CHAPTER 4
Tissue: The Living Fabric

Chapter Outline and Student Objectives

Epithelial Tissue (pp. 101–112)
1. List several characteristics that typify epithelial tissue.
2. Describe the criteria used to classify epithelia structurally.
3. Name and describe the various types of epithelia, indicate their chief function(s) and location(s).
4. Contrast a sheet of covering or lining epithelium with an epithelial membrane. Name and describe the three varieties of epithelial membranes.
5. Compare endocrine and exocrine glands relative to their general structure, product(s), and mode of secretion.
6. Describe how multicellular exocrine glands are classified structurally and functionally.

Connective Tissue (pp. 112–123)
7. Describe common characteristics of connective tissue.
8. List the structural elements of connective tissue and describe each element.
9. Explain the bases for classification of connective tissue.
10. Describe the types of connective tissue found in the body, and note their characteristic functions.

Muscle Tissue (pp. 123–125)
11. Compare and contrast the structures and body locations of the three types of muscle tissue.

Nervous Tissue (p. 125)
12. Note the general characteristics and functions of nervous tissue.

Tissue Repair (pp. 125–127)
13. Describe the process of tissue repair involved in the normal healing of a superficial wound.

Developmental Aspects of Tissue (pp. 127–129)
14. Name the three primary germ layers, and indicate the primary tissue classes arising from each.
15. Briefly mention tissue changes that occur with age. Cite possible causes of such changes.

Preview of Selected Key Terms

Tissue (tissu = woven) A group of similar cells (and their intercellular substance) specialized to perform a specific function; primary tissue types of the body are epithelial, connective, muscle, and nervous tissue.

Epithelial (eh'-pih-the'-lè-ul) (epi = upon, over; thel = delicate) Pertaining to a primary tissue that covers the body surface, lines its internal cavities, and forms glands.

Gland One or more cells specialized to secrete a particular product called a secretion.

Mesenchyme (meh'-zin-kim) Common embryonic tissue from which all connective tissues arise.

Matrix Specialized extracellular substance secreted by connective tissue cells that determines the specialized function of each connective tissue type; typically includes ground substance (fluid to hard) and fibers (collagen, elastic, and/or reticular).

Fibroblast/fibrocyte (blast = bud, forming; cyte = cell) The fibroblast is a young, actively mitotic cell that forms the fibers of connective tissue; in its mature state, it becomes a fibrocyte, which maintains the matrix.

Chondroblast/chondrocyte The actively mitotic and mature cell forms, respectively, of cartilage.

Osteoblast/osteocyte The actively mitotic and mature cell forms, respectively, of bone.

Macrophage (ma'-krö-faj') (macro = large; phago = eat) A protective cell type common in connective tissue, lymphatic tissue, and certain body organs that phagocytizes tissue cells, bacteria, and other foreign debris.

Germ layers Three cellular layers (ectoderm, mesoderm, and endoderm) that represent the initial specialization of cells in the embryonic body and from which all body tissues arise.

Cells that exist as isolated unicellular (one-cell) organisms, such as amoebas, are rugged individualists. They alone obtain and digest their food, carry out
gas exchange, and perform all the other activities necessary to keep themselves alive and healthy. But in the multicellular human body, cells do not operate independently or in isolation. Instead, they form tight, interdependent cell communities that function cooperatively. Individual cells are specialized, with each type performing specific functions that help maintain homeostasis and benefit the body as a whole. The specialization of our cells is obvious: Muscle cells look and function quite differently from skin cells, which in turn are easily distinguished from cells of the brain.

Cell specialization allows the various parts of the body to function in very sophisticated ways, but this division of labor also has certain hazards. When a particular group of cells is indispensable, its loss can severely disable or even destroy the body.

Groups of closely associated cells that are similar in structure and perform a common function are called tissues (tissu = woven). There are four primary tissue types that interweave to form the "fabric" of the body: epithelial, connective, muscle, and nervous tissue, and each has several subdivisions or varieties. 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 protection (epithelial), support (connective), movement (muscle), and control (nervous). However, these terms reflect only a small part of the total tissue functions.

As explained in Chapter 1, tissues are organized into organs such as the kidneys and the heart. Most organs contain several tissue types, and the arrangement of the tissues determines the organ's structure and what it is able to do. The study of tissues, or histology, complements the study of gross anatomy. Together they provide the structural basis for understanding organ physiology.

The close correlation between tissue structure and function makes the study of tissues intriguing, but the value of any learning is to increase our ability to perceive relationships and see how things "fit" or work together. Learning the characteristic patterns of each tissue type will allow you to predict the function of an organ once its structure is known, and vice versa.

### Epithelial Tissue

**Epithelial** (eh"-pih-thé'-lë-ul) **tissue**, or **epithelium**, occurs in the body as (1) covering and lining epithelium and (2) glandular epithelium. Covering and lining epithelium is found on free surfaces of the body such as the outer layer of the skin, dipping into and lining the open cavities of the digestive and respiratory systems, lining blood vessels and the heart, and covering the walls and organs of the closed ventral body cavity. Since epithelium forms the boundaries that mark us off from the outside world, nearly all substances received or given off by the body must pass through epithelium. Glandular epithelium fashions the glands of the body.

Epithelium is highly specialized to accomplish many functions, including protection, absorption, filtration, and secretion. Each of these functions will be described in detail as we consider various types of epithelium, but briefly, the epithelium of the skin protects underlying tissues from mechanical and chemical injury and bacterial invasion; that lining the digestive tract is specialized to absorb substances; and that found in the kidneys performs nearly the whole functional "menu"—absorption, secretion, and filtration. Secretion is the chief specialty of glands.

#### Special Characteristics of Epithelium

Epithelial tissues have many characteristics that distinguish them from other tissue types.

1. **Cellularity.** Epithelial tissue is composed almost entirely of cells. In muscle and connective tissues, cells are often widely separated by extracellular matrix. This is not true of epithelium, where cells are close together.

2. **Specialized contacts.** Epithelial cells fit close together to form continuous sheets. Adjacent cells are bound by lateral contacts, including tight junctions and desmosomes (see Chapter 3), which reduce or eliminate the extracellular space between them.

3. **Polarity.** Epithelium always has one free (apical) surface—the portion of the epithelium exposed to the body exterior or the cavity of an internal organ. Some exposed plasma membrane surfaces are smooth and slick; others exhibit cell surface modifications such as microvilli or cilia. Microvilli, fingerlike extensions of the plasma membrane, increase tremendously the exposed surface area and are common in epithelia that absorb or secrete substances (intestinal lining and kidney tubules). Cilia projecting from the epithelial lining of the trachea and certain other internal tracts propel substances along the epithelial surface.

4. **Avascularity (ä"-vas"-kyoo-layr'-ih-të).** Epithelium may be well supplied by nerve fibers but is avascular (has no blood vessels within it). Epithelial cells receive their nourishment by diffusion of substances from blood vessels in the underlying connective tissue layer.

5. **Basement membrane.** Epithelium rests on a thin supporting basal lamina (bä"-zul la'-mih-nuh),
which separates it from the underlying connective tissue. The basal lamina is a nonliving, adhesive material formed largely of glycoproteins secreted by the epithelial cells. The connective tissue cells, just deep to the basal lamina, secrete a similar extracellular material containing fine collagenous or reticular fibers; this layer is called the reticular (rih-‘thih’-koyo-‘ler) lamina. The basal lamina of the epithelium and the reticular lamina of the connective tissue together form the basement membrane. The basement membrane reinforces the epithelial sheet, helping it to resist stretching and tearing forces, and defines the space that may be occupied by the epithelial cells.

An important characteristic of cancerous epithelial cells is their failure to respect this boundary, which they penetrate to invade the tissues beneath.

6. Regeneration. Epithelium has a high regenerative capacity. Some epithelia are exposed to friction, and their surface cells tend to abrade off; others are damaged by hostile substances (bacteria, acids, smoke) in the external environment and die. As long as epithelial cells receive adequate nutrition, they are able to replace lost cells rapidly by cell division.

Classification of Epithelia

The many types of epithelia are identified structurally according to two criteria: the shape of the cells and the number of cell layers present (Figure 4.1). All epithelial cells are irregularly polyhedral (many-sided) in cross section, but differ in cell height. On the basis of height, there are three common shapes of epithelial cells. Squamous (skwá’-mus) cells are (many-sided) in cross section, but differ in cell height. Wide; and columnar (kuh-lum’-nur) cells are tall and column-shaped. In each case, the shape of the nucleus conforms to that of the cell. The nucleus of a squamous cell is thin and flattened; that of a cuboidal cell is spherical; and a columnar cell nucleus is elongated from top to bottom and is usually located close to the cell base. Nuclear shape is an important structural characteristic to keep in mind when you attempt to distinguish epithelial types.

On the basis of cell arrangement (layers), there are two major varieties of epithelium: simple and stratified. Simple epithelia are composed of a single layer of cells. Simple epithelia are typically found where selective absorption and filtration occur and where the thinness of the barrier helps to speed the process. Stratified epithelia consist of multiple cell layers stacked one on top of the other. They are typically found in high abrasion areas, where protection is important, such as the skin surface and the lining of the mouth.

The terms denoting shape and arrangement of epithelial cells are combined to describe epithelia fully, as shown in Figure 4.2. There are four major classes of simple epithelia: simple squamous, simple cuboidal, simple columnar, and a highly modified simple epithelium called pseudostratified (pseudo = false).

There are also four major classes of stratified epithelium: stratified squamous, stratified cuboidal, stratified columnar, and a modified stratified squamous epithelium called transitional epithelium. In terms of body distribution and abundance, only stratified squamous and transitional epithelia are significant. Stratified epithelia are named according to the shape of the cells at the free surface, not according to deeper cell types. For example, the surface cells of stratified squamous epithelium are squamous cells, but its basal cells are cuboidal or columnar.

As you read the descriptions of the individual epithelial classes and compare these descriptions with the illustrations in Figure 4.2, keep in mind that tissues are three-dimensional, but that their structure is studied using stained tissue sections mounted on slides and viewed through the microscope. Therefore, a cross-sectional view will differ from a longitudinal view of the same tissue. Depending on the precise plane of the cut made when tissue slides are prepared, the nucleus of a particular cell may or may not be visible, and (frustratingly) the boundaries between epithelial cells are often indistinct.

Simple Epithelia

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

Simple Squamous Epithelium. The cells of a simple squamous epithelium are flattened laterally, and their cytoplasm is sparse (Figure 4.2a). When viewed from the surface, the close-fitting cells resemble a tiled floor; when cut perpendicular to their free surface, the cells resemble fried eggs seen from the side, with their cytoplasm wisping out from the slightly bulging nucleus. Thin and often permeable, this epithelium is found where filtration or the exchange of substances by diffusion is a high priority. Capillary walls, through which exchanges occur between the blood and tissue cells, are composed exclusively of a simple squamous epithelium. In the kidneys, simple squamous epithelium forms part of the filtration membrane; in the lungs, it forms the walls of the air sacs across which gas exchange occurs. Mesothelium (meh-‘zo-thë-‘le-‘um) is the name given to the simple squamous epithelium lining the ventral body cavity and covering its organs.
Simple Cuboidal Epithelium. Simple cuboidal epithelium consists of a single layer of cubical cells (Figure 4.2b). When viewed microscopically, the spherical nuclei stain darkly, causing the layer to look like a string of beads. Important functions of simple cuboidal epithelium are secretion and absorption. In glands, it forms both the secretory portions and the ducts that deliver secretions to their destinations. The simple cuboidal epithelium in the kidney tubules has dense microvilli, betraying its active role in absorption.

Simple Columnar Epithelium. Simple columnar epithelium is seen as a single layer of tall, closely packed cells, aligned like soldiers in a row (Figure 4.2c). Columnar cells are most associated with absorption and secretion. Cells actively involved in secretion have an elaborate Golgi apparatus and usually abundant rough endoplasmic reticulum. This epithelial type lines the digestive tract from the stomach to the rectum. The digestive tract lining has two distinct modifications that reflect its dual function: (1) dense microvilli on the surface of absorptive cells and (2) goblet cells that secrete a protective lubricating mucus. The goblet cells contain "cups," or goblets, of mucus that occupy most of the apical cell volume (see Figure 4.4).

Some simple columnar epithelia display cilia on their free surfaces. This more unusual variety, called simple columnar ciliated epithelium, lines the oviducts and limited areas of the respiratory tract.

Pseudostratified Columnar Epithelium. The cells of pseudostratified (soo'-dō-stra'-tih-fid) columnar epithelium are varied (Figure 4.2d). All of its cells rest on the basement membrane, but some are shorter than others and, as seen in the figure, may not reach the surface of the cell layer. Their nuclei vary in shape and are seen at different levels above the basement membrane, giving the false impression that several cell layers are present. This epithelium may contain goblet cells and is often ciliated, in which case, the epithelium is more precisely called pseudostratified columnar ciliated epithelium. Both cilia and goblet cells are found in the pseudostratified epithelium that lines most of the respiratory tract. The mucus produced traps inhaled dust and other debris, and the cilia act to propel it away from the lungs.

Stratified Epithelia

Stratified epithelia consist of two or more cell layers. Considerably more durable than the simple epithelia, their major (but not their only) function is protection.

Stratified Squamous Epithelium. Stratified squamous epithelium is the most widespread stratified epithelium (Figure 4.2e). Composed of several layers, it is thick and well suited for its protective role in the body. Its free surface cells are squamous; cells of the deeper
layers are cuboidal or, less commonly, columnar. This epithelium is found in areas subjected to wear and tear, and its surface cells are constantly being rubbed away and replaced by mitotic division of the cells of its basal layer. Since epithelium depends on diffusion of nutrients from a deeper connective tissue layer, the epithelial cells farthest from the basement membrane are less viable, and those at the free apical (outer) surface are flattened and atrophied.

Stratified squamous epithelium covers the tongue and lines the mouth, pharynx, esophagus, anal canal, and vagina. A modified form of this tissue, keratinized (keh’-ruh-tin-nizd”) stratified squamous epithelium, forms the outer layer, or epidermis, of the skin. The surface of the epidermis consists of dead cells filled with keratin, a waterproofing protein. The epidermis, which provides a tough yet resilient covering for the body surface, is discussed in Chapter 5.

Stratified Cuboidal Epithelium. Generally formed of only two cell layers, stratified cuboidal epithelium has a very limited distribution in the body (Figure 4.2f). It is found primarily in the ducts of sweat glands and other large glands.

Stratified Columnar Epithelium. True stratified columnar epithelium is rare. Its specific locations are listed in Figure 4.2g. Its free surface cells are columnar; those in deeper layers are small and vary in shape.

Transitional Epithelium. Transitional epithelium forms the lining of urinary organs, which are subjected to considerable stretching and varying internal pressure (Figure 4.2h). Cells of its basal layer are cuboidal or columnar; those at the free surface vary in appearance, depending on the degree of distension of the organ. 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, fewer cell layers are obvious, and the surface cells become flattened and squamouslike. This ability of transitional cells to slide past one another and change their shape accommodates the increasing surface area of a stretching ureter wall as a greater volume of urine flows through the organ; in the bladder, it allows more urine to be stored. Additionally, transitional epithelium appears to have the ability to resist osmotic forces that would act to dilute hypertonic urine stored in the bladder.

Covering and Lining Epithelia

Classification of epithelia by cell type and arrangement allows each epithelium to be described individually and with precision. However, it reveals nothing about the tissue’s body location. In this section, we will describe the covering and lining epithelia using terms that indicate their special locations in the body and/or denote general functional qualities. According to this scheme, there are endothelium and the more complex epithelial membranes.

Endothelium

An endothelium (en-dō-thē’-li-um) is a simple epithelial sheet composed of a single layer of squamous cells attached to a basement membrane. Endothelium provides a slick, friction-reducing lining in all hollow circulatory system organs—lymphatic vessels, blood vessels, and the heart (Figure 4.3a). Capillary walls consist only of endothelium, which, because of its permeability and extreme thinness, encourages the exchange of nutrients and wastes across capillary walls.

Epithelial Membranes

There is tremendous variety in the way the term epithelial membrane is used. Here, epithelial membrane is defined as a continuous multicellular sheet composed of at least two primary tissue types: an epithelium bound to a discrete underlying connective tissue layer. Hence, epithelial membranes can be considered to be simple organs. Most of the covering and lining epithelium take part in forming one of three common types of epithelial membranes: mucous, cutaneous, or serous.

Mucous Membranes. Mucous membranes, or mucosae (myoo-kō’-sē), are epithelial membranes that line body cavities that are open to the exterior, such as those of the digestive, respiratory, and urogenital tracts (Figure 4.3b). In all cases, they are “wet,” or moist, membranes bathed by secretions or, in the case of the urinary mucosa, urine. Notice that the term mucosa refers to the location of the epithelial membrane, not its cell composition, which varies. However, the majority of mucosae contain either stratified squamous or simple columnar epithelia.

Mucous membranes are often adapted for absorption and secretion. Although many mucosae secrete mucus, this is not a requirement. The mucosae of both the digestive and respiratory tracts secrete copious amounts of protective lubricating mucus; that of the urinary tract does not.

All mucosae consist of an epithelial sheet directly underlain by a lamina propria (la’-mih-nuh prō’-prē-uh), a layer of loose connective tissue just deep to the basement membrane. In some, the lamina propria rests on a third (deeper) layer of smooth muscle cells. These variations will be covered in later chapters dealing with the appropriate organ systems.
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Cutaneous Membrane. The cutaneous (kyoo-tä'-nē-us) membrane is your skin (Figure 4.3c). It is an organ consisting of a keratinized stratified squamous epithelium (epidermis) firmly attached to a thick connective tissue layer (dermis). Unlike other epithelial membranes, the cutaneous membrane is exposed to the air and is a dry membrane. Chapter 5 is devoted to this unique organ.

Serous Membranes. Serous membranes, or serosae (suh-rō'-sē), are the moist membranes found in closed ventral body cavities (Figure 4.3d). Each serosa consists of a parietal layer that lines the cavity wall and then reflects back as the visceral layer to cover the outer surface(s) of organs within the cavity. Each of these layers consists of simple squamous epithelium (mesothelium) resting on a tiny amount of loose connective tissue. The mesothelial cells secrete thin, clear serous fluid that lubricates the facing surfaces of the parietal and visceral layers, so that they slide across each other easily. This reduction of friction prevents organs from sticking to the cavity walls and to each other.

The serosae are named according to site and specific organ associations. For example, the serosa lining the thoracic wall and covering the lungs is the pleura; that enclosing the heart is the pericardium; and those of the abdominopelvic cavity and viscera are the peritoneums.
Glandular Epithelia

A gland consists of one or more cells that produce and secrete a particular product. This product, called a secretion, is an aqueous (water-based) fluid, typically containing proteins. Secretion is an active process whereby glandular cells obtain needed substances from the blood and transform them chemically into their secretory product, which is then discharged from the cell. Notice that the term secretion can refer to both the process of secretion formation and release and the product of glandular activity.

Glands are classified as endocrine (en'-duh-krin) or exocrine (ek'-suh-krin), depending on their route of secretion and the general function of their products, and as unicellular or multicellular on the basis of their structure. Most multicellular epithelial glands form by invagination of an epithelial sheet and, at least initially, have ducts connecting them to the epithelial sheet.

Endocrine Glands

Endocrine glands eventually lose their ducts and are often called ductless glands. They produce regulatory chemicals called hormones, which they secrete directly into the extracellular space. The hormones then enter the blood or lymphatic fluid. Since not all endocrine glands are epithelial derivatives, consideration of their structure and function is deferred to Chapter 17.

Exocrine Glands

Exocrine glands are far more numerous than endocrine glands, and many of their products are familiar ones. The multicellular glands secrete their products through a duct onto body surfaces or into body cavities. Exocrine glands are a diverse lot. They include sweat and oil glands, salivary glands, the liver (which secretes bile), the pancreas (which synthesizes digestive enzymes), mammary glands, mucous glands, and many others.

Unicellular Exocrine Glands. Unicellular exocrine glands are single cells interposed in an epithelium between cells with other functions. They have no ducts. In humans, all such glands produce mucin (myoo'-sin), a complex glycoprotein that dissolves in water. Once dissolved, mucin forms a slimy coating (mucus) that both protects and lubricates surfaces. Unicellular glands include the goblet cells of the intestinal and respiratory mucosae (Figure 4.4), as well as mucin-producing cells found in other body regions. Although unicellular glands probably outnumber multicellular glands, unicellular glands are the less well-known of the two gland types.

Multicellular Exocrine Glands. Multicellular exocrine glands have three common structural elements: an epithelium-derived duct, a secretory unit, and, in all but the simplest glands, supportive connective tissue that surrounds the secretory unit and supplies it with blood vessels and nerve fibers. Often, the connective tissue forms a fibrous capsule that extends into the gland proper and divides the gland into lobes.

Multicellular glands can be divided into two major categories on the basis of their duct structures. Simple glands have a single unbranched duct, whereas compound glands have a branching or divided duct. The glands can be further described according to the struc...
Figure 4.5 Type of multicellular exocrine glands. Multicellular glands are classified according to duct type (simple or compound) and the structure of their secretory units (tubular, alveolar, or tubuloalveolar).

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<thead>
<tr>
<th>Surface epithelium</th>
<th>Duct</th>
<th>Secretory epithelium</th>
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<tbody>
<tr>
<td>TUBULAR SECRETORY STRUCTURE</td>
<td>ALVEOLAR SECRETORY STRUCTURE</td>
<td>TUBULOALVEOLAR SECRETORY STRUCTURE</td>
</tr>
<tr>
<td>Simple duct structure (duct does not branch)</td>
<td>(a) Simple tubular Example: intestinal glands</td>
<td>(d) Simple alveolar Example: Seminal vesicle glands of the male reproductive system</td>
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<td></td>
<td>(b) Simple coiled tubular Example: sweat glands</td>
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<td></td>
<td>(c) Simple branched tubular Example: stomach (gastric) glands</td>
<td>(e) Simple branched alveolar Example: sebaceous (oil) glands</td>
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<tr>
<td>Compound duct structure (duct branches)</td>
<td>(f) Compound tubular Example: Brunner's glands of small intestine</td>
<td>(g) Compound alveolar Example: pancreas</td>
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<tr>
<td></td>
<td></td>
<td>(h) Compound tubuloalveolar Example: salivary glands</td>
</tr>
</tbody>
</table>

Since multicellular glands secrete their products in different ways, they can also be classified functionally, according to their secretory behavior. Most exocrine glands are merocrine (mayr'-ō-krin) glands, which secrete their products by exocytosis shortly after the products are produced. The secretory cells are not altered in any way. The pancreas, most sweat glands, and salivary glands belong to this class (Figure 4.6b).
Holocrine (hō'-luh-krin) glands accumulate their products within them until the secretory cells rupture. (They are replaced by the division of underlying cells.) Since holocrine gland secretions include the synthesized product plus dead cell fragments (holos = all), you could say that their cells “die for their cause.” Sebaceous (oil) glands of the skin are the only true example of holocrine glands (Figure 4.6a).

Apocrine (a'-puh-krin) glands also accumulate their products, but in this case, accumulation occurs only at the cell apex (just beneath its free surface). Eventually, the apex of the cell pinches off (apo = from, off) and the secretion is released. The cell repairs its damage and repeats the process again and again. The mammary glands and some sweat glands release their secretions by this mechanism (Figure 4.6c).

Connective Tissue

Connective tissue is found everywhere in the body. It is the most abundant and widely distributed of the primary tissues, but its amount in particular organs varies greatly. For example, bone and skin are made up primarily of connective tissue, whereas the brain contains very little.

Connective tissue does much more than connect body parts; it has many forms and many functions. Its chief subclasses are connective tissue proper, cartilage, bone, and blood. Its major functions include binding, support, protection, insulation, and, as blood, transportation of substances within the body. For example, cordlike connective tissue structures connect muscle to bone (tendons) and bones to bones (ligaments), and fine, resilient connective tissue invades soft organs and supports and binds their cells together. Bone and cartilage support and protect body organs by providing hard “underpinnings”; fat cushions, insulates, and protects body organs as well as providing reserve energy fuel.

Common Characteristics of Connective Tissue

Despite their multiple and varied functions in the body, connective tissues have certain common properties that set them apart from other primary tissues:

1. Common origin. All connective tissues arise from mesenchyme, an embryonic tissue derived from the mesoderm germ layer, and hence have a common kinship (Figure 4.7).