molecules. **Ribosomal RNA (rRNA)** helps form the ribosomes, where proteins are built. **Messenger RNA (mRNA) molecules** are long, single nucleotide strands that resemble half of a DNA molecule and carry the "message" containing instructions for protein synthesis from the DNA gene in the nucleus to the ribosomes in the cytoplasm.

Protein synthesis involves two major phases: *transcription,* when complementary mRNA is made at the DNA gene, and *translation,* when the information carried in mRNA molecules is "decoded" and used to assemble proteins. These steps are summarized simply in Figure 3.16, and described in more detail next.

Transcription

The word *transcription* often refers to one of the jobs done by a secretary—converting notes from one form (shorthand notes or an audiotape recording) into another form (a typewritten letter, for example). In other words, the same information is transformed from one form or format to another. In cells, **transcription** involves the transfer of information from DNA's base sequence into the *complementary* base sequence of mRNA (Figure 3.16, step 1). Only DNA and mRNA are involved in transcription. Whereas each three-base sequence specifying a particular amino acid on the DNA gene is called a **triplet,** the corresponding three-base sequences on mRNA are called **codons.** The form is different, but the same information is being conveyed. Thus, if the (partial) sequence of DNA triplets is AAT-CGT-TCG, the related codons on mRNA would be UUA-GCA-AGC.

Translation

A translator takes words in one language and restates them in another language. In the **translation phase** of protein synthesis, the language of nucleic acids (base sequence) is "translated" into the language of proteins (amino acid sequence). Translation occurs in the cytoplasm and involves three major varieties of RNA. As illustrated in Figure 3.16, steps 2–5, translation consists of the following events. Once the mRNA attaches to the ribosome (step 2), tRNA comes into the picture. Its job is to transfer, or ferry, amino acids to the ribosome, where they are bound together by enzymes in the exact sequence specified by the gene (and its mRNA). There are about 45 common types of tRNAs, each capable of carrying one of the 20 or so common types of amino acid to the protein synthesis sites. But that is not the only job of the tiny tRNAs. They also have to recognize the mRNA codons "calling for" the amino acid they are toting. They can do this because they have a special three-base sequence called an **anticodon** on their "head" that can bind to the complementary codons (step 3).

Once the first tRNA has maneuvered itself into the correct position at the beginning of the mRNA message, the ribosome moves the mRNA strand along, bringing the next codon into position to be read by another tRNA. As amino acids are brought to their proper positions along the length of mRNA, they are joined together by enzymes (step 4). As an amino acid is bonded to the chain, its tRNA is released and moves away from the ribosome to pick up another amino acid (step 5). When the last codon (the termination, or "stop," codon) is read, the protein is released.

PART II: BODY TISSUES

The human body, complex as it is, starts out as a single cell, the fertilized egg, which divides almost endlessly. The millions of cells that result become specialized for particular functions. Some become muscle cells, others the transparent lens of the eye, still others skin cells, and so on. Thus, there is a division of labor in the body, with certain groups of highly specialized cells performing functions that benefit the organism as a whole.

Cell specialization carries with it certain hazards. When a small group of cells is indispensable, its loss can disable or even destroy the body. For example, the action of the heart depends on a very specialized cell group in the heart muscle that controls its contractions. If those particular cells are damaged or stop functioning, the heart will no longer work efficiently, and the whole body will suffer or die from lack of oxygen.

Groups of cells that are similar in structure and function are called **tissues.** The four primary tissue types—epithelium, connective tissue, nervous tissue, and muscle—interweave to form the fabric of the body. If we had to assign a single term to each primary tissue type that would best describe its overall role, the terms would most likely be *covering* (epithelium), *support* (connective), *movement* (muscle), and *control* (nervous). However, these terms reflect only a tiny fraction of the functions that each of these tissues performs.

As explained in Chapter 1, tissues are organized into *organs* such as the heart, kidneys, and lungs. Most organs contain several tissue types, and the arrangement of the tissues determines each organ's structure and what it is able to do. Thus, a study of tissues should be helpful in your later study of the body's organs and how they work.

For now, we want to become familiar with the major similarities and differences in the primary tissues. Because epithelium and some types of connective tissue will not be considered again, they are emphasized more in this section than are muscle, nervous tissues, and bone (a connective tissue), which are covered in more depth in later chapters.

Epithelial Tissue

Epithelial tissue, or **epithelium** (ep″ĭ-the′le-um; *epithe* = laid on, covering) is the *lining, covering,* and *glandular tissue* of the body. Glandular epithelium forms various glands in the body. Covering and lining epithelium covers all free body surfaces and contains versatile cells. One type forms the outer layer of the skin. Others dip into the body to line its cavities. Since epithelium forms the boundaries that separate us from the outside world, nearly all substances given off or received by the body must pass through epithelium.

Epithelial functions include *protection, absorption, filtration,* and *secretion.* For example, the epithelium of the skin protects against bacterial and chemical damage and that lining the respiratory tract has cilia, which sweep dust and other debris away from the lungs. Epithelium specialized to absorb substances lines some digestive system organs such as the stomach and small intestine, which absorb food into the body. In the kidneys, epithelium both absorbs and filters. Secretion is a specialty of the glands, which produce such substances as perspiration, oil, digestive enzymes, and mucus.

Special Characteristics of Epithelium

Epithelium generally has the characteristics listed below:

- Except for glandular epithelium (described on p. 90), epithelial cells fit closely together to form continuous sheets. Neighboring cells are bound together at many points by cell junctions, including desmosomes and tight junctions.
- The membranes always have one free (unattached) surface or edge. This so-called **apical surface** is exposed to the body's exterior or to the cavity of an internal organ. The exposed surfaces of some epithelia are slick and smooth, but others exhibit cell surface modifications, such as microvilli or cilia.
- The lower surface of an epithelium rests on a **basement membrane,** a structureless material secreted by the cells.
- Epithelial tissues have no blood supply of their own (that is, they are *avascular*) and depend on diffusion from the capillaries in the underlying connective tissue for food and oxygen.
- If well nourished, epithelial cells regenerate themselves easily.

Classification of Epithelium

Each epithelium is given two names. The first indicates the relative number of cell layers it has (Figure 3.17a). The classifications by cell arrangement (layers) are **simple epithelium** (one layer of cells) and **stratified epithelium** (more than one cell layer). The second describes the shape of its cells (Figure 3.17b). On this basis there are *squamous* (skwa′mus) *cells,* flattened like fish scales (*squam* = scale), *cuboidal* (ku-boi′dal) *cells,* which are cube-shaped like dice, and *columnar cells,* shaped like columns. The terms describing the shape and arrangement are then combined to describe the epithelium fully. Stratified epithelia are named for the cells at the *free surface* of the epithelial membrane, not those resting on the basement membrane.

Simple Epithelia

The simple epithelia are most concerned with absorption, secretion, and filtration. Because simple epithelia are usually very thin, protection is not one of their specialties.

Simple Squamous Epithelium **Simple squamous epithelium** is a single layer of thin squamous cells resting on a basement membrane. The cells fit closely together, much like floor tiles. This type of epithelium usually forms membranes where filtration or exchange of substances by rapid diffusion occurs. It is in the air sacs of the lungs, where

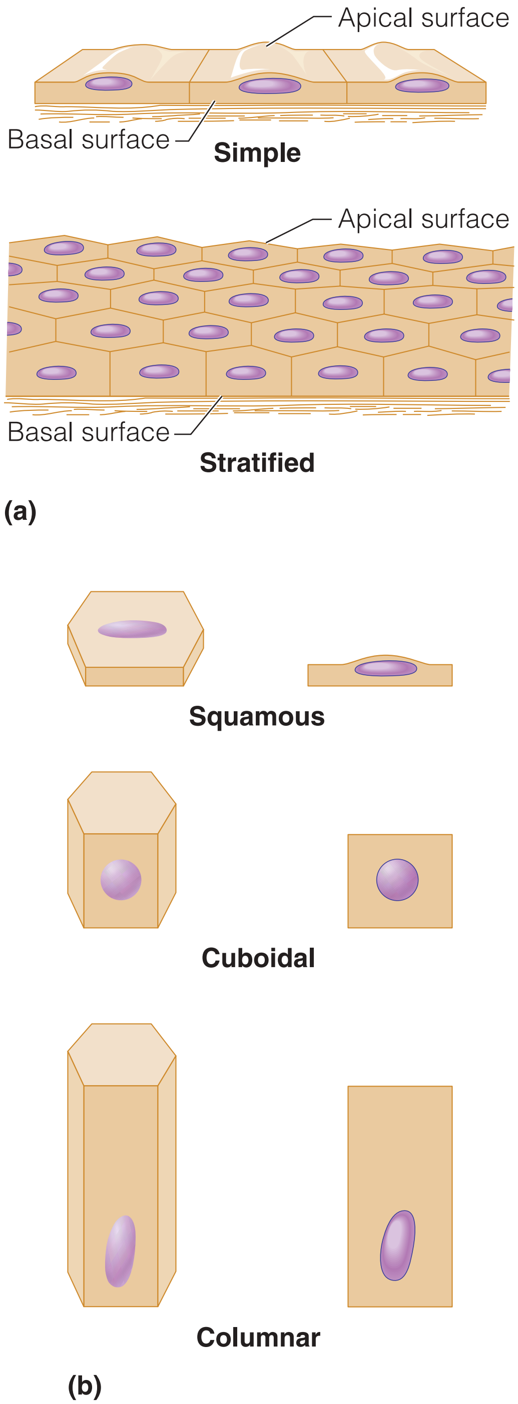


FIGURE 3.17 Classification of epithelia. (a) Classification on the basis of arrangement (layers). **(b)** Classification on the basis of cell shape; for each category, a whole cell is shown on the left and a longitudinal section is shown on the right.

oxygen and carbon dioxide are exchanged (Figure 3.18a), and it forms the walls of capillaries, where nutrients and gases pass between the tissue cells and the blood in the capillaries. Simple squamous epithelium also forms **serous membranes,** or **serosae** (se-ro′se), the slick membranes that line the ventral body cavity and cover the organs in that cavity. The serous membranes are described in more detail in Chapter 4.

Simple Cuboidal Epithelium **Simple cuboidal epithelium,** which is one layer of cuboidal cells resting on a basement membrane, is common in glands and their ducts (for example, the salivary glands and pancreas). It also forms the walls of the kidney tubules and covers the surface of the ovaries (Figure 3.18b).

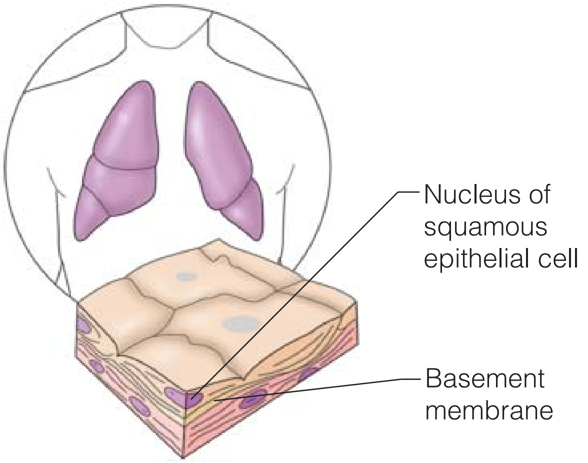
Simple Columnar Epithelium **Simple columnar epithelium** is made up of a single layer of tall cells that fit closely together. **Goblet cells,** which produce a lubricating mucus, are often seen in this type of epithelium. Simple columnar epithelium lines the entire length of the digestive tract from the stomach to the anus (Figure 3.18c). Epithelial membranes that line body cavities open to the body exterior are called **mucosae** (mu-ko′se) or **mucous membranes.**

Pseudostratified Columnar Epithelium All of the cells of **pseudostratified** (soo″do-stră′tĭ-fīd) **columnar epithelium** rest on a basement membrane. However, some of its cells are shorter than others, and their nuclei appear at different heights above the basement membrane. As a result, this epithelium gives the false (*pseudo*) impression that it is stratified; hence its name. Like simple columnar epithelium, this variety mainly functions in absorption and secretion. A ciliated variety (more precisely called *pseudostratified ciliated columnar epithelium*) lines most of the respiratory tract (Figure 3.18d). The mucus produced by the goblet cells in this epithelium traps dust and other debris, and the cilia propel the mucus upward and away from the lungs.

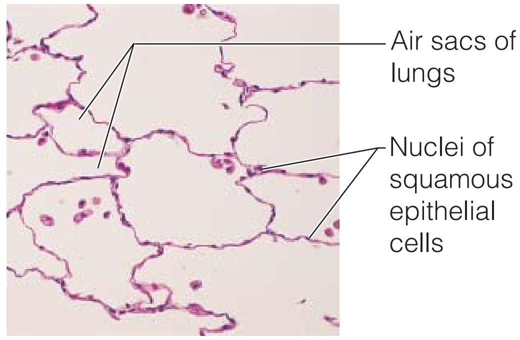
Stratified Epithelia

Stratified epithelia consist of two or more cell layers. Being considerably more durable than the simple epithelia, these epithelia function primarily to protect.

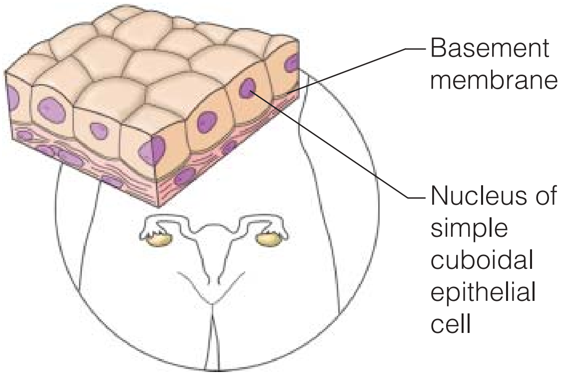
Stratified Squamous Epithelium **Stratified squamous epithelium** is the most common stratified epithelium in the body. It usually consists of several layers of cells. The cells at the free edge are squamous cells, whereas those close to the basement membrane are cuboidal or columnar. Stratified



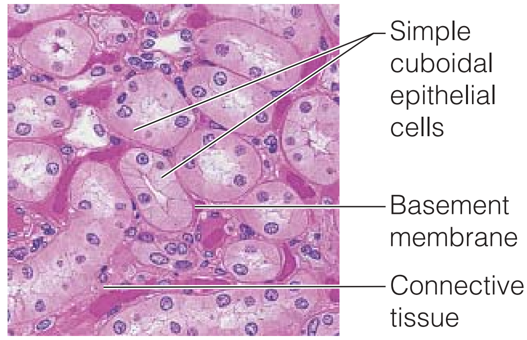
(a) **Diagram:** Simple squamous



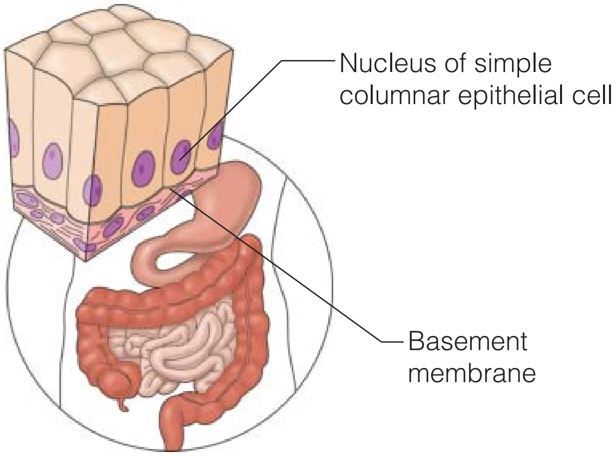
Photomicrograph: Simple squamous epithelium forming part of the alveolar (air sac) walls (400x).



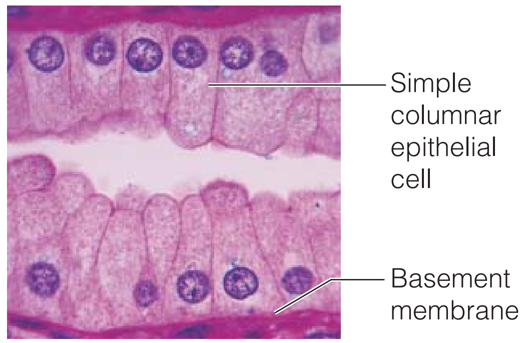
(b) **Diagram:** Simple cuboidal



Photomicrograph: Simple cuboidal epithelium in kidney tubules (400x).

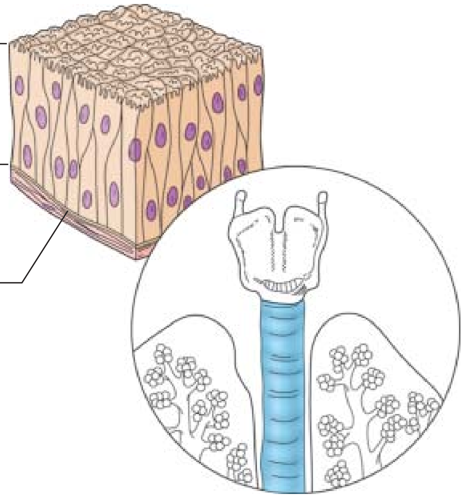


(c) **Diagram:** Simple columnar

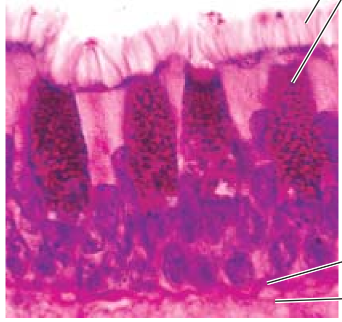


Photomicrograph: Simple columnar epithelium of the stomach lining (1300x).

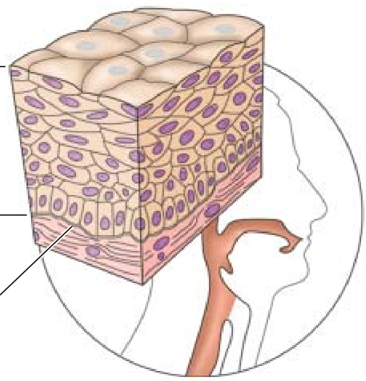
FIGURE 3.18 Types of epithelia and their common locations in the body.



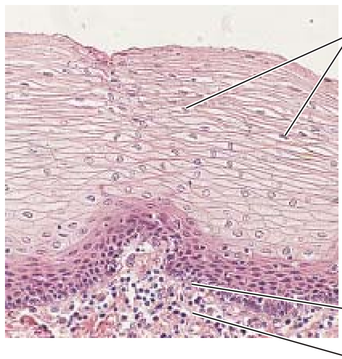
(d) Diagram: Pseudostratified (ciliated) columnar



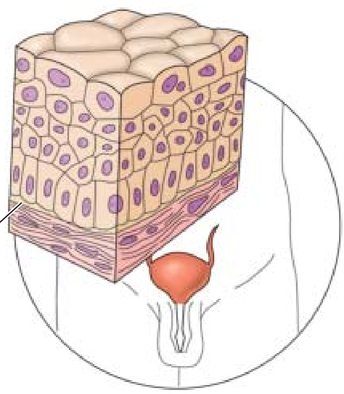
Photomicrograph: Pseudostratified ciliated columnar epithelium lining the human trachea (400x).



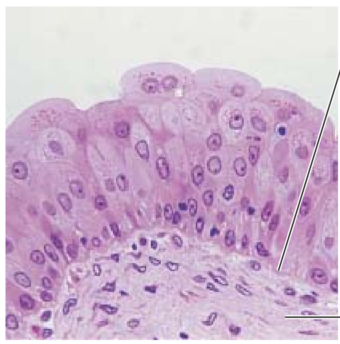
(e) Diagram: Stratified squamous



Photomicrograph: Stratified squamous epithelium lining of the esophagus (300x).



(f) Diagram: Transitional



Photomicrograph: Transitional epithelium lining of the bladder, relaxed state (500x); note the bulbous, or rounded, appearance of the cells at the surface; these cells flatten and become elongated when the bladder is filled with urine.

squamous epithelium is found in sites that receive a good deal of abuse or friction, such as the esophagus, the mouth, and the outer portion of the skin (Figure 3.18e).

Stratified Cuboidal and Stratified Columnar Epithelia **Stratified cuboidal epithelium** typically has just two cell layers with (at least) the surface cells being cuboidal in shape. The surface cells of **stratified columnar epithelium** are columnar cells, but its basal cells vary in size and shape. Both of these epithelia are fairly rare in the body, being found mainly in the ducts of large glands. (Because the distribution of these two epithelia is extremely limited, they are not illustrated in Figure 3.18. They are described here only to provide a complete listing of the epithelial tissues.)

Transitional Epithelium **Transitional epithelium** is a highly modified, stratified squamous epithelium that forms the lining of only a few organs—the urinary bladder, the ureters, and part of the urethra. *All* these organs are part of the urinary system and are subject to considerable stretching (Figure 3.18f). Cells of the basal layer are cuboidal or columnar; those at the free surface vary in appearance. When the organ is not stretched, the membrane is many-layered, and the superficial cells are rounded and domelike. When the organ is distended with urine, the epithelium thins, and the surface cells flatten and become squamous-like. This ability of transitional cells to slide past one another and change their shape (undergo "transitions") allows the ureter wall to stretch as a greater volume of urine flows through that tube-like organ. In the bladder, it allows more urine to be stored.

Glandular Epithelium

A **gland** consists of one or more cells that make and secrete a particular product. This product, called a **secretion,** typically contains protein molecules in an aqueous (water-based) fluid. The term *secretion* also indicates an active *process* in which the glandular cells obtain needed materials from the blood and use them to make their secretion, which they then discharge.

Two major types of glands develop from epithelial sheets. **Endocrine** (en′do-krin) **glands** lose their connection to the surface (duct); thus they are often called *ductless* glands. Their secretions (all hormones) diffuse directly into the blood vessels that weave through the glands. Examples of endocrine glands include the thyroid, adrenals, and pituitary.

Exocrine (ek′so-krin) **glands** retain their ducts, and their secretions empty through the ducts to the epithelial surface. Exocrine glands, which include the sweat and oil glands, liver, and pancreas, are both internal and external. They are discussed with the organ systems to which their products are related.

Connective Tissue

Connective tissue, as its name suggests, connects body parts. It is found everywhere in the body. It is the most abundant and widely distributed of the tissue types. Connective tissues perform many functions but they are primarily involved in *protecting, supporting,* and *binding together* other body tissues.

Common Characteristics of Connective Tissue

The characteristics of connective tissue include the following:

- Variations in blood supply. Most connective tissues are well *vascularized* (that is, they have a good blood supply), but there are exceptions. Tendons and ligaments have a poor blood supply, and cartilages are avascular. Consequently, all these structures heal very slowly when injured. (This is why some people say that, given a choice, they would rather have a broken bone than a torn ligament.)
- Extracellular matrix. Connective tissues are made up of many different types of cells plus varying amounts of a nonliving substance found outside the cells, called the extracellular matrix.

Extracellular Matrix

The **extracellular matrix** deserves a bit more explanation because it is what makes connective tissue so different from the other tissue types. The matrix, which is produced by the connective tissue cells and then secreted to their exterior, has two main elements, a structureless ground substance and fibers. The *ground substance* of the matrix is composed largely of water plus some adhesion proteins and large, charged polysaccharide molecules. The cell adhesion proteins serve as a glue that allows the connective tissue cells to attach themselves to the matrix fibers embedded in the ground substance. The charged polysaccharide molecules trap water as they intertwine. As the relative abundance of these polysaccharides increases, they cause the matrix to vary from fluid to gel-like to firm to rock-hard in its consistency. The ability of the ground substance to absorb large amounts of water allow it to serve as a water reservoir for the body. Various types and amounts of fibers are deposited in the matrix and form part of it. These include collagen (white) fibers distinguished by their high tensile strength, elastic (yellow) fibers (the key characteristic of which is an ability to be stretched and then recoil), and reticular fibers (fine collagen fibers that form the internal "skeleton" of soft organs such as the spleen), depending on the connective tissue type. The building blocks, or monomers, of these fibers are made by the connective tissue cells and secreted into the ground substance in the extracellular space, where they spontaneously join together to form the various fiber types.

Because of its extracellular matrix, connective tissue is able to form a soft packing tissue around other organs, to bear weight, and to withstand stretching and other abuses, such as abrasion, that no other tissue could endure. But there is variation. At one extreme, fat tissue is composed mostly of cells, and the matrix is soft. At the opposite extreme, bone and cartilage have very few cells and large amounts of hard matrix, which makes them extremely strong. Find the various types of connective tissues in Figure 3.19 as you read their descriptions that follow.

Types of Connective Tissue

As noted above, all connective tissues consist of living cells surrounded by a matrix. Their major differences reflect fiber type and the number of fibers in the matrix. From most rigid to softest, the major connective tissue classes are *bone, cartilage, dense connective tissue, loose connective tissue,* and *blood.*

Bone

Bone, sometimes called *osseous* (os′e-us) *tissue,* is composed of bone cells sitting in cavities called *lacunae* (lah-ku′ne) and surrounded by layers of a very hard matrix that contains calcium salts in addition to large numbers of collagen fibers (Figure 3.19a). Because of its rocklike hardness, bone has an exceptional ability to protect and support other body organs (for example, the skull protects the brain).

Cartilage

Cartilage is less hard and more flexible than bone. It is found in only a few places in the body. Most widespread is **hyaline** (hi′ah-lin) **cartilage,** which has abundant collagen fibers hidden by a rubbery matrix with a glassy (*hyalin* = glass), blue-white appearance (Figure 3.19b). It forms the supporting structures of the larynx, or voice box, attaches the ribs to the breastbone, and covers the ends of bones where they form joints. The skeleton of a fetus is made largely of hyaline cartilage; but, by the time the baby is born, most of that cartilage has been replaced by bone.

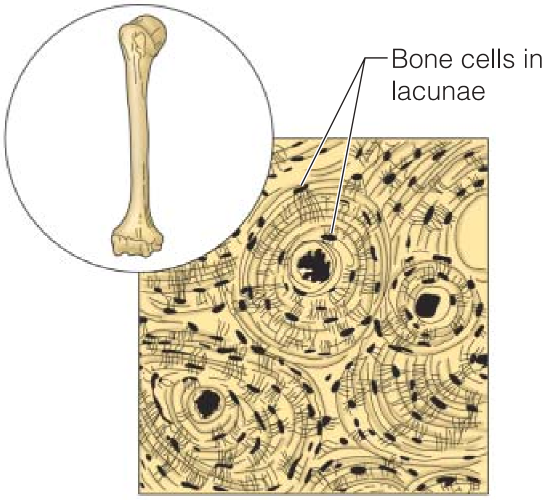
Although hyaline cartilage is the most abundant type of cartilage in the body, there are others. Highly compressible **fibrocartilage** forms the cushionlike disks between the vertebrae of the spinal column (Figure 3.19c). **Elastic cartilage** is found where a structure with elasticity is desired. For example, it supports the external ear. (Elastic cartilage is not illustrated in Figure 3.19.)

Dense Connective Tissue

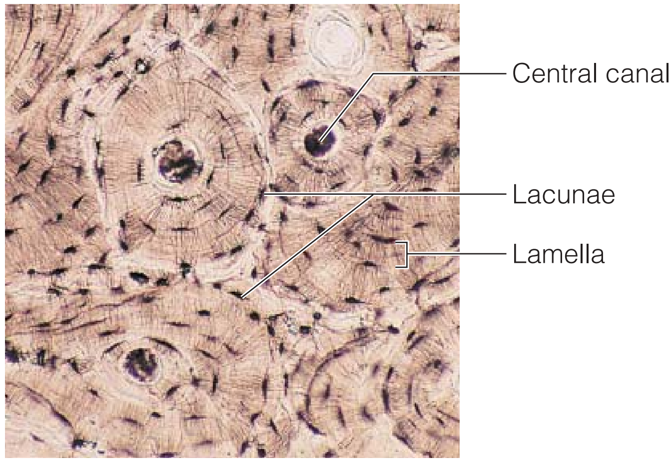
Dense connective tissue, also called **dense fibrous tissue,** has collagen fibers as its main matrix element (Figure 3.19d). Crowded between the collagen fibers are rows of *fibroblasts* (fiber-forming cells) that manufacture the building blocks of the fibers. Dense connective tissue forms strong, ropelike structures such as tendons and ligaments. **Tendons** attach skeletal muscles to bones; **ligaments** connect bones to bones at joints. Ligaments are more stretchy and contain more elastic fibers than tendons. Dense connective tissue also makes up the lower layers of the skin (dermis), where it is arranged in sheets.

Loose Connective Tissue

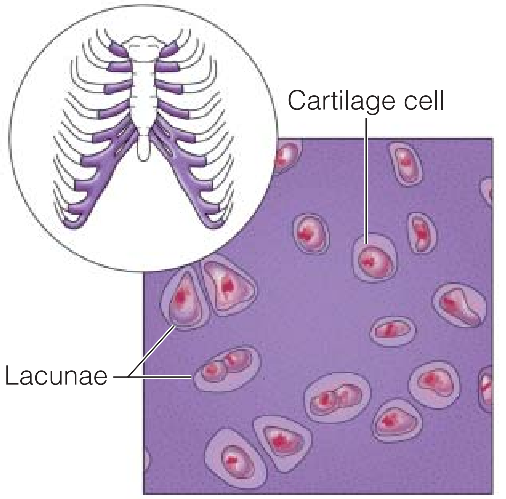
Relatively speaking, the **loose connective tissues** are softer and have more cells and fewer fibers than any other connective tissue type except blood.



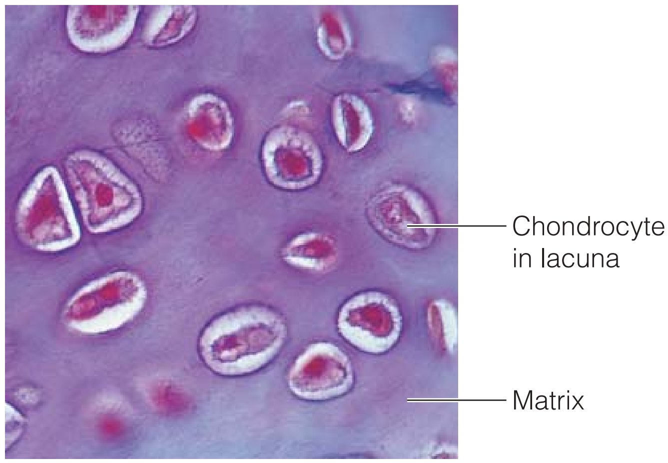
(a) Diagram: Bone



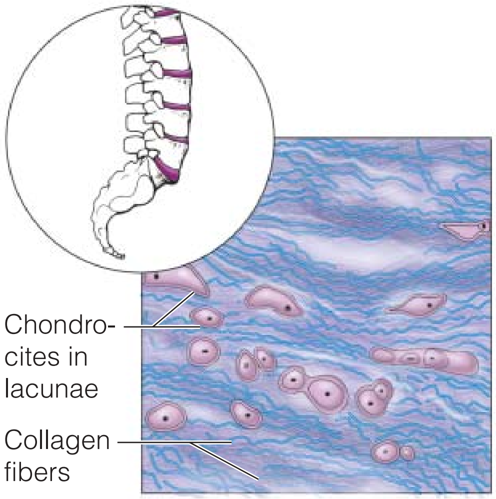
Photomicrograph: Cross-sectional view of ground bone (70x).



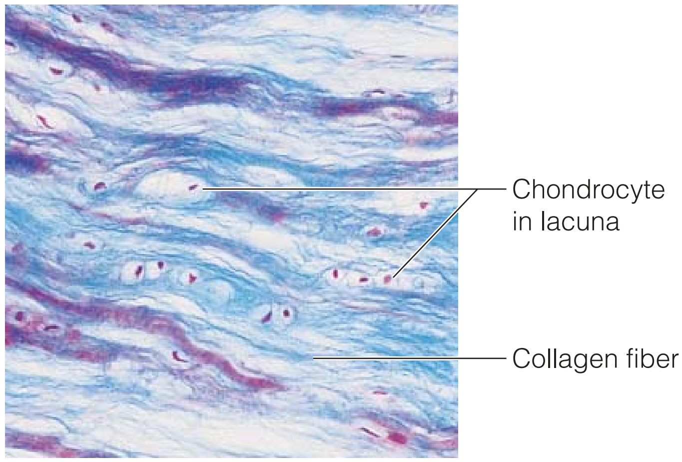
(b) Diagram: Hyaline cartilage



Photomicrograph: Hyaline cartilage from the trachea (300x).

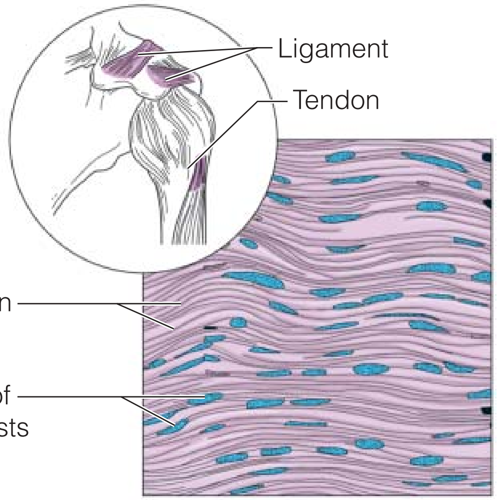


(c) Diagram: Fibrocartilage

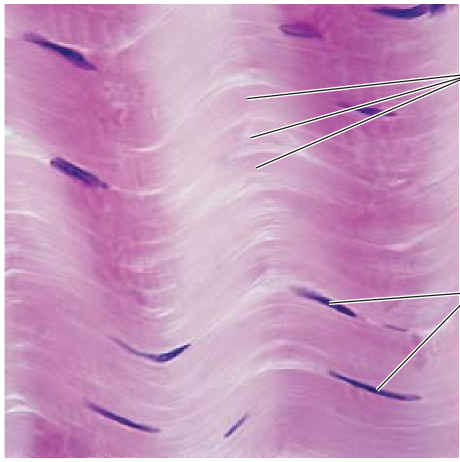


Photomicrograph: Fibrocartilage of an intervertebral disc (200x).

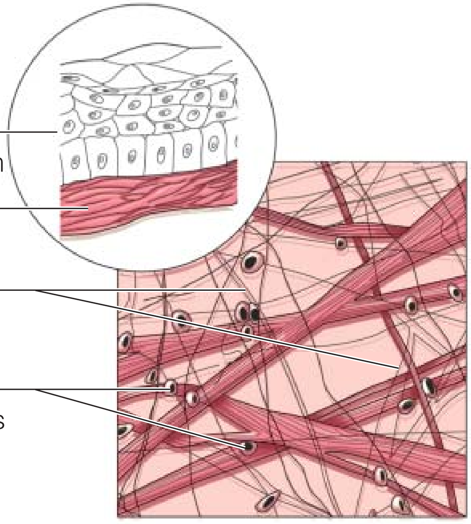
FIGURE 3.19 Connective tissues and their common body locations. (**e, f,** and **g** are subclasses of loose connective tissues.)



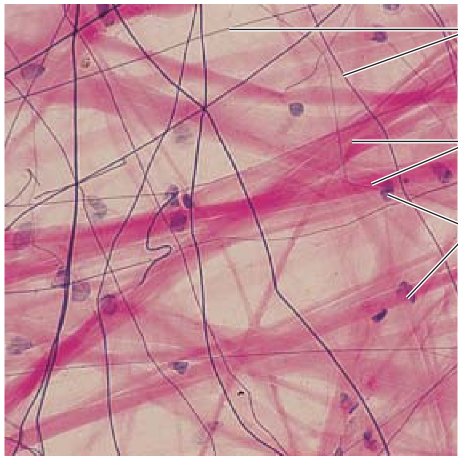
(d) Diagram: Dense fibrous



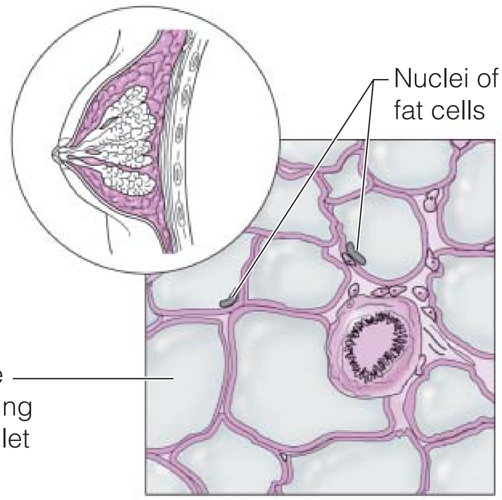
Photomicrograph: Dense fibrous connective tissue from a tendon (1000x).



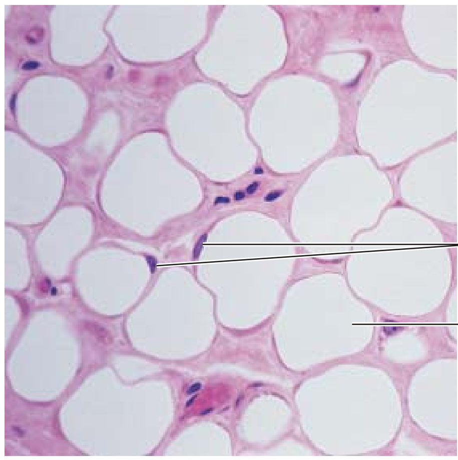
(e) Diagram: Areolar



Photomicrograph: Areolar connective tissue, a soft packaging tissue of the body (400x).

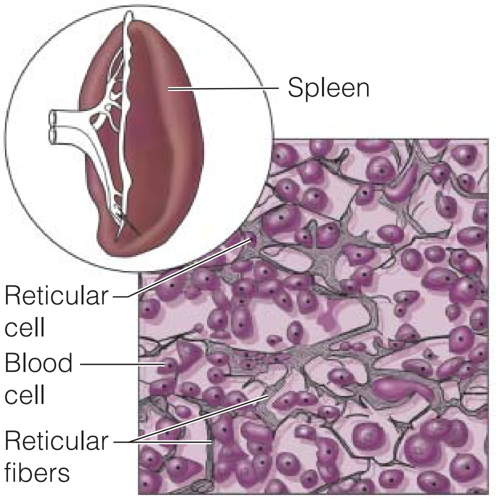


(f) Diagram: Adipose

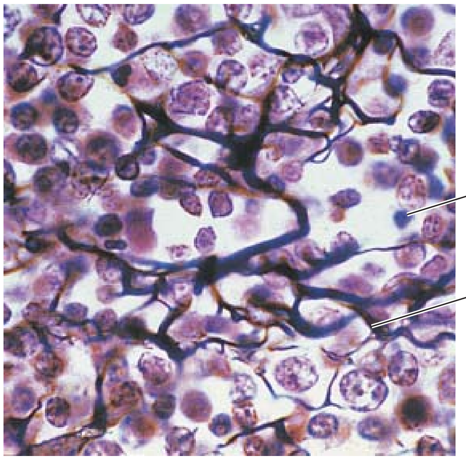


Photomicrograph: Adipose tissue from the subcutaneous layer beneath the skin (600x).

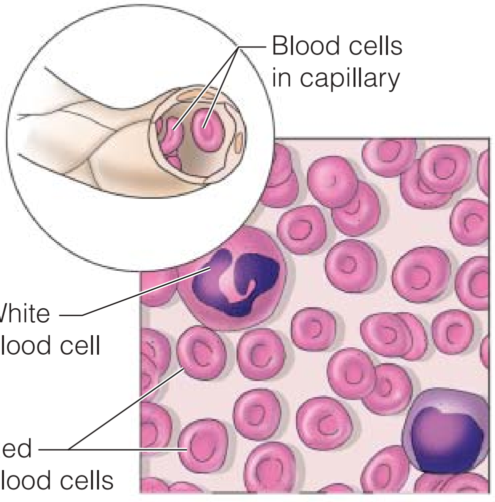
(*Continues on page 94*)



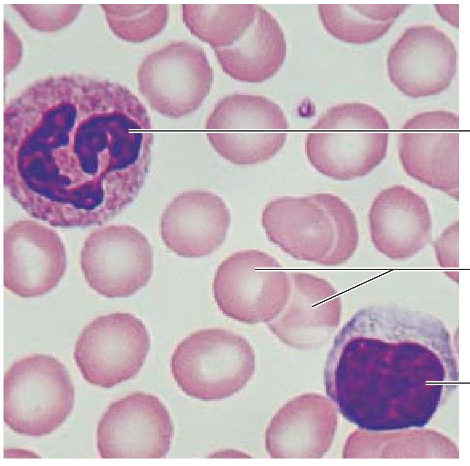
(g) Diagram: Reticular



Photomicrograph: Dark-staining network of reticular connective tissue (350x).



(h) Diagram: Blood



Photomicrograph: Smear of human blood (1500x); two white blood cells are seen among the red blood cells.

FIGURE 3.19 (*continued*) Connective tissues and their common body locations.

Areolar Tissue **Areolar** (ah-re′o-lar) **tissue,** the most widely distributed connective tissue variety in the body, is a soft, pliable, "cobwebby" tissue that cushions and protects the body organs it wraps (Figure 3.19e). It functions as a universal packing tissue and connective tissue "glue" because it helps to hold the internal organs together and in their proper positions. A soft layer of areolar connective tissue called the *lamina propria* (lah′mĭ-nah pro′pre-ah) underlies all mucous membranes. Its fluid matrix contains all types of fibers, which form a loose network. In fact, when viewed through a microscope, most of the matrix appears to be empty space, which explains the name of this tissue type (*areola* = small open space). Because of its loose and fluid nature, areolar connective tissue provides a reservoir of water and salts for the surrounding tissues, and essentially all body cells obtain their nutrients from and release their wastes into this "tissue fluid." When a body region is inflamed, the areolar tissue in the area soaks up the excess fluid like a sponge, and the area swells and becomes puffy, a condition called **edema.** Many types of *phagocytes* wander through this tissue, scavenging for bacteria, dead cells, and other debris, which they destroy.

Adipose Tissue **Adipose** (ad′ĭ-pōs) **tissue** is commonly called *fat*. Basically, it is an areolar tissue in which fat cells predominate (Figure 3.19f). A glistening droplet of stored oil occupies most of a fat cell's volume and compresses the nucleus, displacing it to one side. Since the oil-containing region looks empty and the thin rim of cytoplasm containing the bulging nucleus looks like a ring with a seal, fat cells are sometimes called *signet ring cells*.

Adipose tissue forms the subcutaneous tissue beneath the skin, where it insulates the body and protects it from extremes of both heat and cold. Adipose tissue also protects some organs individually. For example, the kidneys are surrounded by a capsule of fat, and adipose tissue cushions the eyeballs in their sockets. There are also fat "depots" in the body, such as the hips and breasts, where fat is stored and available for fuel if needed.

Reticular Connective Tissue **Reticular connective tissue** consists of a delicate network of interwoven reticular fibers associated with *reticular cells,* which resemble fibroblasts (Figure 3.19g). Reticular tissue is limited to certain sites: it forms the **stroma** (literally, "bed" or "mattress"), or internal framework, which can support many free blood cells (largely lymphocytes) in lymphoid organs such as lymph nodes, the spleen, and bone marrow.

Blood

Blood, or *vascular tissue,* is considered a connective tissue because it consists of *blood cells,* surrounded by a nonliving, fluid matrix called *blood plasma* (Figure 3.19h). The "fibers" of blood are soluble protein molecules that become visible only during blood clotting. Still, we must recognize that blood is quite atypical as connective tissues go. Blood is the transport vehicle for the cardiovascular system, carrying nutrients, wastes, respiratory gases, and many other substances throughout the body. Blood is considered in detail in Chapter 10.

Muscle Tissue

Muscle tissues are highly specialized to *contract,* or *shorten,* to produce movement.

Types of Muscle Tissue

The three types of muscle tissue are illustrated in Figure 3.20. Notice their similarities and differences as you read through the descriptions that follow.

Skeletal Muscle

Skeletal muscle tissue is packaged by connective tissue sheets into organs called *skeletal muscles,* which are attached to the skeleton. These muscles, which can be controlled *voluntarily* (or consciously), form the flesh of the body, the so-called muscular system (see Chapter 6). When the skeletal muscles contract, they pull on bones or skin. The result of their action is gross body movements or changes in our facial expressions. The cells of skeletal muscle are long, cylindrical, multinucleate, and they have obvious *striations* (stripes). Because skeletal muscle cells are elongated to provide a long axis for contraction, they are often called *muscle fibers*.

Cardiac Muscle

Cardiac muscle, covered in more detail in Chapter 11, is found only in the heart. As it contracts, the heart acts as a pump and propels blood through the blood vessels. Like skeletal muscle, cardiac muscle has striations, but cardiac cells are uninucleate, relatively short, branching cells that fit tightly together (like clasped fingers) at junctions called **intercalated disks.** These intercalated disks contain gap junctions that allow ions to pass freely from cell to cell, resulting in rapid conduction of the exciting electrical impulse across the heart. Cardiac muscle is under *involuntary control,* which means that we cannot consciously control