Introduction to Anatomy and Physiology

Lesson 1

ASSIGNMENT 1: ANATOMY AND PHYSIOLOGY

Read in your textbook, *Clinical Anatomy and Physiology for Veterinary Technicians,* pages 1–8 and 90–130. Then read Assignment 1 in this study guide.

Your work as a veterinary technician requires that you understand how your patients' bodies are put together and how their organ systems function. A working understanding of animal anatomy and physiology form the foundation of your education as a veterinary technician. *Anatomy* is the study of the structure of the animal body and the relationships among its parts. *Physiology* is the study of how the body functions. Knowledge of an animal's anatomy and physiology is essential in determining which body parts aren't functioning properly when an animal exhibits signs of illness. For example, a dog's cough might be due to an illness in its lungs or heart, but you wouldn't know this unless you had studied anatomy and physiology. The proper treatment for an ill or diseased animal is also based on principles of physiology. Understanding the principles of anatomy and physiology help you

- Monitor and treat animals more effectively
- Perform medical procedures with greater effectiveness and safety for your patients
- Improve your communication with veterinarians and other veterinary technicians and assistants
- Educate clients regarding the care of their pets

Several methods can be used in the study of anatomy and physiology. *Microscopic anatomy* refers to the study of cells and tissues that require a microscope to visualize. *Macroscopic anatomy* refers to the study of structures that can be seen without a microscope and is also referred to as *gross anatomy.*

Anatomy and physiology can also be studied using either a regional or a systemic approach. The *regional* approach involves the study of all structures and their functions in a specific area of the body (i.e., the head), while *systemic* anatomy refers to the study of structures and functions within specific body systems (i.e., nervous system, endocrine system, etc.).

Anatomical Terms

The most basic terms in the study of anatomy are those used to describe the animal's structure. An animal's body is typically divided into various sections called *planes of reference* (see Figure 1-1 on page 3 of your textbook). These planes are positioned in reference to the body's long axis, the spine. The *median plane* divides the animal down the center into equal left and right halves. A body can have only one median plane. *Sagittal planes* divide the body parallel to the median plane. A body can have more than one sagittal plane on the right and left sides.

A *dorsal plane,* which is perpendicular to the median plane, divides the body into two parts, one containing the belly and the other the back. This plane is sometimes referred to as the *frontal plane,* although today that term is usually used only in reference to humans. A *transverse plane* lies perpendicular (at a right angle) to both the median plane and the frontal plane. The transverse plane divides the body into two sections—one containing the head and the other the tail. Multiple transverse planes starting at the head and running to the tail can exist, essentially making slices through the long axis of the animal's body.

In describing four-legged patients, the plane that divides the limb into cross sections or slices is generally described as the transverse plane of a limb. Other important anatomical terms to master are the directional terms that describe the placement of various body parts in relation to each other.

1. The term *cranial* means closer to the head, whereas *caudal* means closer to the tail. However, when describing regions within the head itself, you can't use the term "cranial," because the entire head is the reference point for that term. Instead, the term *rostral* is used to refer to parts of the head that are closer to the tip of the nose.

2. *Dorsal* means closer to the back or spine. *Ventral* is the opposite of dorsal, and it means nearer to the side of the animal that's closest to the ground.

3. The term *lateral* refers to a position farther away from the median plane (toward the side—either left or right), whereas the term *medial* refers to a position closer to the median plane (which goes through the spine [i.e., center of the body]).

4. *Anterior* means in front of or in the forward part of an organ (i.e., the side you see when you stand face to face with an animal). *Posterior* is the opposite of anterior; it refers to a position or surface toward the rear of the animal. When describing the surfaces of the legs or feet, *anterior* refers to the side you see when you stand face to face with an animal. *Posterior* refers to the surface of the limb that you see when you face the rear of the animal.

5. *Proximal* refers to a body part's being closer to the main portion of the body, whereas *distal* describes a body part that's placed farther out from the main portion of the body. *Proximal* and *distal* are usually used to describe a position on an extremity (limb or tail). In the case of organs where some substance flows in only one direction within that organ (such as the intestines, where food flows away from the mouth and toward the anus), *proximal* means closer to the origin of flow; *distal* means closer to the destination of flow.

6. *Superficial* refers to a position that's located toward the surface of a structure, whereas the term *deep* refers to a position located toward the center of a structure.

7. In the special case of the gastrointestinal system, *orad* refers to movement within the gastrointestinal system in the direction of the mouth, whereas *aborad* describes motion in the direction away from the mouth. Here are examples of the use of directional terms.

   - A dog's heart is closer to the head than is the stomach, so the heart is said to be *cranial* to the stomach, whereas the stomach is said to be *caudal* to the heart.
   - A dog's eye is *rostral* to its ear.
   - The kidneys lie closer to the spine than the stomach, so the kidneys are *dorsal* to the stomach, and the stomach is *ventral* to the kidneys.
   - The foreleg is positioned farther from the median plane than the chest, so the foreleg is *lateral* to the chest wall, and the chest wall is *medial* to the foreleg.
   - The *anterior* chamber of the eye is in front of the *posterior* chamber of the eye, with the two areas being separated by the iris (i.e., the colored part of the eye).
   - The paw is *distal* to the shoulder, and the shoulder is *proximal* to the paw.
   - The skin is *superficial* to the underlying muscle; the muscle is *deep* to the skin.
   - The stomach is *orad* to the intestines, which are *aborad* to the stomach.

Symmetry

One feature common to mammals is bilateral symmetry. *Symmetry* refers to the balance in the distribution of body parts. In animals that exhibit *bilateral symmetry,* the organism's left and right halves are approximate mirror images of each other. Contrast that to a starfish or most flowers, which have *radial symmetry,* meaning their axis of symmetry is around a central point.

Body Cavities

Animals have two main body cavities, the dorsal and ventral cavities, which separate the internal organs into different compartments. The *dorsal body cavity* contains the central nervous system and is subdivided into a cranial cavity and a spinal cavity. The *cranial cavity* is formed from the bones of the skull and contains the brain. The *spinal cavity* is formed from the vertebra and contains the spinal cord. The *ventral body cavity* is also subdivided into two compartments—the thorax and the abdomen. The thoracic and abdominal cavities are separated by the diaphragm. The *thoracic cavity* contains the heart, lungs, and esophagus. The thorax and the organs within it are all covered by a thin membrane called the *pleura,* and the thoracic cavity is therefore sometimes called the *pleural cavity.*

The *abdominal cavity* contains all the organs of the reproductive and urinary systems as well as the stomach and intestinal tract. This cavity and the organs it contains are lined by a membrane called the *peritoneum,* and the abdominal cavity is sometimes called the *peritoneal cavity.*

Taxonomy

Although a thorough discussion of taxonomy is beyond the scope of a veterinary technology course, it's useful to have some understanding of the way in which animals are classified and named. *Taxonomy* is the systematic classification and naming of organisms. Animals are grouped together based on characteristics that they have in common, which are presumed to reflect their evolutionary relationships. The major taxonomic categories, from largest to smallest, are kingdom, phylum, class, order, family, genus, and species.

Most of the patients in veterinary hospitals belong in the phylum Chordata, subphylum Vertebrata (i.e., animals with backbones). Amphibians, reptiles, birds, and mammals all belong in the phylum Chordata, subphylum Vertebrata. However, these four animal groups make up four different classes within the phylum. Members of these different classes have substantial differences in the anatomy and physiology of their organ systems. For example, reptiles have hearts with only three chambers, and birds have a complex system of air sacs associated with their lungs.

In this course, we'll focus mainly on the members of the class Mammalia (mammals). All mammals have certain characteristics in common. They all have hair, mammary glands that secrete milk, four-chambered hearts, seven cervical vertebrae in their necks, and a muscle called a *diaphragm* that separates the abdominal cavity from the chest cavity. Mammals belong to several different *orders* and are grouped together based in large part on the presence of shared anatomical and physiological characteristics:

Order Carnivora—Includes meat eaters, such as dogs and cats

Order Artiodactyla—Includes the even-toed hoofed mammals, like pigs, cows, sheep, and goats (two hooves per limb)

Order Perissodactyla—Includes the odd-toed hoofed mammals, like horses (one hoof per limb)

Order Rodentia—Includes rats, mice, hamsters, and squirrels

Order Lagomorpha—Includes rabbits and hares

Within each order, animals are placed into *families,* which again reflect similarity of structure and a presumed common evolutionary history. Dogs are in the family Canidae, whereas cats are in the family Felidae. Each family is further subdivided into smaller groups called *genera* (singular, *genus*). Each genus is made up of related species.

A *species* is a group of individuals that can interbreed with each other. Each species is given a scientific name, which is composed of two words. The first word in the name is the genus to which the animal belongs; this word is capitalized. The second part of the name is the species; this word isn't capitalized. The scientific name (i.e., combination of genus and species names) is always italicized. The scientific names of the dog, cat, and horse are *Canis familiaris, Felis domesticus,* and *Equus caballus,* respectively.

Your study of anatomy and physiology will focus primarily on mammals. Information on birds, reptiles, and amphibians are included so that you may become familiar with some of the unique features of these species.

The Body's Organization

Almost every animal has the same basic organizational pattern. Starting from the smallest unit and moving to the larger body parts, the levels of organization include cells, tissues, organs, and organ systems. The more complex the animal, the more complicated the organization, but the framework is essentially the same.

Cells

The most basic structure of life is the *cell*. Think of the cell as a building block. If you put enough cells together, you can build an entire animal. Some living things, such as bacteria, are composed of only one cell. Other living things are composed of thousands of cells. Individual cells are so small that most can't be seen by the naked eye. Cells are so small because they're limited by physical restrictions on the strength of their components as well as the distance chemicals must travel inside them. Groups of similar cells that serve a common function are organized into tissues. *Organs* are composed of groups of tissues that have a common function and work together. *Organ systems* are made up of groups of organs with related functions that interact.

Tissues

The arrangement of cells into tissues increases the speed, efficiency, and ability with which cellular tasks are performed. For example, *myocytes* (i.e., muscle cells) can be thought of as individual members of a tug-of-war team; in like manner, muscle tissue can be thought of as the entire tug-of-war team. The pull of an individual isn't as strong or efficient as the pull of the entire team. In the same way, billions of *enterocytes,* the cells inside the intestinal tract, act together to digest food more quickly and efficiently than any individual enterocyte.

Tissues are often distinguishable by the naked eye. For example, meat is muscle tissue, and the muscle tissue in a steak is fairly distinguishable from the fatty tissue around it. When you master some basic anatomy and begin to observe surgeries, you'll find that you'll often be able to distinguish many body tissues. The branch of anatomy that deals with the microscopic structure and composition of tissues is called *histology.* Samples of tissues removed in surgery are often sent off for analysis by a *histopathologist. Histopathology* ("patho" indicates relationship to disease) is the study of both healthy and diseased tissues.

Animals have several types of specialized tissue, although not all animals have all of these tissues (see Box 4-3 on page 128 of your textbook). There are four basic tissue types:

1. Epithelial tissue
2. Connective tissue
3. Muscle tissue
4. Nervous tissue

Epithelial tissue. The first type of tissue, *epithelial tissue,* consists of sheets of cells that cover all of the internal and external surfaces of the body and line all of the body's cavities. Sheets of epithelial cells cover the outer surface of the skin as well as the surfaces of internal organs. Epithelial cells line the digestive tract, urinary tract, and the blood vessels. Some epithelial tissues are specialized to absorb or secrete substances. Epithelial tissue also provides sensory input to other body tissues.

The cells of the epithelium are connected by *cell junctions* (see Figure 4-1 on page 92 of your textbook). There are three types of cellular attachments:

1. *Tight junctions* prevent substances from leaking across the tissue.
2. *Adhering junctions* cement neighboring cells together.
3. *Gap junctions* are open channels between the cytoplasm of adjoining cells.

Epithelial tissues can be categorized according to their shape—*squamous, cuboidal,* or *columnar* (see Figure 4-3 on page 95 of your textbook). Epithelial tissues can also be classified according to their configuration. *Simple epithelium* is a single layer of cells. Multiple layers of epithelial cells characterize *stratified epithelium.*

The surfaces of epithelial cells differ depending on the function of the tissue. Some epithelial cells have irregular surfaces that are covered with many fingerlike projections, called *microvilli.* Those projections serve to increase the surface area of the cell and enhance the cell's ability to absorb or secrete. These types of specialized epithelial cells are common in the digestive and urinary tracts. Other specialized surface projections include *cilia.* These hairlike projections are common on epithelial cells in the respiratory and urogenital tracts, where they serve to aid in transport of materials (see Figure 4-2 on page 93 of your textbook).

Some epithelial tissues are specialized to form *glands* that manufacture and secrete substances such as sweat and hormones. Glands are classified in many ways depending on the structure and function. The majority of the glands present in most animals are *multicellular exocrine glands.* They secrete their products into ducts. *Endocrine glands* are those that secrete their products directly into the blood and lymph vessels.

Multicellular exocrine glands are classified according to the shape of the secreting ducts (branched or unbranched), the shape of their secretory portion (tubular, acinar, or tubuloacinar), the manner in which the secretion is released (merocrine, apocrine, or holocrine), and the type of secretion they produce (mucoid or serous) (see Table 4-1 on page 105 and Figure 4-15 on page 106 of your textbook).

Connective tissue. Perhaps the most diverse group of animal tissues is *connective tissue.* The classification feature unique to this group is that all connective tissues consist of cells embedded in a nonliving matrix. Connective tissues function to bind and support the organism and its body systems. There are six types of connective tissue:

1. Cartilage
2. Bone
3. Fibrous connective tissue
4. Loose connective tissue
5. Adipose tissue
6. Blood

Cartilage cells (chondrocytes) are embedded in a matrix of collagen. Cartilage makes up most of the respiratory passages and is also found in ears. *Bone cells (osteocytes)* are also embedded in a matrix of collagen and minerals and form the skeleton of an organism. *Fibrous* and *loose connective tissues* are both embedded in a matrix of elastin and collagen; these two classifications of connective tissue differ primarily in the arrangement and density of the matrix. Loose connective tissue underlies the skin. Fibrous connective tissue forms tendons and ligaments. *Adipose tissue* is embedded in a lipid matrix. Adipose tissue cells store fat and have a wide distribution in organisms. *Blood* represents a unique type of connective tissue in that the cells aren't embedded in a nonliving matrix (i.e., plasma) but are freely flowing through it. The cells contained in blood are the *erythrocytes* (red blood cells), *leukocytes* (white blood cells), and *platelets.*

Box 4-2 on page 117 of your textbook summarizes the major types of connective tissues.

Membranes. In many parts of the body, connective and epithelial tissues are linked to form structures called *membranes.* Membranes function to cover surfaces, line cavities, and separate organs. The four common types of membranes (see Figure 4-27 on page 118 of your textbook) are

1. Mucous
2. Serous
3. Cutaneous
4. Synovial

Mucous membranes line the organs of the reproductive, urinary, and respiratory tract systems. Mucous membranes consist of an epithelial tissue layer of either simple or stratified epithelial cells, a loose connective tissue layer called the *lamina propria,* and a second connective tissue layer called the *submucosa.* As the name suggests, mucous membranes are capable of producing large amounts of mucus. Mucus contains water, electrolytes, antibodies, and the protein mucin. Mucus functions to reduce friction in the digestive system and entrap particles in the respiratory system. The mucous membranes of the digestive tract are capable of both absorption and secretion.

Serous membranes line the organs within the thoracic, abdominal, and pelvic cavities. The membrane is composed of a sheet of simple squamous epithelial cells that's folded onto itself, forming a double layer. The layer closest to the organ is called the *visceral layer;* the layer closest to the body cavity is the *parietal layer.* Each layer has a thin coating of serous fluid that reduces friction between the cavities and organs. In the abdominal and pelvic cavities, the visceral layer of the serous membranes becomes merged to form supportive ligaments known as the *mesenteries.* These ligaments function to secure organs to the body wall.

Cutaneous membranes are also referred to as the *integument,* which is considered to be an organ system.

Synovial membranes line the joint cavities and are composed only of loose connective and adipose tissue. These membranes produce *synovial fluid,* which reduces friction in the joint spaces.

Muscle tissue. The third type of tissue, *muscle tissue,* consists of specialized cells that can shorten to produce movement when stimulated. Muscle tissues function in movement, maintenance of posture, and contractile functions. Muscle tissues have many specialized structures that enable contraction. The proteins *actin* and *myosin* are essential parts of contractile mechanisms. There are three types of muscle tissue:

1. Smooth muscle
2. Skeletal muscle
3. Cardiac muscle

(See Figure 4-28 on page 126 of your textbook.)

Smooth muscle composes the walls of the digestive tract. It contracts involuntarily in response to specific stimuli from the nervous system. *Skeletal muscle* attaches to bones and is under voluntary control. *Cardiac muscle* is unique to the heart and allows for the contraction and relaxation of heart tissue that provides for the flow of blood through an organism. Each of these three muscle tissue types is structurally different.

Nervous tissue. Finally, *nervous tissue* contains specialized cells that have the ability to conduct electrical impulses. The cellular subunit of nervous tissue is the *neuron.* The neuron is composed of a *cell body,* an *axon,* and *dendrites* (see Figure 4-29 on page 127 of your textbook). Nervous tissue makes up the peripheral and central nervous system. Although some types of nervous tissue are capable of regeneration if damaged, most types don't have this capability. Nervous tissues are also specialized in other ways that provide protection from damage and disease (e.g., the specialized membranes and bones that surround the brain).

Tissue Healing and Repair

When any body tissue is injured, a series of events known as the *inflammatory response* occurs as the body attempts to limit further damage. Subsequent repair of the damage involves organization and regeneration of lost tissue or formation of scar tissue.

When tissues are initially injured, the body responds with a brief period of *vasoconstriction,* in which the blood vessels narrow and cause a decrease in blood flow to the area. This decreased blood flow aids in the control of hemorrhage in the area. *Vasodilation* (widening of the blood vessels) occurs next and causes blood flow to increase. The area becomes warm and red as a result of this increased blood flow. Plasma rushes into the area, causing swelling of the tissues. Clots begin to form as white blood cells begin to remove cellular debris and any infectious organism that may be present. White blood cells are also involved in the control of the inflammatory response. Eventually, the blood vessels return to normal, and swelling and tenderness subside. When the wound edges separate from one another, granulation tissue forms over the injured area. Formation of granulation tissue is a characteristic of *second-intention healing. Granulation tissue* is composed of collagen fibers permeated with many capillaries. This protects the injured area from further damage and inhibits bacteria and other infectious agents from entering the area. Epithelial cells enter the area and actively divide to form a new layer of epithelium around the granulation tissue. Collagen fibers are continually laid down, and eventually, the injured area is completely filled with scar tissue that functions to close the wounded area.

Minor wounds are closed with a process referred to as *first-intention healing.* Granulation tissue isn't formed, and the wound edges heal quickly. *Third-intention healing* involves extensive tissue loss. It's similar to second-intention healing and involves the formation of granulation tissue. However, the severity of tissue loss results in increased healing time for these types of wounds.

Organs

Organs are structures within the body that are made up of different types of tissues working together. Examples of organs include the liver, kidneys, heart, brain, spleen, and urinary bladder. Most organs contain connective tissue in addition to other tissues. Connective tissue helps bind the tissues within the organ together. Often, an organ contains all four primary tissue types. For example, the intestine is a tubelike structure that's lined by epithelial cells that help break down and absorb nutrients. The intestine also contains muscle fibers that move material within the tube, nervous tissue that stimulates the muscle, and connective tissue that gives the organ structural strength. Likewise, the heart is lined on all of its surfaces by epithelium and contains muscle cells that contract to pump blood, nervous tissue that regulates the heart rate, and tough connective tissue that holds it all together.

The combinations of different functions performed by diverse tissues within the organ are usually complementary, which means each tissue helps the others carry out their tasks. The intestinal tissue previously mentioned carries out the process of digesting and absorbing food. The muscle tissue moves the food along so it reaches all the enterocytes. The enterocytes and myocytes aid each other in the overall process.

Organ Systems

The next level of organization in the body is the organ system. *Organ systems* are collections of organs and structures that cooperate to perform an essential function for the body as a whole. When an animal takes in food, various organs of the digestive system work together to process the food. The food is chewed in the mouth, and then the tongue and the back of the throat are used to swallow. The food moves to the esophagus, which transports it to the stomach, where the food is retained temporarily and partially digested. The food then enters the small intestine, where it's further digested with the aid of the pancreas and liver. Finally, the colon further modifies the remaining food by turning it into waste, which is eventually excreted as stool. So you can see, an act as simple as eating involves the interaction of multiple cells, tissues, and organs working together as the digestive system. The overall function of this organ system involves the breakdown of food into nutrients small enough to be absorbed into the bloodstream and the elimination of wastes.

Later, we'll examine the organ systems one by one, looking at the structure and function of each as well as the relationships among the different organ systems. We'll focus primarily on mammals, but some information on birds, reptiles, and amphibians will be included so that you may begin to become familiar with some unique aspects of the anatomy and physiology of these species.

Self-Check 1

At the end of each section of *Animal Anatomy and Physiology 1,* you'll be asked to pause and check your understanding of what you've just read by completing a "Self-Check" exercise. Answering these questions will help you review what you've studied so far. Please complete *Self-Check 1* now.

Questions 1–5: Match the following terms with their definitions by placing the letter of the best definition in the blank space next to each term.

_______ 1. Cranial

_______ 2. Rostral

_______ 3. Median plane

_______ 4. Aborad

_______ 5. Lateral

a. Designation for parts of the head that are closer to the tip of the nose

b. Divides animal into right and left halves

c. Moving away from the mouth

d. Toward the side of the body, away from the midline

e. Toward the head

6. Based on your understanding of the term *superficial,* where would you expect the superficial digital flexor tendon in a horse's leg to be found, relative to the deep digital flexor?
   a. It would be closer to the skin than the deep digital flexor tendon.
   b. It would be closer to the body wall than the deep digital flexor tendon.
   c. It would be closer to the hoof than the deep digital flexor tendon.
   d. It would be closer to the median plane than the deep digital flexor tendon.

(Continued)

Self-Check 1

7. Which type of tissue would be found lining the tubes of the airways?

   a. Epithelial
   b. Connective
   c. Muscle
   d. Nervous

8. The first step in the inflammatory response is

   a. vasodilation.
   b. vasoconstriction.
   c. swelling.
   d. clotting.

9. The membranes that line joint cavities are described as

   a. serous.
   b. epithelial.
   c. mucous.
   d. synovial.

10. The membranes that line the organs within the thorax, abdominal, and pelvic cavities are described as

    a. serous.
    b. epithelial.
    c. mucous.
    d. synovial.

Check your answers with those on page 187.

ASSIGNMENT 2: BIOCHEMISTRY

Read in your textbook, *Clinical Anatomy and Physiology for Veterinary Technicians,* pages 9–89 and 283–313. Then read Assignment 2 in this study guide.

Much of the study of anatomy and physiology requires a strong background in basic biology. Your reading assignment for this section is a review of the biochemistry and cell anatomy and physiology that you previously covered in your biology course. A strong foundation in these concepts is vital to your understanding of later topics in anatomy and physiology.

You studied basic chemistry as part of your biology course. Recall that all elements are composed of *atoms.* Although there are more than 100 elements found in nature, living things are composed of only a few of these (see Table 2-1 on page 12 of your textbook). Atoms can join together to form *molecules* and *compounds* through a process called *chemical bonding.* The three types of chemical bonds are covalent, ionic, and hydrogen bonds.

Ionic bonding occurs when atoms either donate or accept electrons from another atom.

The atom that donates an electron becomes positively charged, while the atom that gains an electron becomes negatively charged. The two atoms, which now have opposite electrical charges, are attracted to each other and stay together as a result. The individual atoms that participated in the ionic bond are referred to as *ions.* If the ion has a positive charge, it's called a *cation.* Negatively charged ions are called *anions.* When ionic bonds form between mineral compounds, the resulting compounds are *salts.* Salts such as sodium chloride and calcium phosphate are important in many biochemical processes. Such salts are also referred to as *electrolytes* since they're able to transmit electrical energy. Acids and bases also contain ionic bonds. When dissolved in water, *acids* release hydrogen ions, and *bases* release hydroxyl ions.

Covalent bonding can occur when two atoms each have an unpaired electron in their outer orbitals. Each atom exerts a force on the unpaired electron of the other, pulling them together. The unpaired electrons are then shared between the two atoms. This sharing of electrons may be equal between the two atoms, producing what's called a *nonpolar bond.* It may also be unequal, causing one end of the molecule to have a slight positive charge and the other end to have a slight negative charge. Unequal electron sharing produces a *polar covalent bond.* The bonds that hold the atoms of a water molecule together are polar covalent bonds (see Figure 2-15 on page 19 of your textbook). This bonding gives water many unique properties, which are summarized here.

- *Water is the universal solvent.*

Water molecules surround other molecules and dissolve them (see Figure 2-21 on page 22 of your textbook). Chemicals that dissolve or mix well in water are called *hydrophilic,* while molecules that don't mix well with water are called *hydrophobic.*

- *Water is an ideal transport medium.*

  Molecules that dissolve in water can be carried easily to locations in the body or cell via blood lymph and intracellular and extracellular fluid.

- *Water has a high heat capacity and a high heat of vaporization.*

  Water absorbs heat from biochemical reactions so that the overall temperature of the solution doesn't rise too rapidly. This helps keep the internal environment of an organism at a stable temperature range.

- *Water is used for lubrication.*

  Because water can surround molecules, it serves as a lubricant for moving parts in the body.

Hydrogen bonding occurs when there's a weak attraction between a slightly negative atom in a polar covalent bond and a slightly positive hydrogen atom involved in a second polar covalent bond. This type of bonding occurs between the two strands of DNA molecules and between individual water molecules. This is responsible for the cohesive and adhesive properties of water. *Cohesion* of water molecules results in a high surface tension of water. It's the reason why small particles float on water and insects can "walk on water." *Adhesion* is similar to cohesion but refers to the attraction between water molecules and other charged surfaces. This is partly responsible for the upward movement of water through structures inside tree trunks.

Compounds formed from the joining of elements are classified as either organic compounds or inorganic compounds. *Inorganic compounds* are those that don't contain *hydrocarbons* (carbon and hydrogen bonded together), such as salts and water. *Organic compounds* are all characterized by the presence of hydrocarbons. The hydrocarbon groups are usually bonded to another group of atoms known as the *functional group* that's unique to each type of organic compound.

Organic Compounds

Living things contain four types of organic compounds—carbohydrates, proteins, lipids, and nucleic acids. Table 2-2 on page 26 of your textbook summarizes the organic molecules in living things.

Carbohydrates

Carbohydrates consist of carbon, hydrogen, and oxygen in a 1:2:1 ratio. Cells use them for energy as well as structural materials. There are three main classes of carbohydrates:

1. *Monosaccharides* are simple sugars composed of only one monomer. Examples are glucose, fructose, and ribose.
2. *Oligosaccharides* are short chains of sugar monomers covalently bonded together. If they contain only two sugar monomers, they're known as *disaccharides.* Examples of disaccharides are lactose (milk sugar) and sucrose (table sugar).
3. *Polysaccharides* are complex carbohydrates with many sugar monomers that form chains or branches. These monomers may be of different types and may number in the thousands. Examples include glycogen, starch, and cellulose.

Lipids

Lipids are fats and other oily substances. Cells use them for energy storage, structural support, and as signaling molecules. They're composed of fatty acids attached to glycerol. Triglycerides are the most abundant lipids in the body and provide more than twice the energy as complex carbohydrates when they're broken down. The cell membrane is composed of a class of lipid called a *phospholipid.* Steroids are also lipid molecules.

Proteins

Proteins form enzymes and hormones and control all metabolic and biochemical reactions and processes in cells. Proteins are composed of chains of amino acids joined by peptide bonds. There are 20 different amino acids in the body, which all contain a carbon atom bound to an *amino group,* a *carboxyl group,* and a *side chain* (designated R) (see Figure 2-34 on page 32 of your textbook). The specific side chain present determines which amino acid is formed.

The sequence of amino acids in each type of protein is highly specific and gives a protein its primary structure. A protein's secondary structure is formed by hydrogen bonds at intervals along the length of the amino acid chain that cause it to coil or bend. Bonding of certain amino acids causes further bending and looping of the protein and makes up its third structural level. Finally, the fourth level of protein structure is reached when hydrogen bonds or bonds between R groups join two or more polypeptide chains together (see Figure 2-36 on page 34 of your textbook).

The specific type of proteins made within a particular cell depends on the function of the cell. The genes contained in the molecule *deoxyribonucleic acid (DNA)* provide a code for the production of proteins needed by cells throughout the organism. DNA provides a template for the manufacture of these proteins. Although all cells of an organism have identical DNA, the cells themselves differ, depending on which proteins are made by that particular cell. The genes within the DNA molecule control synthesis of proteins. The process of transcribing and translating the genetic message into a protein requires the molecule ribonucleic acid.

Metabolic reactions inside cells wouldn't occur fast enough to keep an organism alive without enzymes. *Enzymes* are proteins that act as catalysts to speed up the rate of a metabolic reaction. The enzyme isn't destroyed or altered in the process, so it can continue to catalyze reactions. Each type of enzyme recognizes certain substances called *substrates* and binds to them in specific ways. As soon as the enzyme binds to an active site on a substrate, it *catalyzes,* or sets into motion, a reaction. Cells have control mechanisms to adjust how quickly enzymes are produced and to stop an enzyme's action when reactions are no longer necessary.

Nucleotides and Nucleic Acids

Small organic compounds that contain one or more phosphate groups and a five-carbon sugar attached to a nitrogenous base are called *nucleotides* (see Figure 2-39 on page 36 of your textbook). *Adenosine triphosphate (ATP)* is an important nucleotide in the body produced during cellular respiration and used for energy storage. The phosphate bonds of ATP contain energy that's released when enzymes break off ATP's outer phosphate group and attach it to another molecule by the process known as *phosphorylation.* This new molecule is now equipped with the energy it needs to enter a metabolic reaction.

Nucleic acids are either single (as in RNA) or double (as in DNA) strands of covalently bonded nucleotides. Adenine, guanine, cytosine, and thymine are the bases that occur in DNA. RNA is composed of the bases adenine, guanine, cytosine, and uracil.

Because of the unique aspects of the nitrogen bases, the structures of DNA and RNA are different. DNA exists as a double-stranded molecule. The molecule is also twisted into a double helix. Because the space between DNA strands is small, the nitrogen bases can pair only in specific ways. The hydrogen bonds that form between the two DNA strands always link the bases in either an adenine-thymine pair or a cytosine-guanine pair. Unlike DNA, RNA is usually a single-stranded molecule, although some RNA molecules may have double-stranded regions within them.

There are three types of RNA in cells, and all are used in the translation of genes into proteins:

1. *Messenger RNA* (abbreviated *mRNA*)
2. *Ribosomal RNA* (abbreviated *rRNA*)
3. *Transfer RNA* (abbreviated *tRNA*)

The first step in protein synthesis is *transcription.* Enzymes bind to the DNA molecule at the location of a gene to unwind and uncoil the molecule. The molecule *RNA polymerase* then interacts with the DNA and allows for the movement of nucleoside triphosphates into the space between the unwound DNA strands. One strand is used as a template, and complementary base pairs align along the DNA strand. The other DNA strand remains inactive. In this way, a strand of mRNA is made that has the same sequence of base pairs as the inactive DNA strand, except that uracil is substituted for thymine. For example, a DNA sequence with the bases TACGATT has a complementary DNA strand with bases ATGCTAA, and an mRNA strand is made with the bases AUGCUAA.

Once a specific *stop sequence* (which marks the end of a gene) of base pairs is recognized, transcription ends and the DNA molecule rewinds. The RNA molecule that has just been created is modified and then enters the cell cytoplasm. Protein synthesis occurs at the *ribosome.* Recall that ribosomes may be free in the cytoplasm or attached to the rough endoplasmic reticulum. The mRNA binds to the ribosome and allows for tRNA to read the code on the mRNA. The code is present in each group of three bases in the mRNA molecule. Each of the 20 amino acids found in proteins of living things has a specific set of base triplets (referred to as a *codon*) on the mRNA. For example, the codons UUU or UUC on mRNA both correspond to the amino acid phenylalanine. The amino acid phenylalanine is attached to a tRNA molecule that has an anticodon (i.e., complementary base) of AAA or AAG. A specific enzyme called aminoacyl-tRNA-synthetase is used to attach the correct amino acid to its corresponding tRNA molecule. The tRNA molecules continue to read the mRNA codons and attach appropriate amino acids. As this process continues, adjacent amino acids form peptide bonds. When specific stop sequences are reached (i.e., codons that don't code for any amino acid [called *stop codons*]), translation of the message ends and the protein is released.

Mutations are changes in DNA that can result in abnormal protein synthesis. Mutations can be random or the result of exposure to mutagenic substances. There are several types of mutations:

- *Point mutations*—One nitrogen base is substituted for another.
- *Nonsense mutations*—A change in a codon for an amino acid into a stop codon occurs.
- *Frameshift mutations*—Nucleotide bases are either added or deleted, causing a change in the entire sequence of amino acids.

Mutations that occur in the DNA of gametes are genetic. Those that occur randomly in somatic cells are nongenetic.

Cell Structure

You studied cellular structure in detail in your biology course. Recall that all living things are made of cells. The body of an animal patient is typically made up of many billions of cells, each of which has a specialized structure and performs a particular function. Cells come in a wide variety of shapes and sizes. Often the structure of a cell reflects its function (see Figure 2-1 on page 9 of your textbook). Nerve cells, which carry electrical messages from one region to another, are long and thin. Muscle cells, which produce movement in the body by shortening in length, are long, cylindrical cells packed full of contractile proteins.

When cells are examined with a regular light microscope in a veterinary hospital, they're usually first prepared with a special staining process. Unstained cells would be relatively transparent and thus hard to see, but the pigments in the stain bind to some of the larger cellular structures and make them visible. The nucleus is usually quite visible in a stained cell because the DNA and ribonucleic acid (RNA) in the nucleus stain darkly. The cytoplasm of most stained cells looks much lighter in color. Despite a great diversity of cell types, most cells share the same basic components. Let's review some of the important cell structures described in your textbook.

Cell Membrane

The *cell membrane* is the structure surrounding the cell that forms a barrier between the inside of the cell and the outside. This membrane is composed of a double layer of phospholipids, which are embedded with protein molecules. The fat molecules act as a barrier to most substances, whereas the proteins act as channels or carriers to selectively allow certain substances across. Think of the cell membrane as the cell's "traffic cop," directing traffic into and out of the cell as well as protecting the cell from the environment. The cell membrane is a very active, dynamic structure that keeps certain chemicals out of the cell and retains others.

The outer surface of the cell membrane also contains *receptors,* which are structures to which hormones and other chemicals outside of the cell can bind. This binding action signals the cell to carry out particular functions.

The cell membrane also features other molecules that act like glue to hold the cell together. In some cells the membrane is quite rigid, whereas in others it's fluid and flexible, allowing the cell to change shape. Some cells use this membrane flexibility to extend fingerlike projections called *pseudopodia* (from *pseudo* [false] and *podia* [feet]). Pseudopodia allow the cell to move around or engulf substances to bring them into the cell. Certain white blood cells can move by means of such pseudopodia and can use their cell membranes to attack bacteria or viruses to destroy them.

Cytoplasm and Organelles

The *cytoplasm* is the region inside the cell membrane but outside the nucleus. When you look at a typical stained cell, you can usually identify the region of the cytoplasm—it usually stains lightly and looks quite empty. However, the cytoplasm is actually packed full of *organelles* (see Table 3-1 on pages 47–48 of your textbook) that are generally too small to see with a regular light microscope even when the cell is stained. You can think of the organelles as being analogous to the parts of a city. Each organelle has a specific function; together, the organelles make the cell work in the same way that the parts of a city work together.

Mitochondria are the power plants of the cell. Through the breakdown of nutrients like glucose, the mitochondria produce adenosine triphosphate (ATP). The breakdown of ATP provides the immediate source of energy that cells need to carry out processes like growth, reproduction, movement, and synthesis of essential molecules for the cell.

The *endoplasmic reticulum* forms a network of tubes, channels, and sacs within the cytoplasm that are associated with synthesis and transport of materials within the cell. *Rough endoplasmic reticulum* is a system of canals whose surface is studded with another type of organelle called ribosomes. *Ribosomes* act like a workbench on which proteins are produced. *Smooth endoplasmic reticulum* has no ribosomes on it. It isn't involved in protein production but is involved in the production of other substances, such as lipids.

The *Golgi apparatus* prepares and packages material for export from the cell. Together, the endoplasmic reticulum and Golgi apparatus are somewhat like an assembly line in a factory. The endoplasmic reticulum makes proteins (like a factory) that it sends to the Golgi apparatus to put into nice little packages to be sent out to the membrane (like a packing plant).

Lysosomes are saclike organelles that contain powerful digestive enzymes to break down substances within the cell. They work like processing or recycling plants.

Nucleus

The *nucleus* directs all of the cell's activities. It's surrounded by a *nuclear membrane* that separates the contents of the nucleus from the cytoplasm. When cells are stained and examined under a microscope, the nucleus usually appears prominent and darkly stained; a nucleolus (described later) is often visible. Inside the nucleus is deoxyribonucleic acid (DNA). DNA contains all of an organism's genetic instructions. The structure of DNA molecules is described as a *double helix.* These molecules of DNA in the nucleus are extremely long and thin; they're associated with special proteins that help organize the strands of DNA. Most of the time, the DNA in the nucleus exists as threadlike material much too tiny to be seen as individual strands. In this form, the genetic material is referred to as *chromatin.* However, before a cell divides, the threadlike chromatin must become condensed or coiled into short, compacted bodies called *chromosomes.* In their compacted form, the genetic material is clearly visible as darkly staining bodies.

Each chromosome is a single, very long piece of DNA (along with some associated proteins). Each species has a characteristic number of chromosomes per cell. Humans have 46 chromosomes (or strands of DNA) in the nucleus of each cell. Dogs have even more—78 chromosomes per cell! Just before a cell divides, you can see individual, compacted chromosomes under the microscope. They look like the letter "X" because each piece of DNA has replicated itself, and the two identical chromosomes are connected near the middle by a structure called the *centromere* (which is the middle of the X in the aforementioned analogy).

Students often get confused about the relationship among chromatin, chromosomes, and genes. *Chromatin* is a term that describes the genetic material when it's diffusely spread out in the nucleus and not compacted into individually visible structures. The word *chromatin* simply means "colored substance." A *chromosome* is a single strand of DNA (and associated proteins) that has been compacted and condensed into a visible structure. A *gene* is a specific region of a chromosome that codes for a single, particular characteristic (e.g., blood type, eye color). Each chromosome has several hundred or more specific genes within it.

If DNA makes up the cell's genetic blueprints, then RNA represents the cell's architects and construction workers, taking the blueprints and turning them into reality. The messages in DNA are copied into an equivalent RNA molecule through a process called *transcription* (to "transcribe" means to copy something). Clumps of RNA often form a very dark round structure called the *nucleolus* that's often visible within a stained nucleus. The transcribed strands of RNA travel outside the nucleus to the cytoplasm, where the RNA message undergoes a process called *translation.* During translation, the ribosomes serve as a workbench on which the particular protein molecule specified by the original DNA blueprint is synthesized. The protein molecule then carries out its unique function.

The genes in the DNA are expressed by these processes of transcription and translation (described later), which result in the production of specific proteins that carry out specific functions within the cell.

Cellular Physiology

Animals are composed mostly of water. The water is separated into three compartments. The majority of the water present in an animal is found within cells and is called *intracellular fluid.* Water found outside cells is called *extracellular fluid,* and extracellular fluid located within tissues is referred to as *interstitial fluid.* Each fluid compartment contains different concentrations of molecules such as ions and proteins. The *plasma membrane* helps maintain the concentrations of substances within the intracellular and extracellular compartments.

Membrane Transport

The plasma membrane is a dynamic structure. That is, it isn't a barrier, but a series of components that interact to perform the barrier function. The plasma membrane functions with other organelles within the cell to maintain fluid composition on both sides of the membrane. This requires that certain substances be transported back and forth across the membrane. The transport processes used by the cell may require cellular energy expenditure. These transport processes are *active.* Other transport processes that are *passive* don't require cellular energy (see Figure 3-2 on pages 64–65 of your textbook).

Passive Transport Processes

Passive transport processes include diffusion, facilitated diffusion, osmosis, and filtration. To understand these processes, it's important that you understand the effect of a gradient. The term *gradient* refers to a difference between two areas. Gradients may be *concentration gradients* (differences in concentration of substances between two areas), *pressure* *gradients* (differences in pressure between two areas), *temperature gradients* (differences in temperature between two areas), or gradients represented by other differences.

In cellular transport, we're usually referring to a concentration gradient that acts to reach equilibrium. The plasma membrane separates the intracellular and extracellular fluid. When any substance that's permeable to the membrane exists in different concentrations on each side of the membrane, the molecules of the substance *diffuse* across the membrane in an effort to equalize the concentrations. Many molecules can cross the membrane this way, so there's no need for the cell to expend energy. *Facilitated diffusion* is a similar process, except that the molecules aren't freely permeable to the membrane. The molecules are bound to other carrier molecules for transport across the membrane. Osmosis is also a process that operates on a concentration gradient. With *osmosis,* the molecular concentration differences dissolved in water on each side of the membrane result in the movement of water molecules across the membrane.

Active Transport Processes

When the cell expends energy to move molecules across the plasma membrane, the processes are referred to as *active transport.* This process may be needed when molecules aren't permeable to the membrane, must be moved against the concentration gradient, or are too large to cross the membrane. Active transport processes require a carrier molecule or involve the modification of the cell membrane. The primary active transport mechanism in cells is involved in the movement of ions—particularly sodium, calcium, and potassium—across the membrane. The transport of these ions occurs against the concentration gradient, so the cell must use energy to move them from one side of the membrane to the other. *Endocytosis* and *exocytosis* also require cellular energy. These processes involve modifications of the plasma membrane to engulf the molecules being transported. The membrane-engulfed sac of molecules can then be brought into the cell by fusing the sac with the plasma membrane.

Cell Reproduction

Mitosis

All higher animals begin life as a single cell—a fertilized egg. The fertilized egg then reproduces itself by dividing into two cells that are genetically identical to each other. All of the subsequent growth and development of an organism as well as the constant replenishment of some cells that occurs in adult animals is carried out by the same process of cell division (i.e., *mitosis*). Many cells in the body (e.g., nerve cells) lose the ability to undergo mitosis after the organism reaches a certain stage of maturity. Other cells, such as the blood cells and cells that line the digestive tract, retain the ability to undergo mitosis for the organism's entire life span. Other cells seem to lose the ability to reproduce, only to regain it under the proper conditions. For example, the *osteoblast* is the cell from which bones are built. Osteoblasts stop dividing and bones stop growing when the organism reaches maturity. However, if a bone is broken, the osteoblasts begin to divide again to heal that bone.

Although the exact stimulus for cell division isn't well understood, certain factors are known to stimulate or inhibit growth in tissues. For example, growth hormone causes cell division in many tissues in the body, whereas sex hormones cause growth in particular tissues, namely mammary or prostate gland tissue. Lack of available nutrients slows the growth of tissue, and certain toxins halt the process of mitosis completely or alter the process severely enough to kill cells.

Most cells spend only a small proportion of their time actively dividing. The stage in the cell's life cycle when no cell division is occurring is called *interphase*. Cells in interphase are busy carrying out whatever functions they have in the body (but aren't dividing). Some cell types, such as nerve cells, spend most of their time in interphase. When stimulated to undergo mitosis, the cell first duplicates its DNA molecules. The identical copies of each chromosome are held together in the middle of the cell at the centromere. Then nuclear division occurs.

Mitosis involves four phases:

1. *Prophase*—The chromosomes begin to coil and condense and become visible as chromosomes, and the nuclear membrane dissolves. The spindle fibers form and attach to the chromosomes at their centromeres to control their movement.
2. *Metaphase*—The spindle fibers line up all of the chromosomes in the middle of the cell.
3. *Anaphase*—The spindles pull the two identical copies of each chromosome apart at the centromere, and the copies are pulled toward opposite ends of the cell.
4. *Telophase*—The chromosomes become less condensed, the spindle fibers disappear, and a nuclear membrane re-forms around each new set of chromosomes.

Cytokinesis follows, in which the cell membrane becomes constricted in the middle of the cell between the two new nuclei. Eventually, the cell becomes pinched into two new *daughter cells,* and the cytoplasmic contents are divided between them. The new cells formed by mitosis are genetically identical to each other as well as to the original cell.

In some diseases, the natural process of mitosis is interrupted as a result of infection or toxic exposure. An example is *aplastic anemia,* a condition in which the cells in bone marrow stop producing blood cells, which leads to *anemia* (insufficient red blood cells) and *leukopenia* (a deficiency of white blood cells). We could find more effective treatment for this kind of illness if we discovered why mitosis is interrupted. Treatment could prevent this mitotic interference and also stimulate mitosis to resume.

Meiosis

Cells in the ovaries and testes undergo a process somewhat similar to mitosis called *meiosis.* In this process, the cells divide to produce eggs or sperm, which have only half as many chromosomes as the parent cell. You'll learn more about meiosis when you study the reproductive system later in your course.

Cellular Metabolism

All metabolic reactions involve energy transformations. The source of energy depends on the type of organism. *Autotrophic organisms* are ones that can transform energy from the sun into chemical energy (e.g., plants). *Heterotrophic organisms* are those that transform chemical energy from autotrophic organisms into usable energy for their own cellular work. Therefore, all life depends on chemical energy produced by plants. The storage form of energy in cells is contained within the chemical bonds of the molecule ATP. ATP is a phosphorylated nucleotide. Breaking the phosphate bonds in the ATP molecule releases energy. When ATP loses a phosphate radical in a reaction called *hydrolysis,* then the nucleotide becomes adenosine diphosphate (ADP). As ATP is used, it needs to be replenished. ATP is replenished by phosphorylating ADP back to ATP.

Catabolism is the breakdown of a substance. A by-product of a catabolic reaction is the production of energy. This energy can be stored or used for bodily functions such as muscle contractions, glandular secretions, and building substances like proteins and nucleic acids. The opposite of catabolism is *anabolism,* which is the construction of more complex compounds from simpler compounds. An anabolic reaction needs energy to drive the reaction. This reaction is seen in tissue replacement, growth, and development.

The most important role of cellular metabolism is to make food energy available to body cells. The body's cells need a constant source of energy because these reactions are occurring at all times in different systems. If we focus on one reaction at a particular time, it can't be catabolic and anabolic simultaneously. However, a catabolic reaction can occur in a cell while an anabolic reaction is occurring in another cell.

The initial step in the production of energy in the cell is *hydrolysis.* Within the intestinal tract, nutrients are broken down before being absorbed by the body. Carbohydrates are broken down into monosaccharides, fats are broken down into fatty acids and glycerol, proteins are broken down into amino acids, and nucleic acids are broken down into nucleotides. The small molecules produced from hydrolysis are then absorbed in the intestinal tract.

The next stages of cellular metabolism occur within cells. Initially, the absorbed molecules are acted upon anaerobically through a process called *glycolysis.* The products of glycolysis are then used in the final stage of metabolism, *aerobic respiration.*

Control of Metabolism

Enzymes are biological catalysts that increase the rate of a chemical reaction and remain unchanged by the reaction. Substrates and their specific enzymes have complementary biochemical shapes. The location on the enzyme molecule that binds with the substrate is referred to as the *active site* (see Figure 12-10 on page 302 of your textbook). Although the protein may undergo a temporary change in shape during the reaction, the protein's initial shape is restored at the conclusion of the reaction.

Many reactions that occur within cells also use *coenzymes* and *cofactors.* These molecules include elements, such as iron and copper, and organic compounds, such as nicotinamide adenine dinucleotide (NAD). Cofactors and coenzymes may be involved in changing the shape of a molecule to improve the ability of the substrate to bind to the active site. Vitamins and minerals are often also involved as cofactors in metabolic reactions (see Table 12-1 on page 296 and Box 12-2 on page 297 of your textbook for a summary of essential vitamins and minerals).

Metabolic Pathways

In ruminants, the microbial population breaks down cellulose into short-chain fatty acids such as acetic acid, propionic acid, butyric acid, and some alcohol. The short-chain fatty acids and alcohol pass through the rumen wall to be absorbed by the bloodstream. A ruminant's energy source is short-chain fatty acids (i.e., volatile fatty acids), whereas the nonruminant's energy source is monosaccharides (i.e., simple sugars).

Each type of nutrient is metabolized through different metabolic pathways. These pathways occur either in the cytoplasm of cells or in the mitochondria. Some metabolic processes require oxygen, whereas others don't. Regardless of the specific mechanism or location where metabolism occurs, all pathways involve a series of reactions that occur in a stepwise fashion. Each step of the pathway also requires specific enzymes.

Nearly all living cells metabolize carbohydrates to produce energy. *Glucose* is the most abundant of the monosaccharides and the most important to biological organisms. This compound is produced during photosynthesis and consumed during cellular respiration. The initial step in the metabolism of glucose varies between ruminant and nonruminant animals. In nonruminants, enzymes in salivary glands and the small intestines *hydrolyze* (i.e., split up compounds through the addition of water) dietary disaccharides and polysaccharides into the monosaccharide glucose. Glucose molecules are then absorbed in the intestinal tract and transported via the blood to the cells. Glucose enters the cells either by active transport or facilitated diffusion. Within the cells, the glucose molecules are either *catabolized* (i.e., broken down) to produce energy in the form of ATP, or they may be converted to *glycogen* (i.e., a large polysaccharide) or fat. In herbivores (ruminants), the polysaccharide cellulose is ingested and broken down to *volatile fatty acids (VFAs),* particularly *propionate* (i.e., any salt of propionic acid). VFAs are then used as a source of energy.

Glycolysis

Cells use the process of *glycolysis* to release energy contained within the glucose molecule. Glycolysis reactions occur within the cytoplasm of the cell. During glycolysis, a molecule of glucose is used to form four molecules of ATP, two molecules of NAD (an electron carrier), and two molecules of pyruvic acid. Because glycolysis reactions also consume energy and other molecules, the end result of glycolysis is two ATP molecules, two molecules of NAD, and one molecule of pyruvic acid.

Glycolysis reactions use a process called *phosphorylation,* which involves binding phosphate groups onto the carbon groups of the glucose molecule. Cells that lack mitochondria aren't capable of further action on pyruvic acid. But many other cells can use pyruvic acid to make more ATP using the process referred to as *cellular respiration.*

Cellular Respiration

Cellular respiration occurs in the presence of oxygen in cells that contain mitochondria. The reactions occur as a series of three distinct sets of reactions. The first set of reactions degrades pyruvic acid to the molecule acetyl coenzyme A (acetyl-CoA) and releases CO_2 and the reduced (i.e., addition of hydrogen) form of NAD (NADH), which is an electron carrier. The next set of reactions is contained in the Krebs cycle. During the *Krebs cycle* reactions, the acetyl-CoA is acted on, and the potential energy in its chemical bonds is transferred to other molecules. The end result from the two molecules of pyruvate generated during glycolysis is an additional two ATP molecules and two additional carrier molecules.

The next set of reactions is referred to as the *electron transport chain.* In these reactions, the carrier molecules generated by glycolysis and the Krebs cycle are acted upon to produce another 28 ATP molecules. In the electron transport chain, hydrogen ions are pumped out of the mitochondria, and the hydrogen electron is passed along a series of reactions with *cytochromes* (chains of electron carrier molecules) embedded in the mitochondrial membrane. The electrons lose their energy as they progress through the series of reactions. The final electron acceptor in the reaction series is oxygen. That energy is transferred into the adenosine triphosphate (ATP) molecule with assistance from the enzyme ATP synthase. Although the reactions of glycolysis, the Krebs cycle, and the electron transport chain produce a total of 38 ATP molecules, two molecules of ATP are used at several steps along the way. Thus, the net yield from one molecule of glucose is 36 ATP molecules. Figure 12-13 on page 307 of your textbook summarizes the reactions of the various pathways of cellular respiration.

In the absence of oxygen, other energy pathways occur. In general, these pathways are much less efficient at ATP formation. *Alcoholic fermentation* and *lactic acid fermentation* are two such pathways. Anaerobic organisms, such as certain bacteria and algae, use these pathways. Although no additional ATP is formed, the fermentation pathways generate electron carrier molecules that can then enter the glycolysis reactions and improve their efficiency.

Lipid Metabolism

Lipids are fats and fatlike substances. Like carbohydrates, lipids do contain carbon, hydrogen, and oxygen, but they contain less oxygen than is found in carbohydrates. Lipids usually aren't soluble in water. Fats and oils serve as energy reserves in animal tissues and plant seeds. Fats and oils are composed of one, two, or three chains of fatty acids linked to one glycerol molecule. If three chains of fatty acids are present, the molecule is called a *triglyceride.*

Lipids are primarily metabolized in liver cells. Cells in the liver remove fats from the blood and hydrolyze the molecules so that the products can be used in the Krebs cycle. Triglycerides are hydrolyzed into a molecule of glycerol and three fatty acid chains. The glycerol is then further metabolized to form acetyl-CoA, which then enters the Krebs cycle. The fatty acid chains are broken down into either acetyl-CoA or ketone bodies. Ketone bodies can also be broken down to form acetyl Co-A (see Figure 12-18 on page 311 of your textbook).

Protein Metabolism

Protein molecules contain energy within the peptide bonds that hold the amino acids in sequence. These bonds can be broken to provide energy for the cell. These reactions occur primarily in the brain, liver, kidney, and skeletal muscle cells. Proteins can be catabolized by deamination (also known as transamination). *Deamination* is the chemical reaction in which the amine group is removed from an amino acid. The products of this reaction are the formation of an alpha-keto acid and ammonium ion. *Transamination* is the interchange of an amine group in one compound for the amine group in another compound or the transposition of an amine group within the same compound. This process allows for the production of ketoacids. These reactions are summarized in Figure 12-20 on page 313 of your textbook.

Before proceeding to the next assignment, take a moment to complete *Self-Check 2.* Remember, you can check your answers by turning to the back of this study guide.

Self-Check 2

Questions 1–5: Match the following terms with their definitions by placing the letter of the best definition in the blank space next to each term.

_______ 1. Mitosis

_______ 2. Transcription

_______ 3. Ribosome

_______ 4. Deoxyribonucleic acid

_______ 5. Telophase

a. Stage of cell division in which the cell becomes pinched into two new daughter cells

b. Cell division that occurs for growth, tissue repair

c. Contains instructions to make all cell proteins

d. Organelle important in the manufacture of protein

e. Copies DNA messages into RNA molecules

6. The binding of sodium and chloride is an example of a(n) ________ bond.

7. Substances that release hydrogen ions when dissolved in water are ________.

8. The nitrogen bases found in RNA are ________, ________, ________, and ________.

9. The nitrogen bases found in DNA are ________, ________, ________, and ________.

10. When a concentration gradient is present, dissolved substances move from an area of ________ concentration to an area of ________ concentration. This process is called ________.

Check your answers with those on page 187.

ASSIGNMENT 3: INTEGUMENTARY SYSTEM

Read in your textbook, *Clinical Anatomy and Physiology for Veterinary Technicians,* pages 131–152, 413–422, and 457–458. Then read Assignment 3 in this study guide.

The *integument* is composed of all four tissue types and is the largest of the body's organ systems. The skin is an *epithelial structure,* meaning it covers and protects the underlying organs from the environment. The most fundamental function of skin is to keep the body contents confined. However, the skin has many other functions:

- It protects against excessively humid or dry conditions.
- It protects against environmental chemicals.
- It protects against infectious organisms, such as bacteria, viruses, fungi, and parasites.
- It helps regulate body temperature.

If you're too hot, the blood vessels in your skin *dilate* (become wider) to increase blood flow to the skin. Heat radiates out of these blood vessels, through the skin, and into the environment. When you get cold, the skin's blood vessels *constrict* (become narrower) to decrease blood flow to the skin. Less blood flow means less heat radiates out of the skin, keeping the heat inside the body. The dilation and constriction of blood vessels in the skin serves another purpose—it helps raise or lower your blood pressure. As the blood vessels dilate, blood pressure drops, and as the blood vessels constrict, blood pressure increases.

The skin produces many structures and chemicals. Hair, horns, and feathers are all extensions of the skin. Glands in the skin produce sweat or oils that help the body lose heat or keep the skin moist. *Melanin* is a pigment that the skin makes when exposed to ultraviolet rays in sunlight. The melanin absorbs the dangerous ultraviolet rays and prevents these rays from penetrating into deeper layers of the skin, where they could cause serious damage. Your skin turns dark when you tan because it's making melanin to protect you from the sun. Melanin also partially determines the color of skin and hair. Vitamin D is manufactured by the skin when it's exposed to sunlight. Although vitamin D doesn't protect from the sun, it's very important in keeping bones healthy.

The skin serves another important purpose—as a sensory organ. The skin is responsible for your sense of touch. If you couldn't feel anything, you would burn yourself, freeze to death, cut yourself to pieces, crush your fingers, and so on. Therefore, the skin keeps you from harming yourself as much as it prevents the environment from harming you.

In some animals, skin coloration or texture provides camouflage, hiding the animal from predators. Other animals use skin color to warn predators that they're poisonous or bad-tasting. Finally, skin color in some animals can attract members of the opposite sex, enabling the animal to mate and reproduce.

Skin Structure

The major functions of skin make it a very complex organ. The skin is comprised of two major layers—the *epidermis* and the *dermis.* Each of these layers is then divided into several parts. Within, or rising out of, these layers are other structures, such as hair and glands. Beneath the skin is the *hypodermis,* or *subcutaneous* layer, which supports the epidermis and dermis. We'll review each of these layers in turn and discuss their structure and function.

Epidermis

The outermost layer of the skin is the *epidermis.* This layer is the one you see when you look at a person or an animal. The epidermis may contain up to five layers. The more wear and tear the area of skin is subject to, the thicker the epidermis, and the more layers you'll find.

The epidermis grows from the inside out. Cells in the bottom layer are continually dividing. These cells then rise to the skin's surface. As the cells move to the surface, they begin dying. By the time they reach the surface, they're completely dead, and all that remains is a shell. As the cells rise to the surface, they also produce increasing amounts of keratin. *Keratin* is a fibrous protein that provides toughness to the cell and, therefore, to the skin. As a cell ages and rises toward the surface, keratin fills the cell, replacing the normal internal structures, including the nucleus. This process is called *keratinization,* and it leads to the cell's death.

The outermost layer of the epidermis is the *horny layer,* called the *stratum corneum.* This layer consists of dead, flattened, fully keratinized cells. The stratum corneum may be several layers thick. It's the first line of defense against attack by the environment or infectious organisms. This is the layer that constantly sheds cells into the environment. When the skin continuously sheds cells, bacteria, other infectious agents, and parasites are shed along with the cells. This process makes it difficult for bacteria to gain a foothold on the skin. The tight connections between the cells in this layer prevent bacteria and chemicals from slipping between the cells and gaining access to the deeper layers of skin.

The second layer from the surface is the *clear layer,* called the *stratum lucidum.* Cells in the stratum lucidum are also dead and completely keratinized. These cells lack a nucleus and other cell organelles. Because these cells look very similar to the cells of the stratum corneum, you would have difficulty seeing this as a distinct layer, except in the skin of the nose and footpads.

Below the stratum lucidum is the *granular layer,* called the *stratum granulosum.* This layer may or may not be present in all areas of the body. In hairless areas, the stratum granulosum may be several layers thick. Like the cells in the stratum lucidum and stratum corneum, cells in the stratum granulosum are flattened in a plane parallel to the skin surface. Granular layer cells are in the process of dying. They're losing their nuclei, and they've nearly stopped producing keratin.

Just beneath the stratum granulosum is the *prickle cell layer,* called the *stratum spinosum.* The stratum spinosum consists of one to three layers of living cells derived from the bottom-most layer. The prickle cells are polyhedral to slightly cuboidal in shape. They aren't actively dividing under normal circumstances, but if the uppermost layers are removed by trauma or disease, these cells can resume cell division to more rapidly replace the missing cells.

The final, deepest layer of the epidermis is the *basal layer,* called the *stratum basale.* This layer consists of a single layer of columnar to cuboidal cells. These cells are actively dividing, giving birth to the cells that are pushed upward to form the upper layers of the epidermis. Two types of cells exist in the stratum basale. The most common cell is the *keratinocyte,* which produces keratin. The other cell type is the *melanocyte,* a cell that makes melanin. Melanocytes are less common, and the number of melanocytes varies depending on the color of that area of skin. Dark skin contains more melanocytes than light skin. The *basement membrane* supports the epidermis and separates it from the dermis.

Dermis

The *dermis* provides both structural and nutritional support to the epidermis. If you look at areas of skin with different thicknesses, you'll find that areas of thick skin have a thick dermis, while areas of thin skin have a thin dermis. The dermis isn't as highly organized as the epidermis and has only one layer. The dermal components consist of fibers, ground substance, and some cells all jumbled together in a hodgepodge fashion.

The dermis consists of collagen, elastin, and reticular fibers. *Collagen* is made of several protein strands braided together, much like a person's hair. The braiding increases the strength of the collagen fibers. *Reticular* fibers are a type of collagen that forms a loose net of thin, delicate fibers. *Elastin* fibers are almost the opposite of collagen fibers. Whereas collagen fibers help hold the skin together by being tough and rigid, elastin fibers stretch like rubber bands, giving the skin flexibility.

Several cell types are found in the normal dermis, including fibroblasts and macrophages. *Fibroblasts* make collagen fibers and also synthesize the ground substance of the dermis.

Hypodermis

Underneath all of the epidermal and dermal structures that make up the skin is the *hypodermis,* or subcutaneous layer. The thickness of the hypodermis depends on the area of the body, as well as the animal's species and weight.

The hypodermis is composed primarily of fat, but it also contains blood vessels, nerves, and connective tissue. The hypodermis stores fat, helps regulate body temperature, and supports the layers above it—the dermis and epidermis—both structurally and nutritionally. Regulation of body temperature is achieved partly through control of the blood flow through blood vessels and partly through the amount of fat (which acts like insulation) present in the hypodermis.

Pigmentation

Melanocytes often contain specialized granules that extend from the cell. These granules contain melanin and are responsible for the variety of skin colors found in animals. Some cells contain many granules and therefore produce dark pigmentation. Fewer granules results in lighter pigmentation.

Paw Pads

Many animals have foot pads composed of thick layers of fat and connective tissue. The pad is tough and thick, containing all five epidermal layers, and is often pigmented. Foot pads often contain sweat glands. Some species have multiple foot pads.

Planum Nasale

The top of the nose is referred to as the *planum nasale;* it's thick and usually pigmented. The epidermal surface contains deep grooves. In some species, the planum nasale contains glands.

Chestnut and Ergot

Horses are unique in possessing additional skin structures not found on other animals. If you look at the medial aspect of the horse's front leg between the *carpus* (the equivalent of your wrist) and the elbow, or at the medial aspect of the hind leg below the hock (the equivalent of your ankle), you'll find a soft horny structure called the *chestnut.* The purpose of the chestnut isn't known, but it may be the remnant of the nail of the second toe that disappeared as horses evolved from a many-toed to a single-toed animal.

If you examine the posterior aspect of the fetlock joint (the joint just proximal to the hoof), you'll find a similar soft horny structure called the *ergot.* The ergot may be the remnant of the nail of the fourth toe, which gradually shrunk with time.

Hair

Hair is a nonliving structure partially composed of keratin. Hair provides warmth; protects the skin from moisture, sunlight, and other damage; and gives some species distinctive markings for protective or reproductive purposes. The number and types of hairs an animal has determine the appearance and color of the hair coat. *Primary hairs,* also called *coarse* or *guard hairs,* are larger, stiffer hairs that provide the rough outer coat of most animals. *Secondary hairs,* also called *fine hairs,* are thinner hairs that make up the undercoat found on some animals. Animals with thick coats have larger numbers of secondary hairs than do animals with short coats.

A specialized type of hair is the *tactile*—also called *sinus*— hair, better known as a *whisker.* Tactile hairs are found on the face and sometimes the legs of animals. These hairs act as "feelers" to help detect objects before the animal runs into them. You may notice that when a cat sniffs something, it may extend its whiskers forward toward the object so that it can feel as well as smell. Tactile hairs are constructed slightly differently from other hairs. They grow straight out of the skin, unlike other hairs that exit the skin at an oblique angle, which gives direction to the hair coat. The follicles of tactile hairs have large numbers of nerve endings compared with normal hairs. These nerve endings make tactile hairs more sensitive to touch.

Hair Structure

All hairs share certain similar features. Hairs are divided into two parts—the shaft and the root. The hair *shaft* is the free portion that rises above the skin surface. It has three components layered over each other. The *cuticle* is a single layer of keratinized cells arranged like shingles on the outside of the shaft. The core of the shaft is the *medulla,* a layer that may not be present in all hairs. Secondary hairs have a much thinner medulla than primary hairs. Between the cuticle and the medulla is the *cortex,* which makes up the bulk of most hairs and is composed of many keratinized cells packed together.

The hair *root* is the portion of the hair beneath the surface of the skin. If you pluck a hair from your skin, you may see a pale, slightly widened or knoblike area at its end. This area is the *hair bulb,* which attaches the hair to the dermis at a slight upward bump in the dermis called the *papilla.* Each hair root lies in and arises from a *hair follicle,* a shaft that's continuous with the skin's surface. Part of the hair follicle, the *outer root sheath,* grows down from the epidermis, while the other part, the *inner root sheath,* grows upward from the dermal papilla. Hairs originate from division of keratinocytes in the dermal papilla and hair bulb. Melanocytes are also present in the hair bulb and outer root sheath and are partly responsible for the color of the hair shaft.

Associated Structures

Attached to the hair follicle are small muscles, called the *arrector pili muscles,* embedded in the dermis. Contractions of these muscles occur involuntarily in response to cold and fear. This makes the hairs stand up, increasing the thickness of the hair coat. These contractions increase insulation and can make the animal appear larger. Both of these functions are very important to animals, and although they aren't useful to humans, they remain intact.

Hair follicles are arranged in bundles. If you look closely at the hair on your arm, you might see more than one hair protruding through an opening on the skin. This occurs because several hair follicles may fuse near the surface to form one larger follicle that each hair in that bundle uses to reach the surface. In a dog or cat, you might see several secondary hairs emerging from the same follicle as a primary hair. The hair follicle bundles are arranged approximately in rows.

A few other structures are connected to the hair follicle and other parts of the skin. Blood vessels run throughout all areas of the skin, but especially the dermis. Since substances from the blood filter through the dermis to the epidermis, blood vessels carry oxygen and nutrients directly to the dermis and indirectly to the epidermis. Blood vessels also help control body temperature. This control works in conjunction with sweat glands in humans, but not in other species such as dogs or cats.

Two categories of nerves are found in the skin: motor and sensory. *Motor nerves* control movement by stimulating muscles to contract and relax. *Sensory nerves* are responsible for making you aware of how your skin feels and what it's touching. In the skin, the motor nerves are usually involuntary, or unconscious, and control the arrector pili muscles as well as the muscles in the walls of blood vessels. Specialized muscle cells around some of the skin glands causes the glands to secrete their products more forcefully.

Growth

Hair growth occurs in cycles, which explains why hair falls out and regrows. The *anagen* phase is the active growth phase of the cycle. During this phase, the cells of the dermal papilla and hair bulb divide to produce the keratinized cells of the hair shaft. *Telogen* is the "resting" phase. During this phase, these cells aren't dividing, the hair isn't growing, and the hair is retained in the hair follicle for a period of time before being shed. The third phase of the cycle is *catagen.* This is a transitional phase between anagen and telogen in which hair growth slows down. A separation forms between the living cells of the dermal papilla and the dead and dying cells of the hair root and shaft. Some diseases, especially certain hormonal imbalances, increase the number of cells in the telogen phase relative to the anagen phase, therefore causing more hair to shed.

Glands

Sebaceous Glands

Three specific types of glands exist in skin. The first and most common gland is the *sebaceous gland,* which is located in the dermis. Sebaceous glands are microscopic infoldings of the epidermis that are usually associated with hair follicles.

The concentration of sebaceous glands varies with different areas of the body. Hairy areas of the body have large numbers of sebaceous glands, while hairless areas have very few. Examining a sebaceous gland under the microscope displays clusters of foamy-looking, fat-containing cells with an outer layer of reserve cells. This outer layer of cells divides to produce the foamy cells. A small duct connects the sebaceous gland to the superficial part of the hair follicle. Therefore, the sebaceous excretions actually reach the surface of the skin through the hair follicles. The foamy cells rupture and release a substance called *sebum,* which contains cholesterol, fatty acids, and waxy chemicals. Sebum helps to soften the skin to keep it pliable. It also forms a thin film over the stratum corneum to help it retain moisture. Fatty acids and salts contained in sebum help kill bacteria.

Sweat Glands

Apocrine sweat glands are the second most common gland found in skin. Like sebaceous glands, apocrine glands are located in the dermis. These glands are infoldings of the skin associated with hair follicles. The duct of apocrine sweat glands enters the hair follicle just above the opening of the sebaceous gland duct. Apocrine sweat glands make a fluid rich in protein that mixes with sebum to form the protective film over your stratum corneum. *Mammary* glands are a form of apocrine sweat gland that are modified to produce milk. The secretions of sebaceous and apocrine sweat glands mix with debris and bacteria from the skin's surface to form plugs in the hair follicles, which can lead to infection in the hair follicle (known as *acne*).

Eccrine sweat glands are present all over the human body, especially in areas such as the armpits, hands, and feet. Dogs and cats have very few eccrine sweat glands, found only in the footpads. Eccrine sweat glands are located at the junction between the dermis and hypodermis. These glands help regulate body temperature by releasing water, which evaporates to carry off heat. They also help the body excrete salts and small amounts of certain waste products, such as ammonia. Since dogs and cats have very few eccrine glands, they can't use sweat to regulate their body temperature. Therefore, they use other methods to do so, including panting, cutaneous blood vessel dilation and constriction, and the raising or lowering of hairs.

Other Glands

In specific areas of the body of a dog or cat, you can find modifications of the three types of skin glands. *Anal sacs* are combinations of modified sebaceous and apocrine glands that lie on each side of the anus. These sacs produce a foul-smelling secretion that may have been used in the wild to mark territory. If a dog's anal sacs become full, the dog may rub its anus on the ground to squeeze the material out of the sacs and relieve the pressure in them. Occasionally, these glands become plugged up and even infected, which may require minor surgery.

On the dorsal surface of the tail, dogs and cats have high concentrations of sebaceous glands and/or apocrine sweat glands called the "tail glands." These tail glands can become infected or even cancerous. High concentrations of these glands can also be found in the lining of the ear canal, where they're responsible for producing ear wax, and may also become infected.

Claws and Dewclaws

One of the most common specialized skin structures is the *claw.* Claws can be found on many different animals. Claws improve traction during locomotion. They can also be used as a weapon for attack or defense. Other animals use claws for gathering food, tearing food apart, or holding food while carrying or eating it. The claw is simply a modified extension of the dermis and epidermis of the toe. It's composed primarily of horny, or keratinized, epidermal tissue. The outer surfaces of a claw are compressed side to side, making the claw narrower in the lateral directions than in the dorsal-to-ventral direction.

Inside the claw, where it joins the toe, lies vascular tissue, called the *quick,* which grows from the distal bone of the toe. When you trim the claws of a dog or cat, you may cut too much off and cut the quick, making the claw bleed. The less often the claw is trimmed, the further into the claw the quick grows. Conversely, if you trim the claw often, the quick recedes slowly back toward the bone. The dorsal portion of the claw grows faster than the ventral portion (the *sole*), making the claw curve downward as it grows out. Claws left untrimmed or unworn through use sometimes curl all the way around until they penetrate the skin of the toe or foot behind them. You may even see animals whose claws have grown back into the toe, through the toe, then penetrated out the dorsal surface of the toe again!

Dewclaws are remnants of toes that have progressively become smaller as animals evolved from a four-toed stance to a two-toed stance. Dewclaws are more similar to claws than hooves in structure.

Nails are found in primates (such as yourself) and are similar to claws. However, nails have only a keratin outer surface and don't possess a sole. Nails are flattened in the dorsal-ventral direction instead of laterally like claws.

Hooves

The second most common form of modified skin on the foot is the *hoof.* Hooves are found on animals such as horses, cattle, sheep, goats, pigs, antelopes, and so on. Hooves are somewhat less versatile than claws but serve their specific purpose very well. Animals primarily use hooves to move around. However, hooves can also be useful as weapons if the animal kicks with its legs.

The hoof is made of specialized horny epidermal tissue extending over the distal digit. In animals like the horse, only one digit, the middle toe, contacts the ground, so the hoof covers only one digit. In cows, sheep, and pigs, two toes contact the ground; therefore, the hoof covers both digits. Because of the different toe structure in these two different types of hoofed animals, the hooves are different. We'll examine each in turn.

In a horse's hoof, the part you see when the hoof is placed squarely on the ground is the *wall.* This is the hoof's outermost covering (see Figures 5-14 to 5-17 on pages 148–150 of your textbook). Only the very distal edge of the wall is in contact with the ground. The edge of the wall that contacts the ground is where the horseshoe is nailed into the hoof.

When you look at the bottom of a horse's hoof, you see the concave portion of the hoof. This concave portion extends from the outside wall to the ridge in the middle of the hoof, which is known as the *sole*. The sole covers the majority of the hoof surface but doesn't contact the ground much under normal circumstances. The sole is very soft compared with the wall. The sole can be sensitive, since the tissue isn't as horny and is more alive with sensitive blood vessels and nerve endings.

The horse has a central, roughly V-shaped ridge of soft horny material called the *frog.* This horny material isn't found in other hoofed animals like cattle and pigs. The *bars* are the junction of the sole and the frog, where the wall turns in from the posterior part of the foot and melds with the frog. The *bulb* is the soft tissue that covers the heel of the foot just behind the frog. The combination of harder and softer tissues in the horse's hoof creates a pumplike mechanism to keep a steady blood flow to the tissues of the hoof. Every time the hoof is placed on the ground, blood is pumped out of it. When the foot is raised, pressure in the foot drops so that blood can flow back into the foot.

The hooves of pigs and ruminants are less complicated than those of the horse and are often called *claws.* In this kind of hoof, the wall is similar to that of the horse. However, the sole is considerably smaller, and no frog is present. In pigs, the sole is even smaller, and the bulbs are more prominent.

Horns

Horns are perhaps the most unusual modification of the epidermis. They're composed of fibers that are intertwined, packed tightly together, and bound into a single unit by keratin. Horns are true derivatives of skin. They rise from the epidermis and grow throughout life.

The outer layer of a horn is composed of keratin. The inner layer, the *corium,* has small, finger-like projections that extend into the keratin wall to provide support and nutrition. Horns have their own internal blood supply and are partly supported near the base by a *horn core.* The horn core is a hollow extension of the frontal skull bone that communicates with the sinus cavities on the front of the skull. On the outside, the horny outer layer is covered at the base by a layer of softer keratinized tissue comparable to the hoof's periople.

Antlers are different from horns, although they have a similar outward appearance. The antler originates in the dermal layer and is a bony extension of the skull. Instead of an internal blood supply, the antler is supplied with nutrients from a thin outer covering of skin called the *velvet.* Antlers don't grow continuously but are shed and regrown every year and tend to appear only in males of the species.

Birds, Reptiles, and Amphibians

Birds

The avian epidermis is relatively thin, while the dermis is thicker. The dermis contains smooth muscles that innervate the feather follicles and aid in heat regulation. Birds don't have sweat glands. A unique gland present in most birds is the *uropygial,* or *preen, gland* on the dorsal surface at the upper base of the tail. This gland secretes an oily, fatty substance that serves to waterproof the feathers. The bird's beak, or bill, is also a derivative structure of the integument. It's covered with a tough, horny keratin layer. Claws also possess a horny layer derived from specialized scales at the end of each toe. The specific type of claws present varies depending on both the perching and feeding habits of the particular species. Claws and beaks grow continuously.

Feathers are made of protein and originate from a follicle. Besides their obvious uses for flight, feathers also protect the skin and aid in thermoregulation. Various species also use feather movements for communication.

There are six types of feathers (see Figure 19-6 on page 419 of your textbook).

1. *Contour feathers*—These are the most visible feathers and include the flight feathers of the wings and tail.
2. *Semiplume feathers*—These are usually found under contour feathers and provide insulation and aid with buoyancy in water birds.
3. *Down feathers*—These soft, fluffy feathers are located close to the skin and function primarily in insulation.
4. *Filoplume feathers*—These barbless feathers are located on the nape and upper back and play a role in controlling feather movement.
5. *Bristles*—These feathers may be found around the eyes, nostrils, mouth, or toes and play a role in the sense of touch.

6. *Powder down feathers*—These constantly growing feathers create a waxy powder that spreads throughout the rest of the plumage to clean it and provide waterproofing.

The process of feather replacement is called *molting.* The frequency and pattern of molting varies depending on the species. The process begins when a newly developing feather pushes an old one out. The newly emerged feather is covered by an epidermal covering called the *periderm.* The bird removes the periderm during preening. A developing feather is referred to as a *blood feather*. Injury to the feather during development can result in bleeding and usually prevents the feather from developing normally.

Reptiles

Reptile skin is keratinized relatively inelastic. The dermis contains *chromatophores,* pigment-containing cells that allow some species to change their skin color and pattern drastically. Some reptiles have structures within the dermis called *osteoderms* that provide protection. Most reptiles have distinct scales that can vary greatly in size and shape. Other structures such as crests, tubercles, spines, and dewlaps may also be present in some reptiles. Snakes have modified scales that cover the eyes called the *spectacle* or *brille.* The specific size, shape, and arrangement of the scales and scutes aids in species identification and is used in medical record keeping. Scale and scute nomenclature is important for species identification and medical recording.

The process of skin shedding in reptiles is properly termed *ecdysis* (shedding of the skin). Ecdysis occurs on a regular basis as part of normal reptile growth and may also occur in response to skin injury. The pattern and frequency of ecdysis varies depending on the species.

Amphibians

The epidermis of amphibians is very thin and pliable and may contain only a single layer of keratinized skin. Aquatic species lack keratinized epidermis. The amphibian dermis contains chromatophores as well as glands that produce various secretions. Some species' glandular secretions are toxic and serve as defense mechanisms. Amphibians regularly shed the outer layers of the epidermis and usually consume the exuvia.

Summary

As you've seen, the integumentary system is an extremely effective organ in providing protection for the body. Animals have adapted the skin to perform additional functions, including control of temperature and blood pressure, as well as forming weapons for defense. Think how difficult life would be without your skin! You would suffer from exposure to sunlight, from temperature and humidity fluctuations, and from infections. No matter how healthy your internal organ systems, they would suffer extensive damage without the skin. You literally owe your life to your skin!

Now, review the material you've learned in this study guide as well as the assigned pages in your textbook for Assignments 1–3. Once you feel you understand the material, complete *Self-Check 3.* Then check your answers with those provided at the end of this study guide. If you've missed any answers, or you feel unsure of the material, review the assigned pages in your textbook and this study guide. When you're sure that you completely understand the information presented in Assignments 1–3, complete your examination for Lesson 1.

Self-Check 3

1. The part of a horse's hoof that makes up the largest part of the hoof's bottom surface is the ________.

2. ________ gives color to the skin and hair.

3. List the three phases of hair growth.

____

____

____

Questions 4–10: Match the following terms with their definitions by placing the letter of the best definition in the blank space next to each term.

_______ 4. Periople	a. Secretion without loss of cell contents
_______ 5. Apocrine	b. Soft horny covering at the proximal end of the hoof wall
_______ 6. Tactile hair	c. Skin layer where fat is stored
_______ 7. Hypodermis	d. Whisker
_______ 8. Elastin	e. Type of sweat gland
_______ 9. Merocrine	f. Skin layer with collagen
_______ 10. Dermis	g. Fiber-like protein that gives skin flexibility

Check your answers with those on page 187.