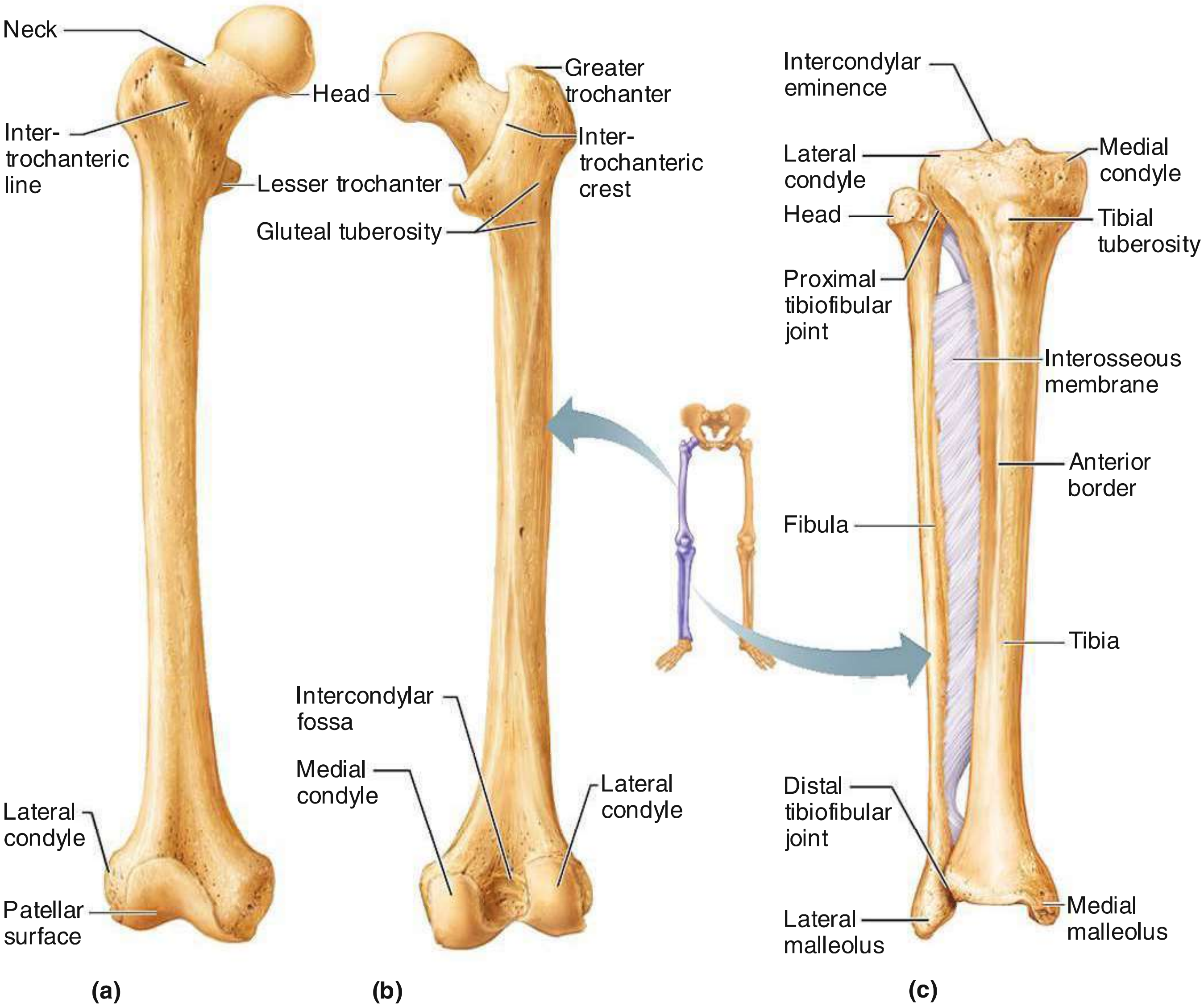


Figure 5.27 Bones of the right thigh and leg. (a) Femur (thigh bone), anterior view. **(b)** Femur, posterior view. **(c)** Tibia and fibula of the leg, anterior view.

the deep **intercondylar fossa.** Anteriorly on the distal femur is the smooth **patellar surface,** which forms a joint with the patella, or kneecap.

Leg

Connected along their length by an **interosseous membrane,** two bones, the tibia and fibula, form the skeleton of the leg (see Figure 5.27c). The **tibia,** or *shinbone,* is larger and more medial. At the proximal end, the **medial** and **lateral condyles** (separated by the **intercondylar eminence**) articulate with the distal end of the femur to form the knee joint. The patellar (kneecap) ligament, which encloses the **patella,** a sesamoid bone (see Figure 6.20c and d), attaches to the **tibial tuberosity,** a roughened area on the anterior tibial surface. Distally, a process called the **medial malleolus** (mal-le′o-lus) forms the inner bulge of the ankle. The anterior surface of the tibia is a sharp ridge, the **anterior border,** that is unprotected by muscles; thus, it is easily felt beneath the skin.

The **fibula,** which lies alongside the tibia and forms joints with it both proximally and distally, is thin and sticklike. The fibula has no part in forming the knee joint. Its distal end, the **lateral malleolus,** forms the outer part of the ankle.

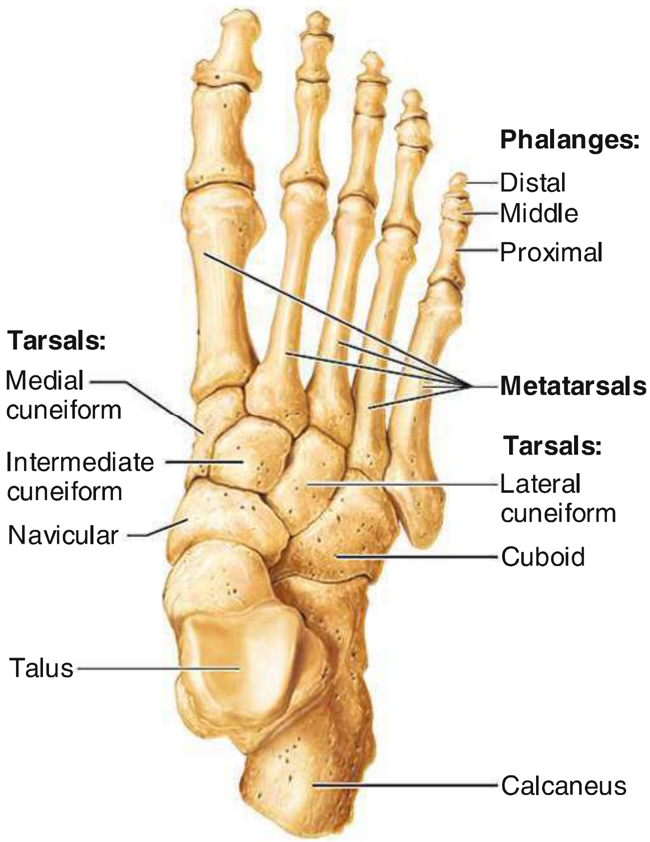


Figure 5.28 Bones of the right foot, superior view.

Foot

The foot, composed of the tarsals, metatarsals, and phalanges, has two important functions. It supports our body weight and serves as a lever that allows us to propel our bodies forward when we walk and run.

The **tarsus,** forming the posterior half of the foot, is composed of seven **tarsal bones** (Figure 5.28). Body weight is carried mostly by the two largest tarsals, the **calcaneus** (kal-ka′ne-us), or heelbone, and the **talus** (ta′lus; "ankle"), which lies between the tibia and the calcaneus. Five **metatarsals** form the sole, and 14 **phalanges** form the toes. Like the fingers of the hand, each toe has three phalanges, except the great toe, which has two.

The bones in the foot are arranged to form three strong arches: two longitudinal (medial and lateral) and one transverse (Figure 5.29). *Ligaments*, which bind the foot bones together, and *tendons* of the foot muscles help to hold the bones firmly in the arched position but still

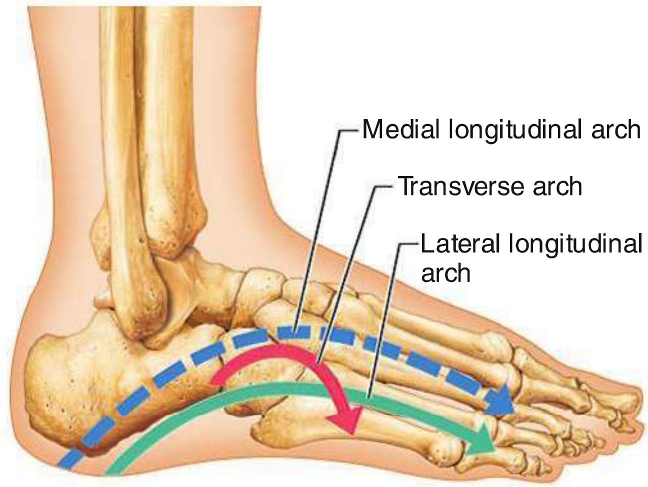


Figure 5.29 Arches of the foot.

allow a certain amount of give or springiness. Weak arches are referred to as "fallen arches" or "flat feet."

DID YOU GET IT?

28. What two bones form the skeleton of the leg?

29. Bo's longitudinal and medial arches have suffered a collapse. What is the name of Bo's condition?

30. Which lower limb bone has an intertrochanteric line and crest and an intercondylar fossa?

For answers, see Appendix D.

Joints

✓ Name the three major categories of joints, and compare the amount of movement allowed by each.

With one exception (the hyoid bone of the neck), every bone in the body forms a joint with at least one other bone. **Joints,** also called **articulations,** are the sites where two or more bones meet. They have two functions: They hold the bones together securely but also give the rigid skeleton mobility.

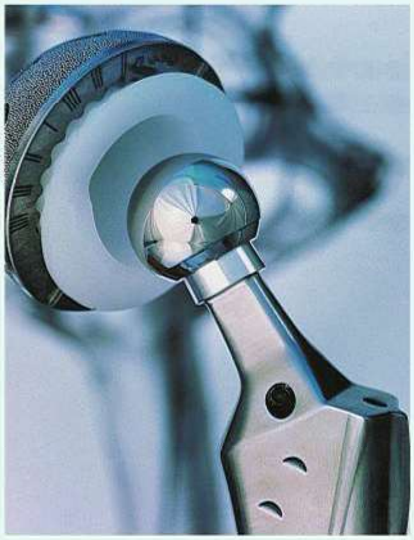
The graceful movements of a ballet dancer and the rough-and-tumble grapplings of a football player illustrate the great variety of motion that joints allow. With fewer joints, we would move like robots. Nevertheless, the bone-binding function of joints is just as important as their role in mobility. The immovable joints of the skull, for instance, form a snug enclosure for our vital brain.

Joints: From Knights in Shining Armor to Bionic Humans

The technology for fashioning joints in medieval suits of armor developed over centuries. The technology for creating the prostheses (artificial joints) used in medicine today developed, in relative terms, in a flash—less than 60 years. The history of joint prostheses dates to the 1940s and 1950s, when World War II and the Korean War left large numbers of wounded who needed artificial limbs. Today, well over a third of a million Americans receive total joint replacements each year, mostly because of the destructive effects of osteoarthritis or rheumatoid arthritis.

To produce durable, mobile joints requires a substance that is strong, nontoxic, and resistant to the corrosive effects of organic acids in blood. In 1963, Sir John Charnley, an English orthopedic surgeon, performed the first total hip replacement and revolutionized the therapy of arthritic hips. His device consisted of a metal ball on a stem and a cup-shaped polyethylene plastic socket anchored to the pelvis by methyl methacrylate cement. This cement proved to be exceptionally strong and relatively problem free. Hip prostheses were followed by knee prostheses (see photos a and b), but it took another ten years before smoothly operating total knee joint replacements became a reality. Today, the number of knee replacements equals the number of hip replacements.

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



(a) A hip prosthesis.

(b) X ray of right knee showing total knee replacement prosthesis.

Replacement joints are not yet strong or durable enough for young, active people. The problem is that the prostheses work loose over time, so researchers are trying to enhance the fit between implant and bone. One solution is to strengthen the cement that binds them (simply eliminating air bubbles from the cement increases its durability). Another solution currently being tested is a robotic surgeon, ROBODOC (photo c), to drill a better-fitting hole for the femoral prosthesis in hip surgery. In cementless prostheses, researchers are exploring ways to get the bone to grow so that it binds strongly to the implant.

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

(c) Physician explaining how the ROBODOC machine can be used for hip joint replacement.

Joint replacement therapy is coming of age, but equally exciting are techniques that call on the patient's own tissues to regenerate, such as these three:

- Osteochondral grafting: Healthy bone and cartilage are removed from one part of the body and transplanted to the injured joint.
- Autologous chondrocyte implantation: Healthy chondrocytes are removed from the body, cultivated in the lab, and implanted at the damaged joint.
- Stem cell regeneration: Undifferentiated stem cells are removed from bone marrow and placed in a gel, which is packed into an area of eroded cartilage.

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

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

Joints are classified in two ways—functionally and structurally. The functional classification focuses on the amount of movement the joint allows. On this basis, there are **synarthroses** (sin″ar-thro′sēz), or immovable joints; **amphiarthroses** (am″fe-ar-thro′sēz), or slightly movable joints; and **diarthroses** (di″ar-thro′sēz), or freely movable joints. Freely movable joints predominate in the limbs, where mobility is important. Immovable and slightly movable joints are restricted mainly to the axial skeleton, where firm attachments and protection of internal organs are priorities.

Structurally, there are *fibrous, cartilaginous,* and *synovial joints.* These classifications are based on whether fibrous tissue, cartilage, or a joint cavity separates the bony regions at the joint. As a general rule, fibrous joints are immovable, and synovial joints are freely movable. Although cartilaginous joints have both immovable and slightly movable examples, most are amphiarthrotic. Because the structural classification is more clear-cut, we will focus on that classification scheme here. The joint types are shown in **Figure 5.30**, described next, and summarized in **Table 5.3**.

Fibrous Joints

In **fibrous joints,** the bones are united by fibrous tissue. The best examples of this type of joint are the *sutures* of the skull (Figure 5.30a). In sutures, the irregular edges of the bones interlock and are bound tightly together by connective tissue fibers, allowing essentially no movement. In *syndesmoses* (sin-dez-mo′sēz), the connecting fibers are longer than those of sutures; thus the joint has more "give." The joint connecting the distal ends of the tibia and fibula is a syndesmosis (Figure 5.30b).

Cartilaginous Joints

In **cartilaginous joints,** the bone ends are connected by fibrocartilage. Examples of this joint type that are slightly movable (amphiarthrotic) are the *pubic symphysis* of the pelvis (Figure 5.30e) and *intervertebral joints* of the spinal column (Figure 5.30d), where the articulating bone surfaces are connected by pads (discs) of fibrocartilage. The hyaline-cartilage epiphyseal plates of growing long bones and the cartilaginous joints between the first ribs and the sternum are immovable (synarthrotic) cartilaginous joints referred to as *synchondroses* (Figure 5.30c).

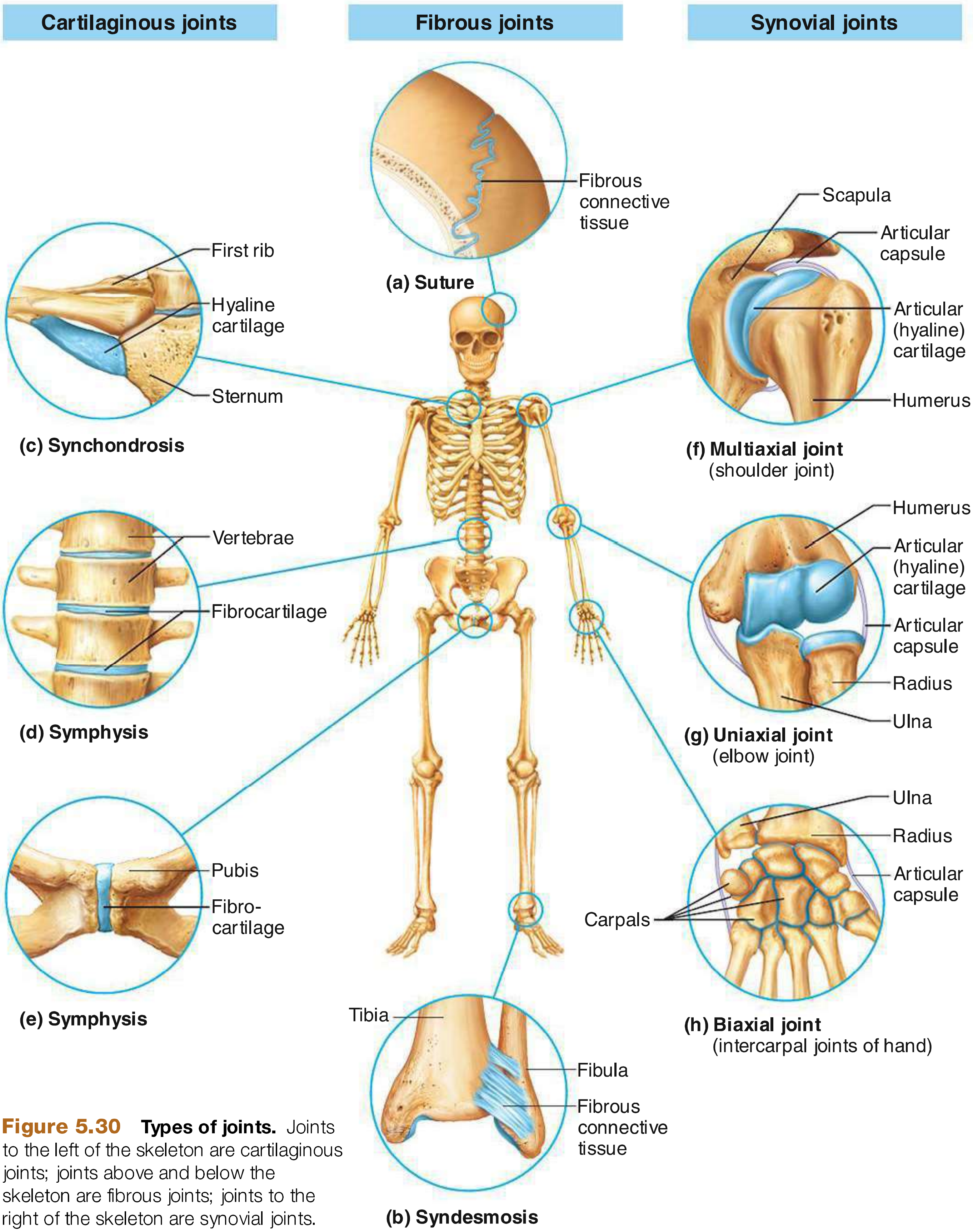


Figure 5.30 **Types of joints.** Joints to the left of the skeleton are cartilaginous joints; joints above and below the skeleton are fibrous joints; joints to the right of the skeleton are synovial joints.

Table 5.3 Summary of Joint Classes

Structural class	Structural characteristics	Types	Mobility
Fibrous	Bone ends/parts united by collagenic fibers	Suture (short fibers)	Immobile (synarthrosis)
		Syndesmosis (longer fibers)	Slightly mobile (amphiarthrosis) and immobile
		Gomphosis (periodontal ligament)	Immobile
Cartilaginous	Bone ends/parts united by cartilage	Synchondrosis (hyaline cartilage)	Immobile
		Symphysis (fibrocartilage)	Slightly movable
Synovial	Bone ends/parts covered with articular cartilage and enclosed within an articular capsule lined with synovial membrane	Plane, Hinge, Pivot, Condylar, Saddle, Ball and socket	Freely movable (diarthrosis; movements depend on design of joint)

Synovial Joints

Synovial joints are joints in which the articulating bone ends are separated by a joint cavity containing synovial fluid (see Figure 5.30f–h). They account for all joints of the limbs.

All synovial joints have four distinguishing features (**Figure 5.31**):

1. **Articular cartilage.** Articular (hyaline) cartilage covers the ends of the bones forming the joint.
2. **Articular capsule.** The joint surfaces are enclosed by a sleeve or layer of fibrous connective tissue, which is lined with a smooth *synovial membrane* (the reason these joints are called synovial joints).
3. **Joint cavity.** The articular capsule encloses a cavity, called the joint cavity, which contains lubricating synovial fluid.
4. **Reinforcing ligaments.** The fibrous layer of the capsule is usually reinforced with ligaments.

Bursae and tendon sheaths are not strictly part of synovial joints, but they are often found closely associated with them (see Figure 5.31). Essentially bags of lubricant, they act like ball bearings to reduce friction between adjacent structures during joint activity. **Bursae** (ber′se; "purses") are flattened fibrous sacs lined with synovial membrane and containing a thin film of synovial fluid. They are common where ligaments, muscles, skin, tendons, or bones rub together. A **tendon sheath,** also shown in Figure 5.31, is essentially an elongated bursa that wraps completely around a tendon subjected to friction, like a bun around a hot dog.

HOMEOSTATIC IMBALANCE

A **dislocation** happens when a bone is forced out of its normal position in the joint cavity. The process of returning the bone to its proper position, called **reduction,** should be done only by a physician. Attempts by an untrained person to "snap the bone back into its socket" are usually more harmful than helpful. ◗

Types of Synovial Joints Based on Shape

The shapes of the articulating bone surfaces determine what movements are allowed at a joint. Based on such shapes, our synovial joints can be

Q: *How does this pint type differ structurally from cartilaginous and fibrous pints?*

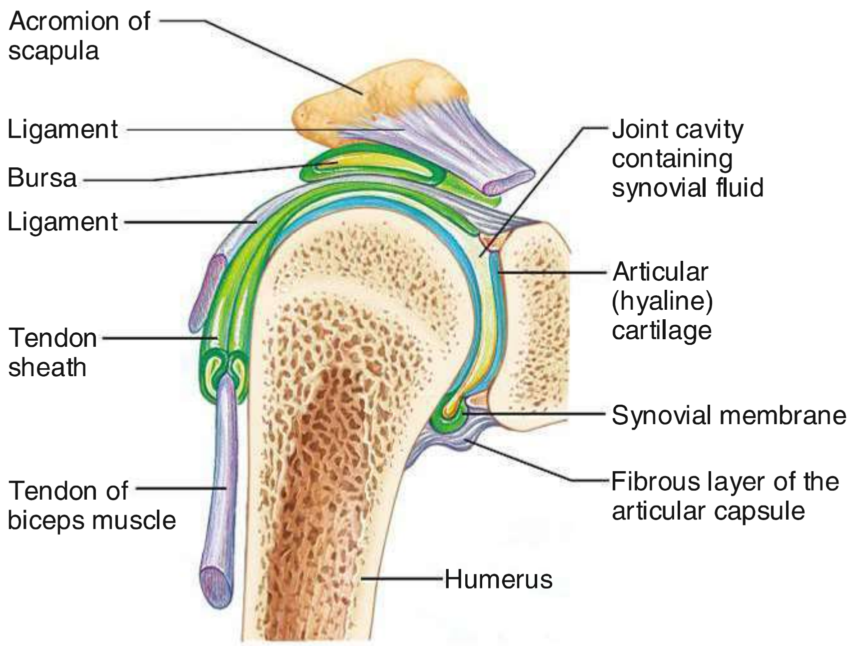


Figure 5.31 General structure of a synovial joint.

classified as *plane, hinge, pivot, condylar, saddle,* and *ball-and-socket pints* (**Figure 5.32**).

- In a **plane joint** (Figure 5.32a), the articular surfaces are essentially flat, and only short slipping or gliding movements are allowed. The movements of plane joints are *nonaxial;* that is, gliding does not involve rotation around any axis. The intercarpal joints of the wrist are the best examples of plane joints.
- In a **hinge joint** (Figure 5.32b), the cylindrical end of one bone fits into a trough-shaped surface on another bone. Angular movement is allowed in just one plane, like a mechanical hinge. Examples are the elbow joint, ankle joint, and the joints between the phalanges of the fingers. Hinge joints are classified as *uniaxial* (u″ne-aks′e-al; "one axis"); they allow movement around one axis only, as indicated by the single magenta arrow in Figure 5.32b.
- In a **pivot joint** (Figure 5.32c), the rounded end of one bone fits into a sleeve or ring of bone (and possibly ligaments). Because the rotating bone can turn only around its long axis, pivot joints are also uniaxial joints (see the single arrow in Figure 5.32c). The proximal radioulnar joint and the joint between the atlas and the dens of the axis are examples.
- In a **condylar joint** (kon′dĭ-ler; "knuckle-like"), the egg-shaped articular surface of one bone fits into an oval concavity in another (Figure 5.32d). Both of these articular surfaces are oval. Condylar joints allow the moving bone to travel (1) from side to side and (2) back and forth, but the bone cannot rotate around its long axis. Movement occurs around two axes, hence these joints are *biaxial* (*bi* = two), as in knuckle (metacarpophalangeal) joints.
- In **saddle joints,** each articular surface has both convex and concave areas, like a saddle (Figure 5.32e). These biaxial joints allow essentially the same movements as condylar joints.

A: *It has a pint cavity instead of cartilage or fibrous tissue separating the articulating bones.*

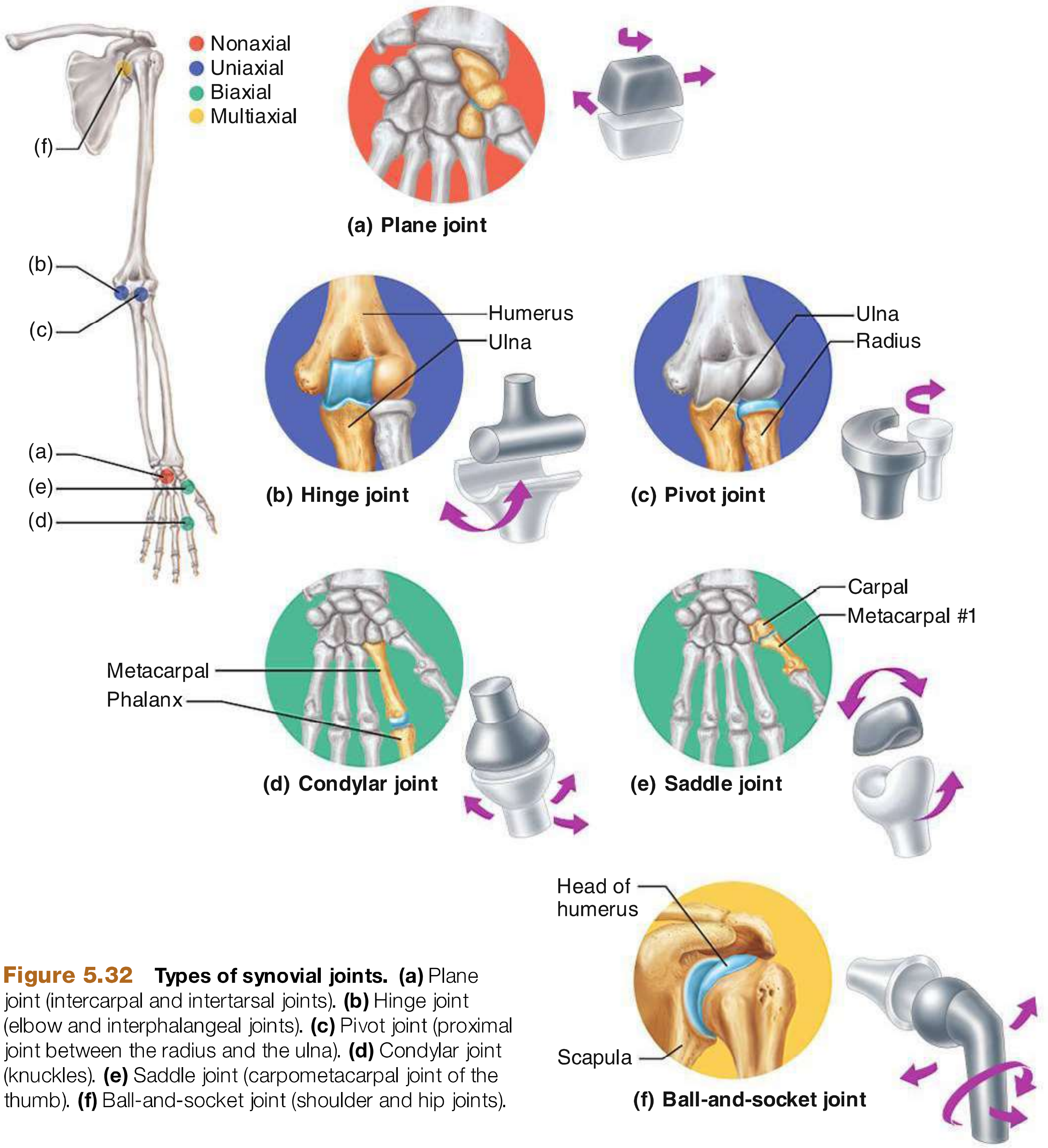


Figure 5.32 Types of synovial joints. (a) Plane joint (intercarpal and intertarsal joints). **(b)** Hinge joint (elbow and interphalangeal joints). **(c)** Pivot joint (proximal joint between the radius and the ulna). **(d)** Condylar joint (knuckles). **(e)** Saddle joint (carpometacarpal joint of the thumb). **(f)** Ball-and-socket joint (shoulder and hip joints).

The best examples of saddle joints are the carpometacarpal joints in the thumb, and the movements of these joints are clearly demonstrated by twiddling your thumbs.

- In a **ball-and-socket joint** (Figure 5.32f), the spherical head of one bone fits into a round socket in another. These *multiaxial* joints allow movement in all axes, including rotation (see the four arrows in Figure 5.32f), and are the most freely moving synovial joints. The shoulder and hip are examples.

Because they relate to muscle activity, we discuss the various types of movements that occur at synovial joints in detail in the next chapter.

HOMEOSTATIC IMBALANCE

Few of us pay attention to our joints unless something goes wrong with them. Joint pain and inflammation may be caused by many things. For example, falling on one's knee can cause a painful **bursitis,** called "water on the knee," due to inflammation of bursae or synovial membrane. Sprains and dislocations are other types of joint problems that result in swelling and pain. In a **sprain,** the ligaments or tendons reinforcing a joint are damaged by excessive stretching, or they are torn away from the bone. Both tendons and ligaments are cords of dense fibrous connective tissue with a poor blood supply; thus, sprains heal slowly and are extremely painful.

Few inflammatory joint disorders cause more pain and suffering than arthritis. The term **arthritis** (*arth* = joint; *itis* = inflammation) describes over 100 different inflammatory or degenerative diseases that damage the joints. In all its forms, arthritis is the most widespread, crippling disease in the United States. All forms of arthritis have the same initial symptoms: pain, stiffness, and swelling of the joint. Then, depending on the specific form, certain changes in the joint structure occur.

Acute forms of arthritis usually result from bacterial invasion and are treated with antibiotic drugs. The synovial membrane thickens and fluid production decreases, leading to increased friction and pain. Chronic forms of arthritis include osteoarthritis, rheumatoid arthritis, and gouty arthritis, which differ substantially in their later symptoms and consequences. We will focus on these forms here.

Osteoarthritis (OA), the most common form of arthritis, is a chronic degenerative condition that typically affects the aged. Eighty-five percent of people in the United States develop this condition. OA, also called "wear-and-tear arthritis," affects the articular cartilages. Over the years, the cartilage softens, frays, and eventually breaks down. As the disease progresses, the exposed bone thickens and extra bone tissue, called **bone spurs,** grows around the margins of the eroded cartilage and restricts joint movement. Patients complain of stiffness on arising that lessens with activity, and the affected joints may make a crunching noise (**crepitus**) when moved. The joints most commonly affected are those of the fingers, the cervical and lumbar joints of the spine, and the large, weight-bearing joints of the lower limbs (knees and hips).

The course of osteoarthritis is usually slow and irreversible, but it is rarely crippling. In most cases, its symptoms are controllable with a mild analgesic such as aspirin, moderate activity to maintain joint mobility, and rest when the joint becomes very painful. Some people with OA claim that rubbing capsaicin (a hot pepper extract) on the skin over painful joints provides relief. Others swear to the pain-reducing ability of glucosamine sulfate, a nutritional supplement.

Rheumatoid (roo′mah-toid) **arthritis (RA)** is a chronic inflammatory disorder. Its onset is insidious and usually occurs between the ages of 40 and 50, but it may occur at any age. It affects three times as many women as men. Many joints, particularly those of the fingers, wrists, ankles, and feet, are affected at the same time and usually in a symmetrical manner. For example, if the right elbow is affected, most likely the left elbow will be affected also. The course of RA varies and is marked by remissions and flare-ups (*rheumat* = susceptible to change or flux).

RA is an autoimmune disease—a disorder in which the body's immune system attempts to destroy its own tissues. The initial trigger for this reaction is unknown, but some suspect that it results from certain bacterial or viral infections.

RA begins with inflammation of the synovial membranes. The membranes thicken and the joints swell as synovial fluid accumulates. Inflammatory cells (white blood cells and others) enter the joint cavity from the blood and release a deluge of inflammatory chemicals that destroy body tissues when released inappropriately as in RA. In time the inflamed synovial membrane thickens into a **pannus** ("rag"), an abnormal tissue that clings to and erodes articular cartilages. As the cartilage is destroyed, scar tissue forms and connects the bone ends. The scar tissue eventually ossifies, and the bone ends become firmly fused (**ankylosis**) and often deformed (**Figure 5.33**). Not all cases of RA progress to the severely crippling ankylosis stage, but all cases involve restricted joint movement and extreme pain.

Figure 5.33 X-ray image of a hand deformed by rheumatoid arthritis.

Current therapy for RA involves many different kinds of drugs. Some, like methotrexate, are immunosuppressants. Others, like etanercept (Enbrel), neutralize the inflammatory chemicals in the joint space and (hopefully) prevent joint deformity. However, drug therapy often begins with aspirin, which in large doses is an effective anti-inflammatory agent. Exercise is recommended to maintain as much joint mobility as possible. Cold packs are used to relieve the swelling and pain, and heat helps to relieve morning stiffness. Replacement joints or bone removal are the last resort for severely crippled RA patients.

Gouty (gow′te) **arthritis,** or **gout,** is a disease in which uric acid (a normal waste product of nucleic acid metabolism) accumulates in the blood and may be deposited as needle-shaped crystals in the soft tissues of joints. This leads to an agonizingly painful attack that typically affects a single joint, often in the great toe. Gout is most common in men and rarely appears before the age of thirty. It tends to run in families, so genetic factors are definitely implicated.

Untreated gout can be very destructive; the bone ends fuse, and the joint becomes immobilized. Fortunately, several drugs (colchicine, ibuprofen, and others) are successful in preventing acute gout attacks. Patients are advised to lose weight if obese, to avoid foods such as liver, kidneys, and sardines, which are high in nucleic acids, and to avoid alcohol, which inhibits excretion of uric acid by the kidneys.

DID YOU GET IT?

31. What are the functions of joints?

32. What is the major difference between a fibrous joint and a cartilaginous joint?

33. Where is synovial membrane found, and what is its role?

34. What two joints of the body are ball-and-socket joints? What is the best example of a saddle joint?

For answers, see Appendix D.

Developmental Aspects of the Skeleton

✓ Identify some of the causes of bone and joint problems throughout life.

As we described earlier, the first "long bones" in the very young fetus are formed of hyaline cartilage, and the earliest "flat bones" of the skull are actually fibrous membranes. As the fetus develops and grows, both the flat and the long bone models are converted to bone (**Figure 5.34**). At birth, some fontanels still remain in the skull to allow for brain growth, but these areas are usually fully ossified by 2 years of age. By the end of adolescence, the epiphyseal plates of long bones that provide for longitudinal growth in childhood have become fully ossified, and long-bone growth ends.

The skeleton changes throughout life, but the changes in childhood are most dramatic. At birth, the baby's cranium is huge relative to its face (**Figure 5.35a**). The rapid growth of the cranium before and after birth is related to the growth of the brain. By 2 years, the skull is three-quarters of its adult size; and, by 8 to 9 years, the skull is almost of adult size and proportions. However, between the ages of 6 and 11, the head appears to enlarge substantially as the face literally grows out from the skull. The jaws increase in size, and the cheekbones and nose become more prominent as respiratory passages expand and the permanent teeth develop.

The so-called primary curvatures of the vertebral column are present at birth and are convex posteriorly, so an infant's spine is arched, like that of a four-legged animal. The secondary curvatures are convex anteriorly and are associated with a child's later development. They result from reshaping of