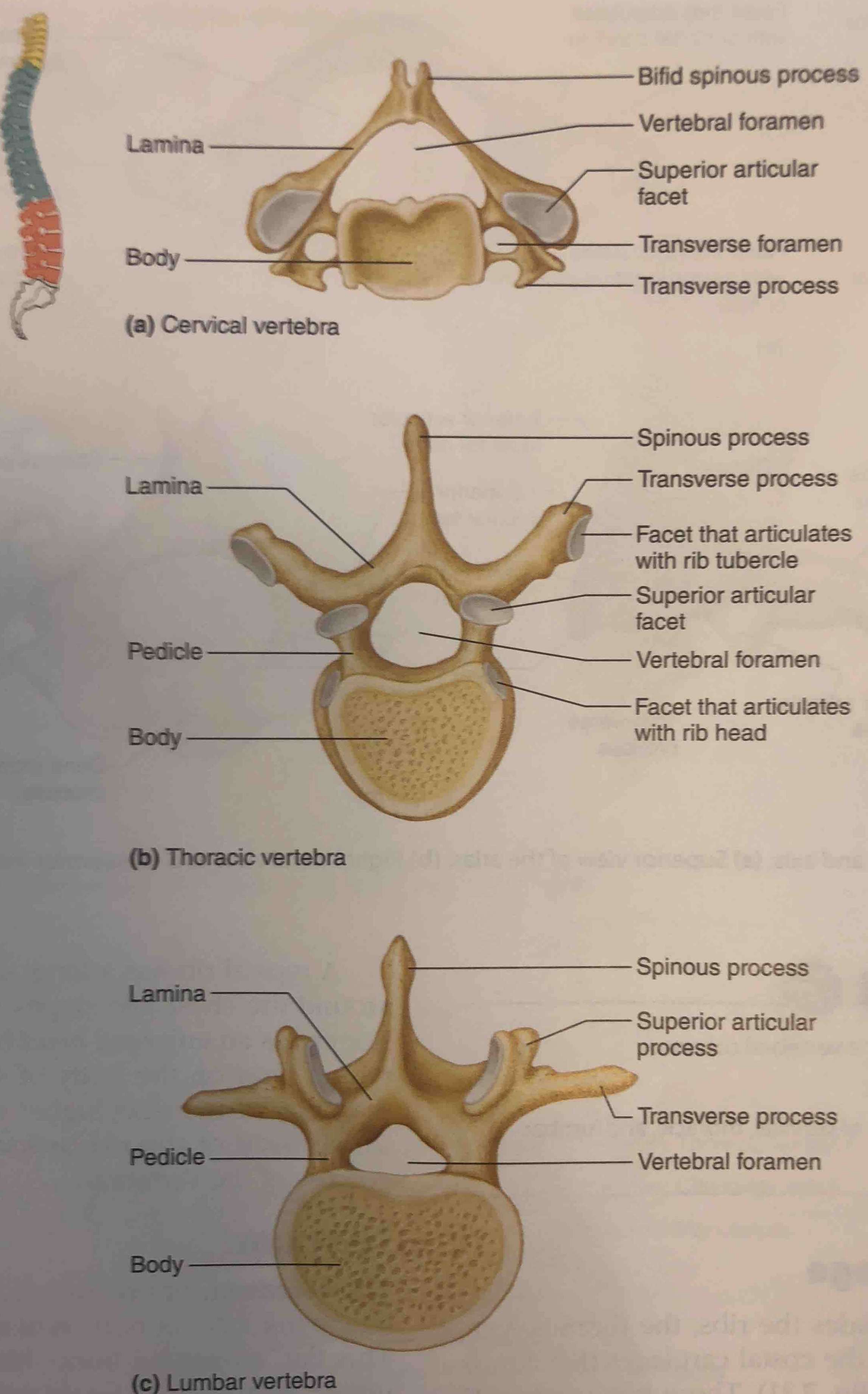
TABLE 7.1 Bones of the Adult Skeleton

1. Axial Skeleton		
a. Skull		
8 cranial bones		
frontal 1	temporal 2	
parietal 2	sphenoid 1	
occipital 1	ethmoid 1	
14 facial bones		
maxilla 2	lacrimal 2	
zygomatic 2	nasal 2	
palatine 2	vomer 1	
inferior nasal concha 2		
mandible 1		22 bones
b. Middle ear bones		
malleus 2		
incus 2		
stapes 2		6 bones
c. Hyoid		
hyoid bone 1		1 bone
d. Vertebral column		
cervical vertebra 7		
thoracic vertebra 12		
lumbar vertebra 5		
sacrum 1		
coccyx 1		26 bones
e. Thoracic cage		
rib 24		
sternum 1		25 bones

2. Appendicular Skeleton	
a. Pectoral girdle	
scapula 2	
clavicle 2	4 bones
b. Upper limbs	
humerus 2	
radius 2	
ulna 2	
carpal 16	
metacarpal 10	
phalanx 28	60 bones
c. Pelvic girdle	
hip bone 2	2 bones
d. Lower limbs	
femur 2	
tibia 2	
fibula 2	
patella 2	
tarsal 14	
metatarsal 10	
phalanx 28	60 bones
Total	206 bones



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



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

Changes in the intervertebral discs may cause various problems. Each disc is composed of a tough outer layer of fibrocartilage and an elastic central mass. With age, these discs degenerate—the central masses lose firmness, and the outer layers thin and weaken, developing cracks. Extra pressure, as when a person falls or lifts a heavy object, can break the outer layer of a disc, squeezing out the central mass. Such a rupture may press on the spinal cord or on a spinal nerve that branches from it. This condition—a ruptured or herniated disc—may cause back pain and numbness or loss of muscular function in the parts innervated by the affected spinal nerve.

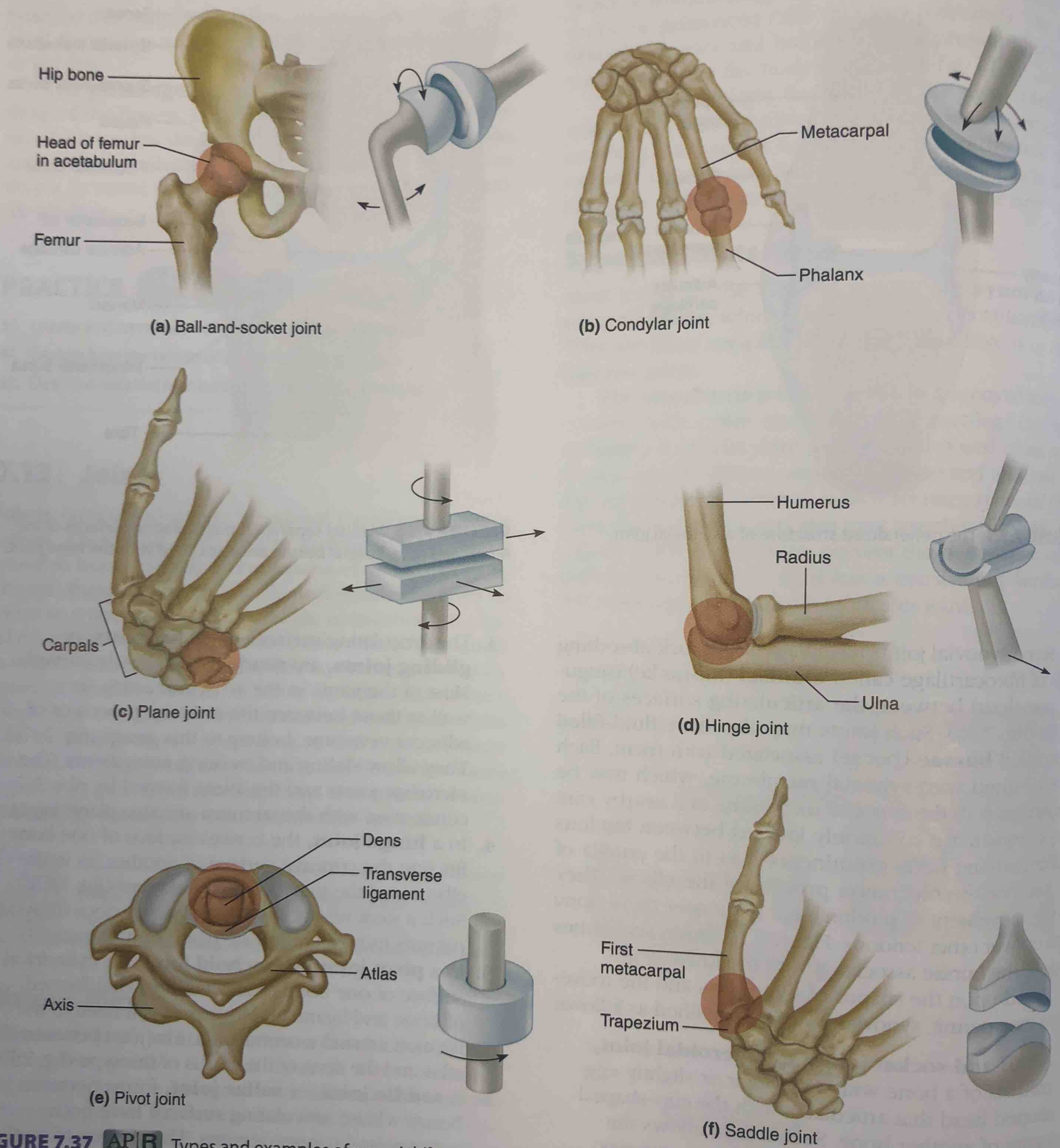


FIGURE 7.37 APR Types and examples of synovial (freely movable) joints. **(a-f)**

CLINICAL APPLICATION 7.2
Joint Disorders

Joints must support weight, provide a variety of body movements, and are used frequently. Trauma, overuse, infection, a misdirected immune system attack, or degeneration can injure joints. Consider some common joint problems.

Sprains

Sprains result from overstretching or tearing the connective tissues, including cartilage, ligaments, and tendons, associated with a joint, but they do not dislocate the articular bones. Usually a forceful wrenching or twisting sprains a wrist or ankle. For example, inverting an ankle too far can sprain it by stretching the ligaments on its lateral surface. Severe injuries may pull these structures loose from their attachments.

A sprained joint is painful and swollen, restricting movement. Immediate treatment of a sprain is rest; more serious cases require medical attention. However, immobilization of a joint, even for a brief period, causes bone resorption and weakens ligaments. Consequently, exercise may help strengthen the joint.

Bursitis

Overuse of a joint or stress on a bursa may cause *bursitis*, an inflammation of a bursa. The bursa between the calcaneus (heel bone) and the Achilles tendon may become inflamed as a result of a sudden increase in physical activity using the feet. Bursitis is treated with rest. Medical attention may be necessary.

Arthritis

Arthritis causes inflamed, swollen, and painful joints. More than a hundred different types of arthritis affect millions of people worldwide. The most common types of arthritis are rheumatoid arthritis (RA), osteoarthritis (OA), and Lyme arthritis.

Rheumatoid Arthritis (RA)

Rheumatoid arthritis, an autoimmune disorder (a condition in which the immune system attacks the body's healthy tissues), is painful and debilitating. The synovial membrane of a joint becomes inflamed and thickened. Then the articular cartilage is damaged, and fibrous tissue infiltrates, interfering with joint movements. Over time, the joints may ossify, fusing the articulating bones. RA may affect many joints or only a few. It is often accompanied by muscular atrophy, fatigue, and other symptoms.

Osteoarthritis (OA)

Osteoarthritis, a degenerative disorder, may result from aging or a poorly healed injury, or it may be inherited. Articular cartilage softens and disintegrates gradually, roughening the articular surfaces. Joints become painful, with restricted movement. OA usually affects the most active joints, such as those of the fingers, hips, knees, and the lower vertebral column.

If a person with osteoarthritis is overweight or obese, the first treatment is usually an exercise and dietary program to lose weight. Nonsteroidal anti-inflammatory drugs (NSAIDs) such as aspirin and ibuprofen have been used for many years to control osteoarthritis symptoms. NSAIDs called COX-2 inhibitors relieve inflammation without the gastrointestinal side effects of earlier drugs, but they are prescribed only to people who do not have risk factors for cardiovascular disease, to which some drugs are linked.

Lyme Arthritis

Lyme disease, a bacterial infection passed in a tick bite, causes intermittent arthritis of several joints, usually weeks after the initial symptoms of rash, fatigue, and flulike aches and pains. Lyme arthritis was first observed in Lyme, Connecticut, where an astute woman alerted a prominent rheumatologist to the fact that many of her young neighbors had what appeared to be the very rare juvenile form of rheumatoid arthritis. Researchers then traced the illness to a tick-borne bacterial infection. Antibiotic treatment that begins as soon as the early symptoms are recognized may prevent Lyme arthritis. Other types of bacteria can cause arthritis, too.

FIGURE 7.38 APR Joint movements illustrating abduction, adduction, lateral flexion, extension, and flexion.

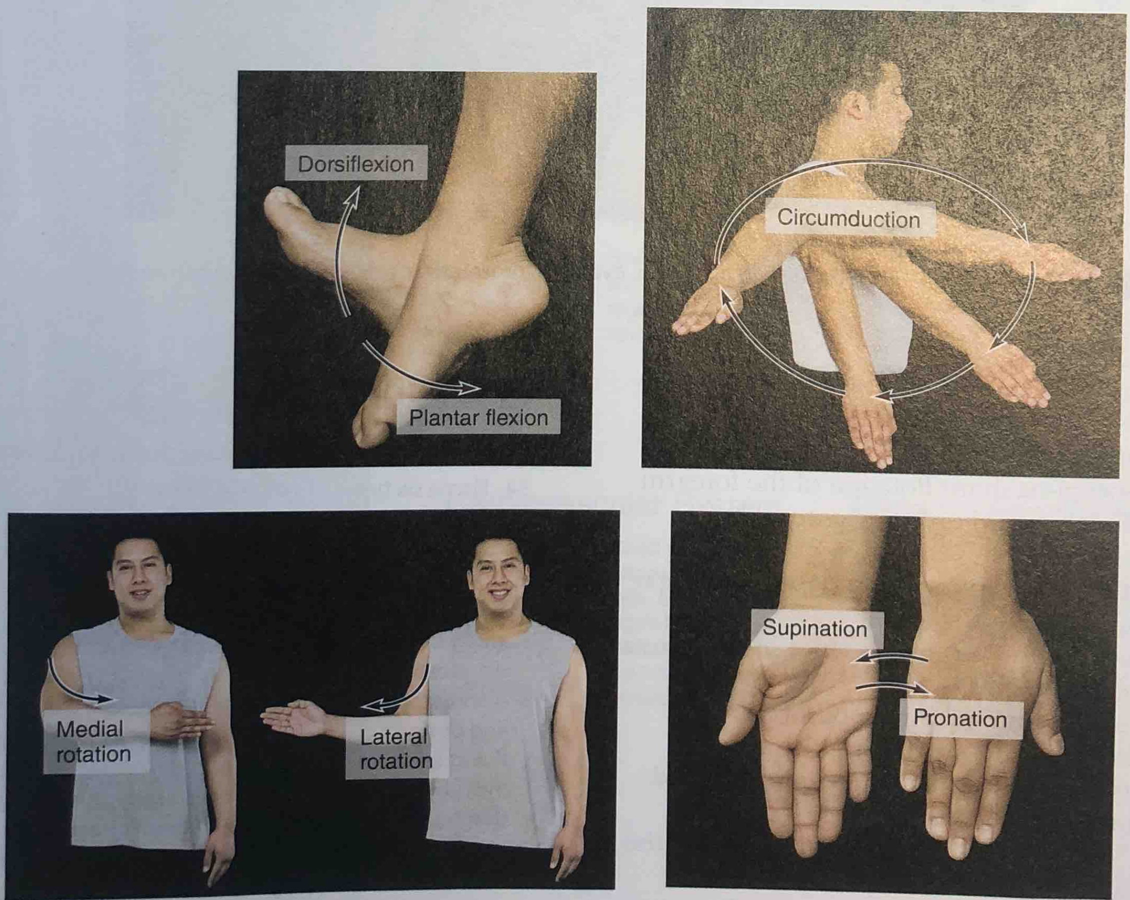


FIGURE 7.39 APR Joint movements illustrating dorsiflexion, plantar flexion, circumduction, rotation, supination, and pronation.