CHAPTER 1

Basics of Structure and Function

CHAPTER OUTLINE

In general, the study of anatomy refers to the study of the structure of body parts and includes gross anatomy (identification by unaided visual means) and microscopic anatomy (identification by microscopic assistance that usually begins at the cellular level). The study of physiology is a study of the functions of the body, or as sometimes stated, "how the body works," and includes biophysical and biochemical processes and precludes a knowledge of anatomy. Although anatomy and physiology can be taught as separate entities, overlaps are unavoidable and it follows that greater productivity is obtained by integrating the two disciplines.

The study of anatomy and physiology is assisted by prerequisite courses, which include chemistry, physics, biology, and quantitative skills in mathematics. With this in mind, we will rely not only on your previous preparation, but also on the desire to advance your knowledge with application to animal anatomy and physiology. This chapter provides basics of structure and function that should be helpful to you as you study the chapters that follow.

THE CELL, ITS STRUCTURE AND FUNCTIONS

1. **What separates the cell cytoplasm from interstitial fluid?**
2. **What are organelles?**
3. **Define the nuclear membrane.**
4. **What does chromatin become in dividing cells?**
5. **Differentiate between granular and agranular endoplasmic reticula and their associated functions.**
6. **Are the vesicular structures of the endoplasmic reticulum separate or interconnected?**
7. **What is the function of the Golgi apparatus?**
8. **What organelle is the site of the citric acid cycle?**
9. **What is the principal substance of lysosomes?**
10. **What cellular function are the centrioles associated with? What is their location within the cell known as?**

Functional Anatomy and Physiology of Domestic Animals, Fifth Edition. William O. Reece and Eric W. Rowe.

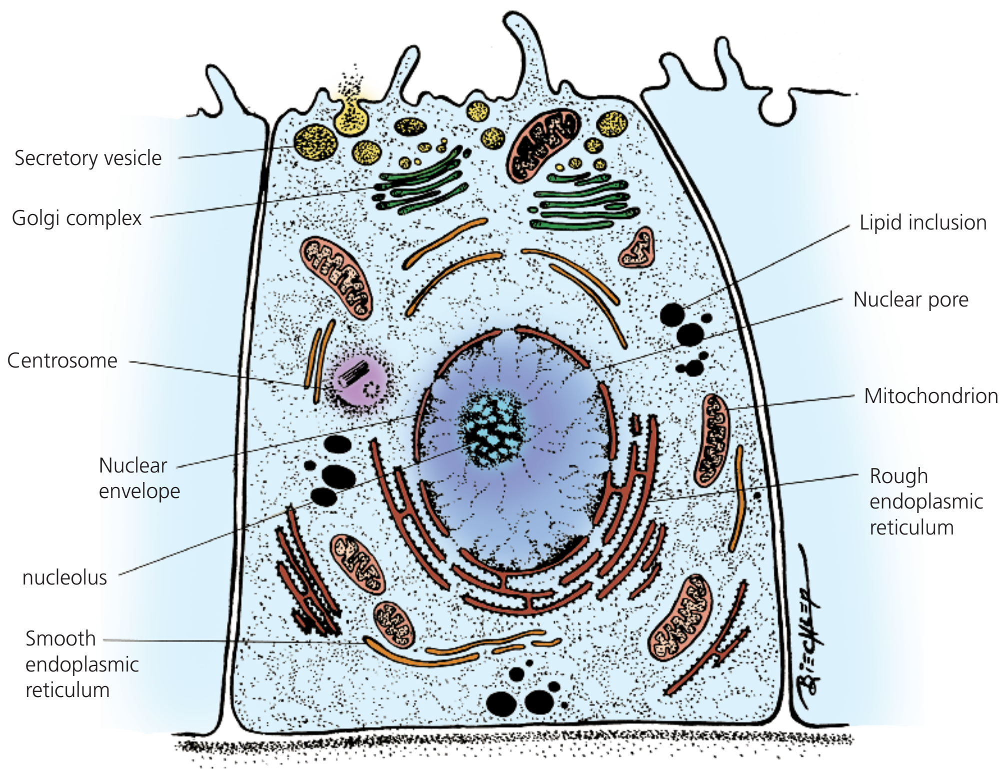
Companion Website: www.wiley.com/go/reece/functional

The number of cells in an animal is in the trillions and for the human has been estimated to be about 100 trillion. Each of these cells had their start beginning with fertilization of an oocyte. The appearance of cells varies with the organ of which they are a part and will be shown and described when encountered. Cells are highly organized chemical systems and share many features that are shown schematically in *Figure 1-1*. The basic components of a cell are the **plasma membrane (cell membrane)** that bounds the cell and gives it limits; the **cytoplasm**, which is the homogenous ground substance that forms the background in which the formed elements are suspended; and the **nucleus**. The nucleus is separated from the cytoplasm by a nuclear membrane and the cytoplasm is separated from the surrounding fluids (interstitial fluid) by a cell membrane. The cell membrane is usually pliable and is composed of phospholipids and proteins. The phospholipid molecules occur in two layers. The protein molecules may be associated with either the outer or inner layer and may penetrate completely or incompletely (see Chapter 2).

Because of cell specialization, no cell can be called typical. The cytoplasm is the location of diverse metabolic activities and is filled with both minute and large dispersed particles and organelles.

The Organelles

The **organelles** are highly organized physical structures represented in *Figure 1-1* and, in addition to the cell membrane, consist of the nucleus, endoplasmic reticulum, Golgi apparatus, mitochondria, lysosomes, and centrioles. These structures assist the cytoplasm with its metabolic activities by receiving materials into the cell, synthesizing new substances, generating energy, packaging materials for transport to other parts of the



■ **FIGURE 1-1** Schematic drawing of the general organization of a cell. (From Eurell JA, Frappier BL. Dellmann's Textbook of Veterinary Histology. 6th edn. Ames, IA: Blackwell Publishing, 2006.)

cell or to the circulation, excretion of waste products, and reproduction.

Nucleus

The nucleus is the control center of the cell, controlling its chemical reactions and reproduction. It contains large quantities of **DNA**. Nuclear components consist of a nuclear membrane, one or more nucleoli, and chromatin, all bathed in **nuclear sap (nucleoplasm)**. The **nuclear membrane** (also called nuclear envelope) consists of two membranes wherein the outer membrane is continuous with the endoplasmic reticulum, and the space between the two nuclear membranes, the lumen, is also continuous with the lumen of the endoplasmic reticulum. Numerous nuclear pores penetrate both layers. These pores permit exchange between the nucleoplasm of the nucleus and the cytoplasm of the cell, including movement of **RNA** synthesized in the nucleus, out into the cytoplasm. The **nucleolus** does not have a limiting membrane and is a structure that contains large amounts of RNA and proteins that are found in ribosomes. **Chromatin** appears as dark-staining particles throughout the nucleoplasm in the nondividing cell. In the dividing cell, the chromatin organizes into chromosomes.

Endoplasmic Reticulum

The **endoplasmic reticulum (ER)** is a network of tubular and flat vesicular (small thin-walled cavity) structures in the cytoplasm that all interconnect with one another. The fluid within the lumen of the ER is continuous with the fluid in the nuclear envelope and is different from the fluid in the cytoplasm. A large number of small granular particles called **ribosomes** are attached to the outer surfaces of many parts of the ER. Where these are present they are called the **granular** or **rough ER**, and where they are not present they are called the **agranular** or **smooth ER**. Ribosomes are composed of a mixture of RNA and proteins and function in the synthesis of proteins. The agranular ER functions in the synthesis of lipid substances and other enzymatic processes of the cell.

Golgi Apparatus

The **Golgi apparatus** is closely related to the ER. It is prominent in secretory cells, being well developed in cells secreting enzymes and hormones. It packages materials made in the cell and transforms them into units that are then distributed outside the cell. The packaging begins when vesicles pinch off from the ER and then fuse with the Golgi apparatus. The vesicular substances are then processed in the Golgi apparatus to form lysosomes or other secretory vesicles, which become surrounded by a membrane. They are then released from the Golgi apparatus for storage or use in the cell or are transported to the cell membrane, where they are released into the extracellular fluid as a secretion.

Mitochondria

Mitochondria are the "powerhouses" of the cell because they are the principal sites for energy production. The number in a cell depends on the amount of energy required, and mitochondria increase in number when cellular needs increase. A mitochondrion is composed of an outer and an inner membrane. The **inner membrane** has infoldings that provide **shelves** for the attachment of oxidative phosphorylation enzymes (enzymes for production of energy). The **inner cavity** consists of a **matrix** (supporting substance) that contains enzymes and coenzymes (cofactors) required for extracting energy from nutrients. The matrix is the site of the **citric acid cycle** (also known as the tricarboxylic acid cycle and Krebs cycle).

Lysosomes

The vesicular organelles called **lysosomes** are formed by the Golgi apparatus and then become dispersed throughout the cytoplasm. Because lysosomes contain digestive enzymes, their presence in the cytoplasm provides an intracellular digestive system allowing digestion of damaged cellular structures, food particles ingested by the cell, and bacterial cells.

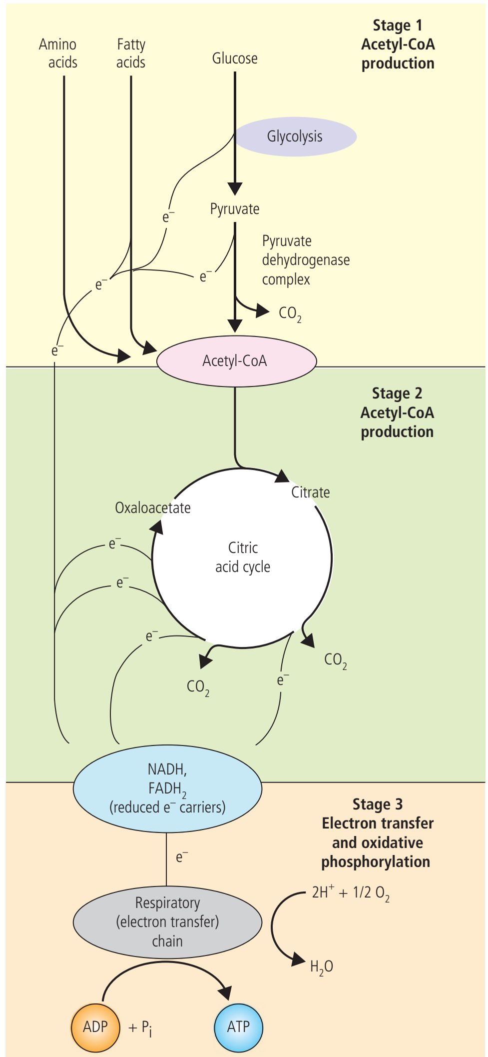
Centrosome

The centrosome is located in the cytoplasm, close to the nucleus, and contains two centrioles. The centrioles are usually oriented at right angles to each other and each consists of nine groups of three microtubules arranged in a circle. During cell division the centrosome serves as a spindle pole and helps to organize the microtubules.

■ ENERGY PRODUCTION

1. **What substance is formed from the catabolism of carbohydrates, lipids, and proteins to begin the aerobic stage of energy production via the citric acid cycle?**
2. **What are the cofactors involved in the transfer of electrons from the citric acid cycle to the electron transport chain?**
3. **Where are the electron receptors of the electron transport chain located?**
4. **What is the energy substance produced by oxidative phosphorylation?**
5. **What is metabolic water?**
6. **What is the location for oxygen consumption by the body?**

Within mitochondria, energy is released from molecules by controlled metabolic oxidation. The aerobic (occurring in the presence of oxygen) stage in the catabolism of carbohydrates, lipids, and proteins begins after the formation of acetyl-Co A from respective glucose, fatty acids, and some amino acids (*Figure 1-2*). The acetyl-Co A that has been formed undergoes oxidation via the citric acid cycle within the mitochondrial matrix. Oxidation of acetyl groups involves the abstraction of electrons and their transfer to the cofactors nicotinamide adenine dinucleotide (NAD) and flavin adenine dinucleotide (FAD), wherein the cofactors are reduced to NADH and $FADH_2$. The electrons carried by NADH and $FADH_2$ are funneled to the electron transfer chain, a chain of electron acceptors that are an integral part of the inner membrane (the shelf membrane) of the mitochondrion. In the electron flow that follows, adenosine triphosphate (ATP), a high-energy substance, is synthesized from adenosine diphosphate (ADP) in the process of oxidative phosphorylation. Also, NADH and $FADH_2$ are reoxidized and hydrogen ions



■ **FIGURE 1-2** Catabolism of proteins, fats, and carbohydrates resulting in the release of energy. Stage 3, via the electron transfer chain, provides for the oxidative phosphorylation of adenosine diphosphate (ADP) and the production of a high-energy substance, adenosine triphosphate (ATP). This is the location of oxygen consumption by the body and production of metabolic water. (Adapted from Nelson DL, Cox MM. Lehninger Principles of Biochemistry. 3rd edn. New York: Worth Publishers, 2000.)

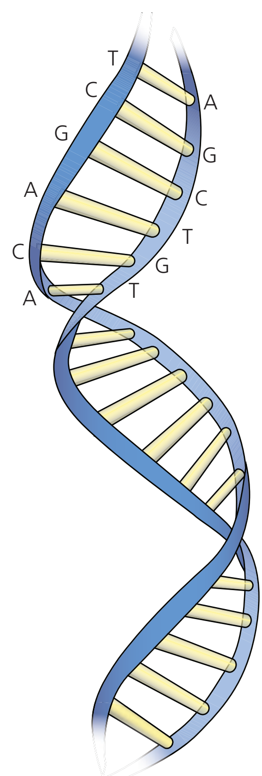
(H^+) combine with oxygen (O_2) to form water (H_2O). About 90% of the total ATP formed by glucose metabolism is formed during oxidative phosphorylation, described above. The water formed at this location is referred to as metabolic water (see Chapter 2), and oxygen consumption for the body also occurs at this location (see Chapter *10*).

■ FUNCTIONS OF DNA AND RNA

1. **What comprises each chromosome?**
2. **What are the chemical bases that make up the two nucleotide chains of DNA?**
3. **How are the two nucleotide chains bound together and what are the complementary positions of the bases?**
4. **What is the relationship of the histone proteins to the nucleotide chains?**
5. **Where is the chemical location for the beginning of DNA replication?**
6. **What is the point of attachment of the two newly formed chromosomes (chromatids) called?**
7. **Describe a gene as related to the DNA molecule.**
8. **What are the four stages of mitosis?**
9. **What is the name of each pair of replicated centrioles?**
10. **Visualize and describe each of the four stages of mitosis, recognizing interphase as a period between successive sequences.**
11. **Is DNA in the nucleus able to enter the cytoplasm to initiate the synthesis of protein?**
12. **What are the separate functions of mRNA, tRNA, and rRNA?**
13. **How is protein synthesis related to allergies and tissue rejection by individual animals?**

DNA and Its Replication

The nucleus is composed mostly of the **chromosomes**, those structures providing for inherited and individual characteristics of an animal. Each chromosome is made up of a large molecule of DNA wrapped in the form of **double helices** (a helix is a spiral form) around a core of histone proteins. DNA is made up of two extremely long **polynucleotide chains**, each containing the **purine bases** adenine and guanine and the **pyrimidine bases** thymine and cytosine (*Figure 1-3*). A **nucleotide** is formed by the combination of one molecule of phosphoric acid, one molecule of deoxyribose, and one of the four bases. The chains are bound together by hydrogen bonding between the bases, with adenine bonding to thymine and guanine to cytosine. The bonding relationship is referred to as **complementary** (i.e., they are not identical). Whenever adenine

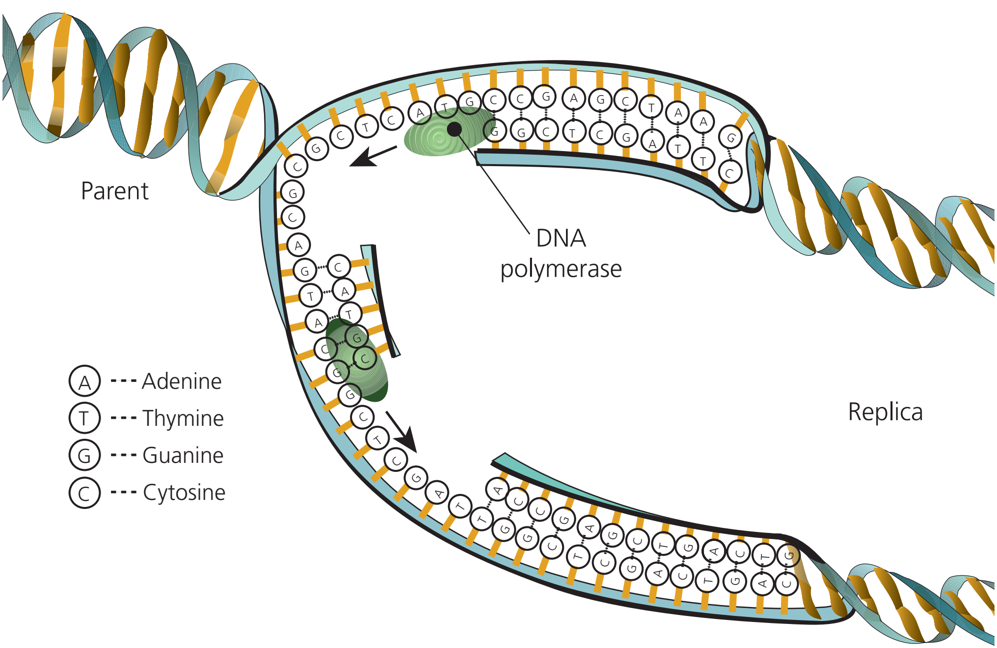


■ **FIGURE 1-3** Two polynucleotide chains constitute the double helix of the DNA molecule. Obligatory base pairing occurs between A (adenine) and T (thymine), and also between G (guanine) and C (cytosine). The chains are held together by hydrogen bonding between bases. Histone proteins form a core between the nucleotide chains.

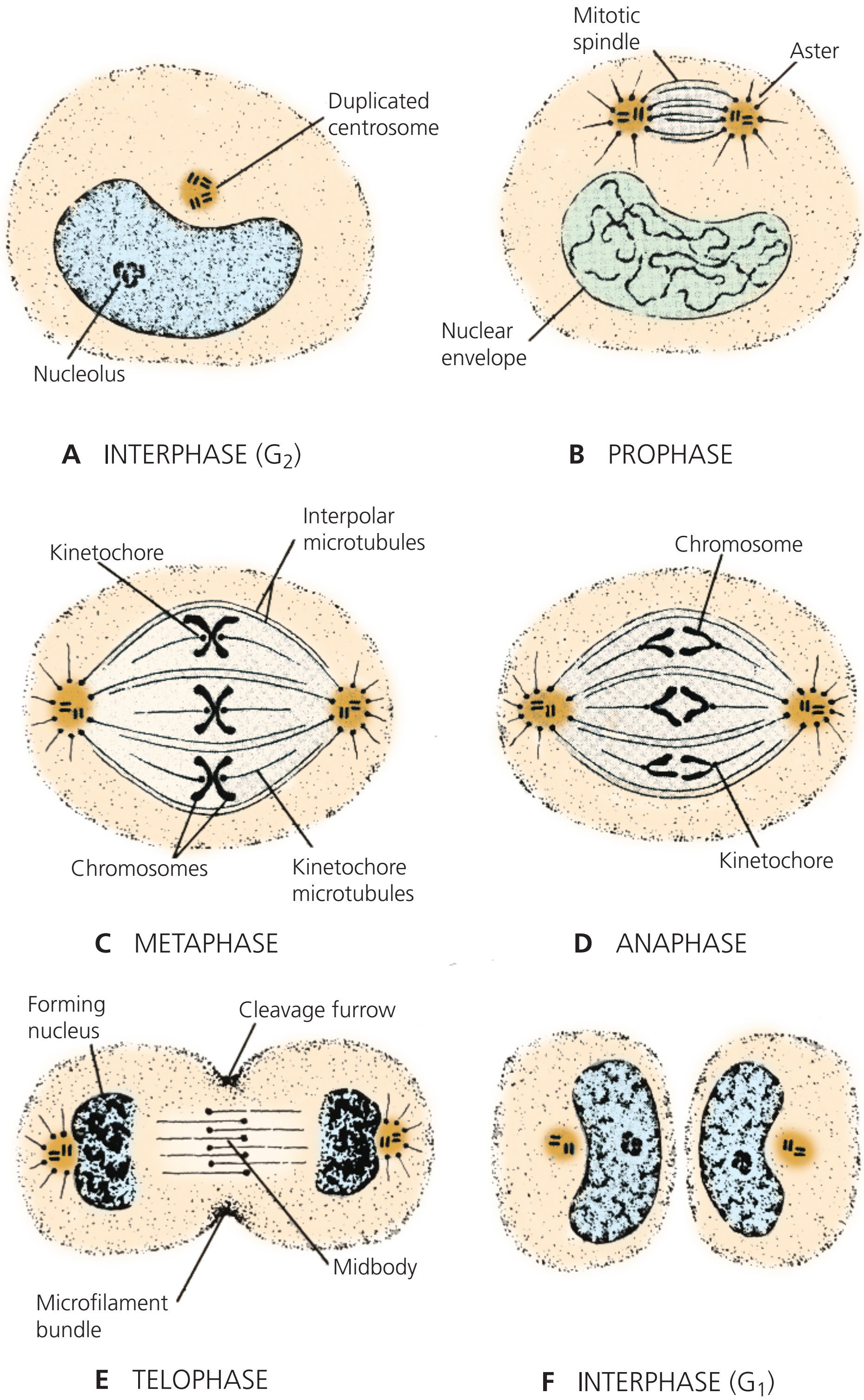
appears on one strand, thymine will be in the same position on the opposite strand. The **histones** are positively charged proteins that associate strongly with DNA by ionic interactions with its many negatively charged phosphate groups. About half of the mass of chromatin is DNA and half is histones. The whole complex of DNA and histones is called chromatin. Before cell division, the coiling around the histone proteins is loosened and replication of DNA begins by splitting the double helices at the point of junction of complementary bases. The separate strands then serve as a template for the formation of its complementary base when replication (making a facsimile or copy) takes place (*Figure 1-4*). The result is that each of the two original strands of each chromosome is now paired with a new complementary strand, forming two spiral helix chromosomes wherever there was one before. The two newly formed chromosomes remain temporarily attached to each other (until the time for mitosis) at a point called the centromere, located near their center. These duplicated but attached chromosomes are called chromatids. The units of heredity are the genes on the chromosomes, and each gene is a portion of the DNA molecule. Large numbers are attached end-on-end on the long, double-stranded, helical molecules of DNA that have molecular weights measured in the billions.

Mitosis

Mitosis is the division of somatic cells (body cells, as opposed to reproductive cells) in which complex nuclear division precedes cytoplasmic fission and involves a sequence of four stages: **prophase**, **metaphase**, **anaphase**, and **telophase** (*Figure 1-5*). The period between successive sequences is called **interphase**. Prior to initiating mitosis two important things must be duplicated: (1) The chromosomes (DNA) and (2) the centrosome. The centrosome is made up of



■ **FIGURE 1-4** Replication of DNA. Coiling around histone proteins is loosened and the double helices split at a point of junction of complementary bases. The separate strands serve as a template for formation of its complementary base. Two new double-helix chromosomes formed where only one was before. (From Frandson RD, Wilke WL, Fails AD. Anatomy and Physiology of Farm Animals. 7th edn. Ames, IA: Wiley-Blackwell, 2009.)



■ **FIGURE 1-5** Diagrammatic representation of the stages of mitosis. See text for details. (From Cormack DH. Ham's Histology. 9th edn. Philadelphia, PA: JB Lippincott Company, 1987.)

two centrioles and when duplicated each will serve as a future pole during cell division. In *Figure 1-5A* the centrosome has duplicated, as indicated by the four centrioles located within it. As prophase begins, the two centrosomes separate and begin to move to opposite poles of the cell (*Figure 1-5B*). In the process, each centrosome sends microtubules in all directions and is now referred to as an aster. When microtubules from each aster connect with each other they form the mitotic spindle. As the cell enters metaphase (*Figure 1-5C*) the nucleus breaks down and allows some of the spindle microtubules to interact with a specialized region on the duplicated chromosomes, referred to as the kinetochore. The microtubules that connect with the kinetochore are referred to as kinetochore microtubules while those that connect the two poles are interpolar microtubules. The interaction between the microtubules and chromosomes results in the chromosomes being aligned at the midway point between the spindle poles. As anaphase starts, the duplicated chromosomes separate and are pulled in opposite directions towards one of the spindle poles by the kinetochore microtubules (*Figure 1-5D*). In telophase, the chromosomes arrive at their respective spindle pole and a new nucleus forms around the chromosomes (*Figure 1-5E*). At the end of anaphase/beginning of telophase, a constriction called the cleavage furrow develops around the middle of the cell, which will finish by separating the cytoplasm so two daughter cells are created, each with their own nucleus and cytoplasm.

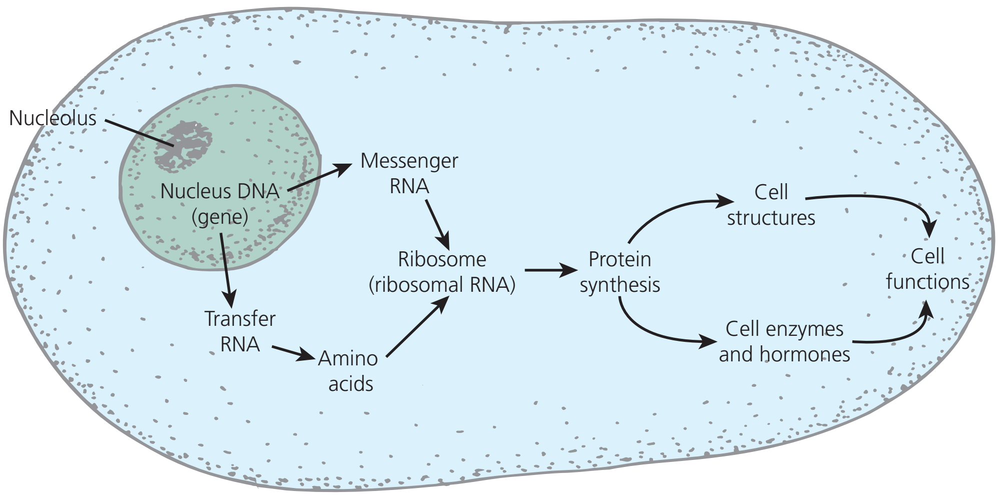
RNA and Protein Synthesis

Genes control the formation of cell proteins by a complex process of coding, the so-called genetic code. Because of its large size and inability to enter the cytoplasm, DNA in the nucleus is not able to directly control the synthesis of protein that occurs in the cytoplasm. RNA molecules that are synthesized from DNA accomplish this. The first of these, messenger RNA (mRNA), moves into the cytoplasm through nuclear pores carrying the code for the synthesis of proteins (transcription) and establishes a position with a granular ER ribosome where protein molecules are made. A second, transfer RNA (tRNA), is synthesized by DNA and moves to the cytoplasm, where it picks up an amino acid and carries it to the mRNA. There the amino acid is fitted into the code for the production of a specific protein molecule (translation). Each of 20 tRNAs are specific for each of the 20 amino acids. The third type of RNA is ribosomal RNA (rRNA), found in ribosomes. It is believed that it serves as a physical structure on which the protein is formed. The sequence of protein synthesis is shown in *Figure 1-6*. Because of the transfer of information required for protein synthesis from DNA molecules in the nucleus, it can be seen that proteins are specific to each individual animal. Introduction of proteins foreign to an animal results in allergies, tissue rejection, and other incompatibilities.

■ EMBRYOLOGY

1. **Differentiate between diploid and haploid.**
2. **How does meiosis contrast with mitosis?**
3. **What is meiosis accompanied by division of the cells called in the female and in the male?**
4. **Define embryology.**
5. **Differentiate among gamete, zygote, morula, and blastocyst.**
6. **What does the trophoblast contribute to in fetal development?**
7. **Name the three germ layers established as embryonic development proceeds.**
8. **What two major events are signified by the development of the germ layers?**

Fertilization is the first event of reproduction at the cellular level and requires the joining of the female sex cell (gamete), known as the oocyte, with the male

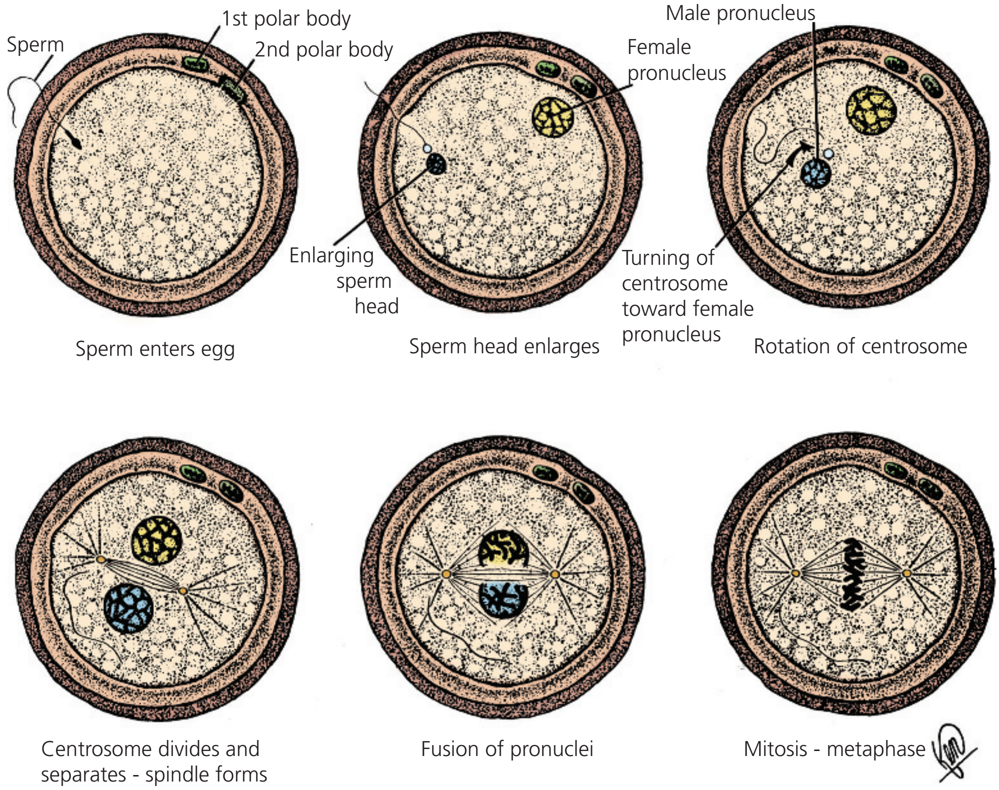


■ **FIGURE 1-6** A schematic summary of genetic coding and its role in protein synthesis and related cell functions.

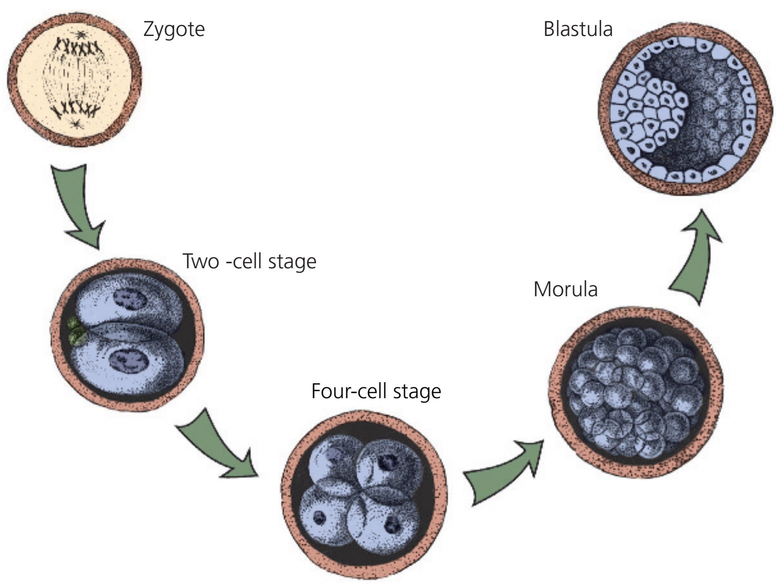
gamete, known as the **spermatozoon**. So that the fertilized oocyte will have the normal number of chromosomes (**diploid** or **2n**), each gamete must be reduced in chromosome numbers by one-half (**haploid** or **n**) while still in the reproductive systems of the respective female and male. This reduction in chromosomes is called **meiosis**, in contrast to **mitosis**, whereby each cell after division retained the 2n chromosome number. Meiosis accompanied by division of the cells is called **oogenesis** in the female and **spermatogenesis** in the male. The joined gametes, now known as a **zygote**, will have the proper number of chromosomes (2n) for the species, and further development beyond fertilization will proceed by mitosis. Fertilization and the beginning of mitosis for the formation of a new individual are shown in *Figure 1-7*. For further details of spermatogenesis, oogenesis, and fertilization, see Chapters *14* and 15.

Embryology is the study of prenatal (before birth) development of an individual and, as indicated above, it begins with the zygote. Mitotic divisions continue and form a cluster of cells known as a **morula** that proceeds to a **blastula** (*Figure 1-8*). The cavity of the blastula, the **blastocele**, is formed when uterine fluid diffuses into the spaces between the cells of the morula. As the fluid accumulates, it gradually separates the cells into an outer layer of cells called the **trophoblast** and an **inner cell mass** that forms the body of the embryo (*Figure 1-9A*). The trophoblast contributes to the **fetal placenta (extraembryonic membranes)** that secures the position of the embryo in the uterus and provides for its nutrition from the maternal connection (see Chapter *15*).

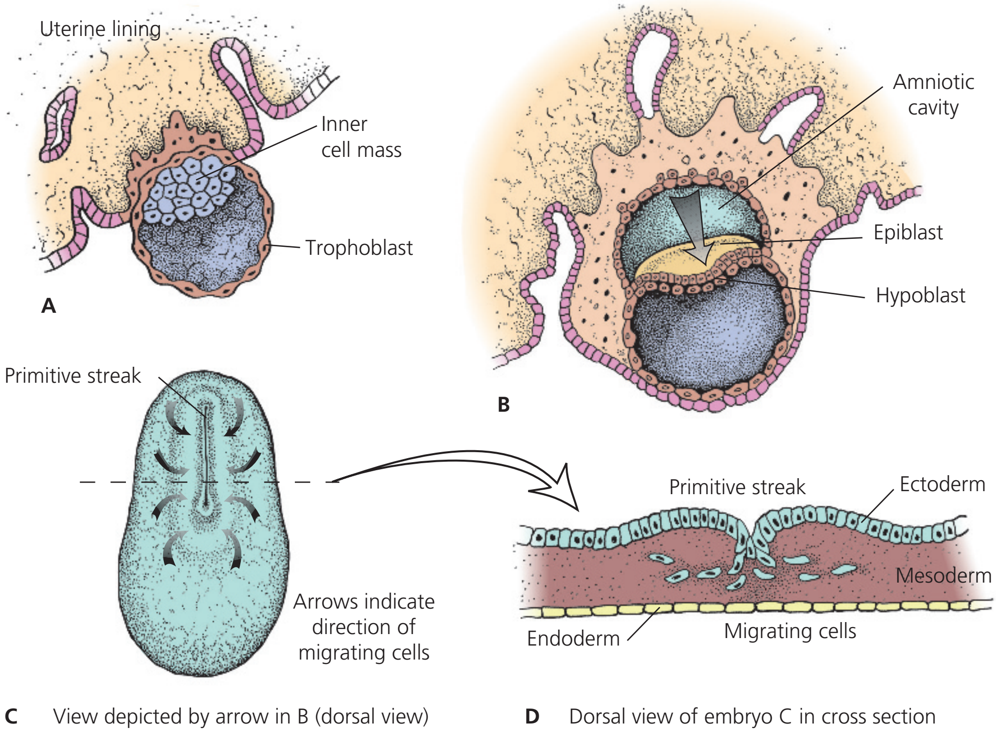
The portion of the inner cell mass closest to the trophoblast is the **epiblast** and the portion adjacent to the blastocele is the **hypoblast** (*Figure 1-9B*). The cavity formed dorsal to the epiblast is the **amniotic cavity** of the embryo (see Chapter *15*). Proliferating hypoblast cells migrate to line the blastocele. This lining becomes the **endoderm**. The endoderm grows into the blastocele and generates the lungs, gut, liver, and other visceral organs. The **ectoderm** develops from proliferating outer cells of the inner cell mass (epiblast cells) and migrates toward a longitudinal axis location known as the primitive streak, a thickening of epiblast cells (*Figure 1-9C*). Skin and all of its derivatives (e.g., hair, hooves, mammary glands) and the entire nervous system are formed from ectoderm. The cells between ectoderm and endoderm become **mesoderm** (*Figure 1-9D*). The mesoderm grows between the ectoderm and endoderm and splits into two layers that form a cavity between the



■ **FIGURE 1-7** Schematic diagrams of fertilization. Meiosis in spermatozoa and oocytes (division of chromosome numbers by one-half) occurs while in respective male and female reproductive systems. Entrance of a spermatozoon into an oocyte is followed by fusion of respective pronuclei to form a zygote with a proper chromosome number (2n or diploid). Cell division will proceed by mitosis to form a new individual. (From Crouch JE. Functional Human Anatomy. 4th edn. Philadelphia, PA: Lea & Febiger, 1985.)



■ **FIGURE 1-8** Continued mitotic division from zygote to blastula. (From Frandson RD, Wilke WL, Fails AD. Anatomy and Physiology of Farm Animals. 7th edn. Ames, IA: Wiley-Blackwell, 2009.)



■ **FIGURE 1-9** The formation of the germ layers, ectoderm, mesoderm, and endoderm. **A.** Embryo embeds in the wall of the uterus. **B.** Formation of epiblast and hypoblast layers. The amniotic cavity is formed dorsal to the epiblast, and the hypoblast cells migrate to line the cavity of the blastula (blastocele), which becomes endoderm. **C.** Embryo viewed from above. The primitive streak is a thickening of epiblast cells on the longitudinal axis that migrate toward the primitive streak and become ectoderm. **D.** Cross-section through the region of the primitive streak showing migration of cells between ectoderm and endoderm that become mesoderm. (From Frandson RD, Wilke WL, Fails AD. Anatomy and Physiology of Farm Animals. 7th edn. Ames, IA: Wiley-Blackwell, 2009.)

two layers known as the **coelom (precursor of body cavities)**. The pericardial, pleural, and abdominopelvic cavities are derived from the coelom. Skeletal, smooth, and cardiac muscle, the kidneys, the skeleton, and other connective tissues develop from mesoderm. The establishment of the germ layers is the first segregation of cell groups clearly distinct from one another by way of their definite relations within the embryo. Also, establishment of the germ layers marks the transition between that period of development when an increase in the number of cells was the only outstanding event to one when differentiation and specialization are the dominating aspects of growth. The germ layers are the source of all body structures.

■ TISSUES

1. **Differentiate among cells, tissues, organs, and systems as units of structure in the body.**
2. **Name the four basic tissues in the body.**
3. **Where are the general locations of epithelium?**
4. **What is the function of a basement membrane?**
5. **How does epithelium receive nutrition and discharge waste?**
6. **How is epithelium classified according to the number of cell layers?**
7. **How is epithelium classified according to the shape of the surface cells?**

8. **Where are the locations of endothelium, mesothelium, and mesenchymal epithelium that are derived from mesoderm and have the appearance of simple squamous epithelium that is derived from ectoderm or endoderm?**
9. **Know where each of the several classifications of epithelium is located.**
10. **What is the distinguishing feature between endocrine and exocrine glands?**
11. **Differentiate among holocrine, merocrine, and apocrine glands.**
12. **What are the two types of epithelial membranes and where are they located?**
13. **What are the chief functions performed by the connective tissue types?**
14. **What cells produce the intercellular substance of ordinary connective tissue?**
15. **What are the intercellular substances of loose connective tissue? How do they differ?**
16. **Differentiate between dense regular and irregular connective tissue.**
17. **Recognize that cartilage, bone, and blood are other elements of connective tissue.**

In considering units of structure within the body, a first consideration involved the cell. The next involves **tissues**, which, as a unit, are composed of cells having similar features of structure and function. Two or more tissues, when combined to perform certain functions, are known as **organs** (e.g., the heart and liver are organs). Combinations of organs of similar or related functions, working together as a unit, are represented by **body systems** (e.g., the digestive system and the respiratory system). Most of this book is organized by systems, wherein the cells, tissues, and organs for a system will be studied to recognize the contribution of each in providing for the system's function.

There are four basic tissues in the body, namely: (1) **epithelial tissue (epithelium)**, (2) **connective tissue**, (3) **nervous tissue**, and (4) **muscle tissue**. Unlike nervous and muscle tissues, epithelial and connective tissues are not considered in individual chapters as a system. Therefore, some identifying features will now be given.

Epithelium

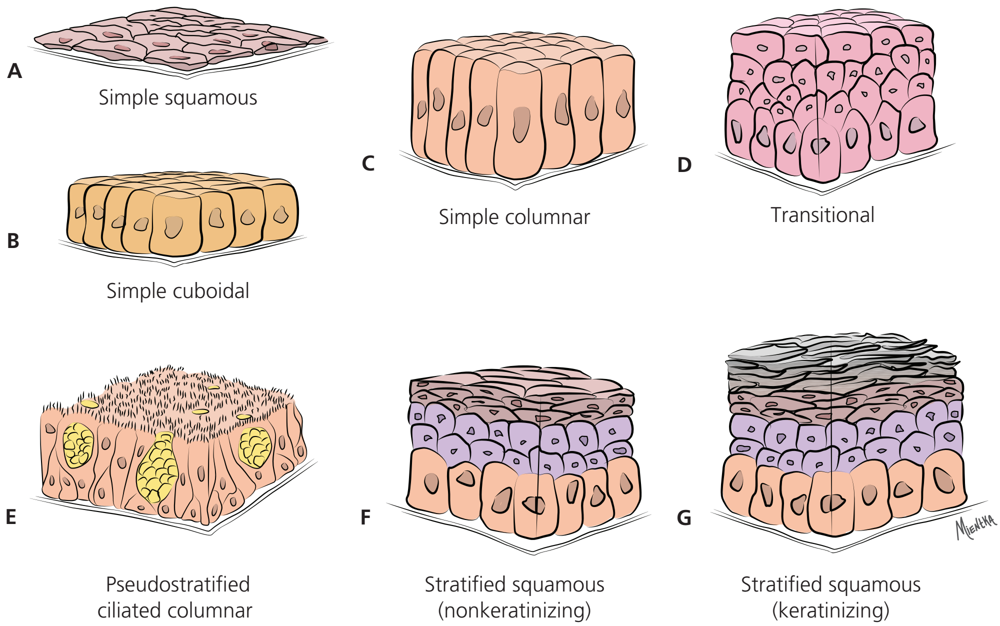
Epithelial tissues cover the body surface, line body cavities, and form glands and other structures (e.g., hair, hooves, and horns). With few exceptions, epithelium originates from ectoderm or endoderm, and the cells lie on a noncellular basement membrane. The **basement membrane** serves an adhesive function so that the cells are held closely to the underlying connective tissue, thereby giving greater strength to the tissue.

Epithelial tissues are not penetrated by blood vessels but rather receive nutrition and discharge waste by diffusion via blood vessels in the underlying or neighboring connective tissue.

Classification

When classified according to the number of layers of cells in the tissue, **simple epithelium** (one layer) and **stratified epithelium** (two or more layers) are recognized. There is also a classification according to shape of the surface cells, namely: (1) **squamous** (thin and plate-like), (2) **cuboidal**, being about equal in height and width (appear square in a cut perpendicular to the surface), and (3) **columnar**, in which the cells are taller than they are wide and in a perpendicular section are rectangular.

The types of epithelium that commonly exist throughout the body are illustrated in *Figure 1-10*. It will be noted that each is identified according to the number of layers



■ **FIGURE 1-10** Epithelial tissue classifications. The epithelial cells are shown lying on a noncellular basement membrane that serves an adhesive function holding the cells closely to the underlying connective tissue.

and also the shape of the cell, and the following are identified:

1. Simple squamous epithelium (*Figure 1.10A*).

   Simple squamous epithelium consists of a single layer of thin, flat cells of irregular outlines that fit together, with cement substances between their borders, to form a continuous, thin membrane. It is not adapted to withstanding wear and tear but rather to performing a filtering function (e.g., some portions of kidney tubules).

   There are three tissues that have the same appearance as simple squamous epithelium but differ because they are derived from mesoderm rather than ectoderm or endoderm. In these instances they are known as endothelium, mesothelium, and mesenchymal epithelium. **Endothelium** is the simple layer of squamous cells forming the inner lining of the heart, blood vessels, and lymph vessels. **Mesothelium** is the simple squamous epithelium that lines the great body cavities (pleura and peritoneum). **Mesenchymal** epithelium is found in more discrete locations such as the linings of the subarachnoid spaces (in the brain) and chambers of the eye.

2. Simple cuboidal epithelium (*Figure 1-10B*).

   This is a widely distributed tissue, and examples are found in the choroid plexus of the nervous system, the outer covering of the nervous system, the outer covering of the ovary (reproductive system), and the lining of follicles in the thyroid gland (endocrine system).

3. Simple columnar epithelium (*Figure 1-10C*).

   This tissue provides the lining for the digestive tract. The cells may be absorptive, secretory, or both. A common secretory function of these cells is secretion of mucus on the surface of epithelial membranes, and in this capacity they provide a protective function. There are also simple columnar ciliated tissues. **Cilia** are motile extensions of a cell surface that move tubular contents in a single direction. An example of their presence is in the uterine tubes (oviducts).

4. Transitional epithelium (*Figure 1-10D*).

   This tissue is common to the lining of the muscular urinary bladder. It is a stratified epithelium with a varied appearance depending on the fill of the bladder. When the bladder contracts, the epithelium piles up into many layers, but when the bladder fills and is stretched, only two or three layers of cells can be seen.

5. Pseudostratified ciliated columnar with goblet cells (*Figure 1-10E*).

   These tissues seem to consist of many layers but actually have only one layer. The one shown is ciliated, but there are also those that are nonciliated. The stratified appearance is caused by some of the cells being short and other taller cells overlapping them. They both share a common basement membrane. The type shown, with cilia and goblet cells, are found in the respiratory tract. The **goblet cells** provide for a wet surface for entrapment of inhaled particles, and the cilia direct the wet surface toward the mouth.

6. Stratified squamous (*Figure 1-10F* and *G*).

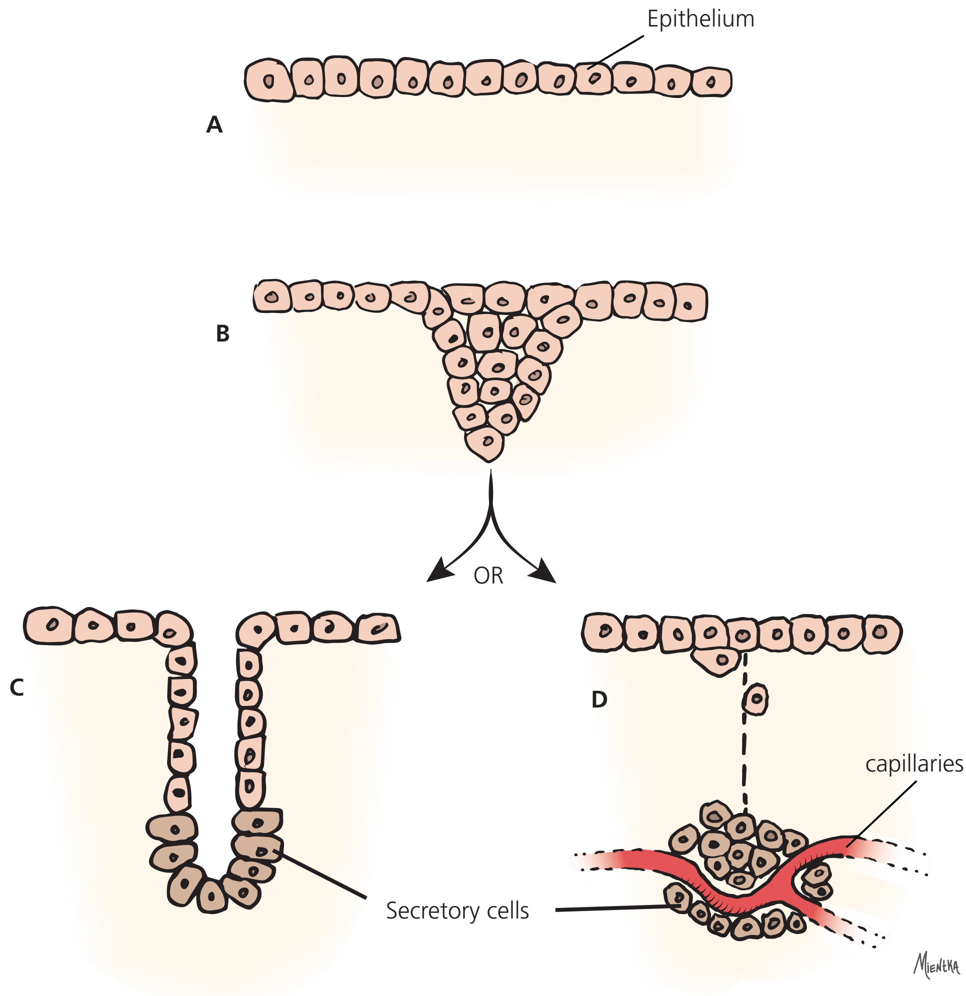
   Stratified membranes serve chiefly to protect. They can withstand more wear and tear than simple membranes. There are different kinds and degrees of protection needed at different places in the body and, accordingly, stratified membranes have dissimilarities. The kind shown in the illustration is nonkeratinized stratified squamous epithelium (*Figure 1-10F*) and is found on wet surfaces subjected to wear and tear. The inside of the mouth and esophagus have this lining, giving protection from coarse foods. Only the surface cells are actually squamous, the deepest layer (on the basement membrane) of cells is columnar. As the deep layer cells undergo mitotic division, the outer cells flatten, die, and finally slough (separate) from the surface. In this way the tissue renews itself. The epidermis (outer layer) of skin is stratified squamous keratinized tissue (*Figure 1-10G*). This differs from nonkeratinized epithelium in that the superficial cells are **keratinized** (also called **cornified**). The cells of this type are also fused with each other. The cornified and fused layer minimizes fluid loss from the body by evaporation and gives greater protection from wear and tear.

Glands

The glands of the body are classified as exocrine or endocrine. Both are secretory, but **exocrine glands** are those that have secretions to the outside of the body (this includes organ lumens) and **endocrine glands** are those that secrete within the body. Exocrine glands must be provided with ducts, which are tubes that convey the glandular secretions to a free surface of the body. Because endocrine secretions are those within the body, no ducts are needed and so they are often referred to as **ductless glands**.

Development of both glands is shown schematically in *Figure 1-11*. It is noted that both originate as a result of surface epithelial cells growing, in the form of either a cord or a tubule, into the connective tissue beneath the membrane. After invasion of the connective tissue, a gland is formed by means of further proliferation and differentiation. The epithelial connection between the gland and surface is retained for exocrine glands, whereas the connection disappears for endocrine glands. Those cells that form the secretory unit secrete their substances into a central cavity or lumen.

Holocrine, **merocrine**, and **apocrine glands** refer to the manner in which the secretory cells of the gland elaborate their secretions. A cell within **holocrine glands** accumulates secretory products in its cytoplasm and then dies and disintegrates. The dead cell and its products constitute the secretion (i.e., the entire cell is secreted).



■ **FIGURE 1-11** The development of exocrine and endocrine glands. **A.** Surface epithelial cells. **B.** Epithelial cells invading into the connective tissue. **C.** An epithelial connection is maintained in exocrine glands but is lost for endocrine glands (**D**).

The sebaceous (oily, fatty) glands of the skin are of this type.

Merocrine glands secrete without any part of the cell being lost. Secretory granules are cytoplasmic inclusions and, although produced by the cytoplasm, they are not actually part of the cytoplasm. Therefore, the secretory granules pass into the lumen of the secretory unit without loss of the secretory cells' cytoplasm. The pancreas and salivary glands are in this group.

Apocrine glands are intermediate between holocrine and merocrine glands because their secretions gather at the outer ends of the gland cells and then pinch off to form the secretions. The mammary glands and some sweat glands belong to this group.

Epithelial Membranes

Epithelial membranes consist of a surface layer of epithelium and an underlying layer of connective tissue. Two kinds that are of importance in the body are mucous membranes and serous membranes.

Mucous membranes, referred to as mucosae, line the hollow organs and cavities that open on the skin surface of the body. These membranes line most of the organs of the digestive, respiratory, urinary, and reproductive systems. The surface epithelium may vary in type, but it is always kept moist by mucus. The connective tissue underlying the epithelium is referred to as the lamina propria.

Serous membranes, referred to as **serosae**, line the body cavities and cover the surfaces of related organs. The surface epithelium is mesothelium over a thin layer of loose connective tissue. The mesothelium provides fluid that serves to moisten and lubricate. Pleura (lining the thorax), pericardium (lining the cavity around the heart), and peritoneum (lining the abdomen and pelvic cavities) are examples of serous membranes.

Connective Tissue

A wide range of tissues that share a common origin from mesoderm represents connective tissues. The chief functions performed by the various cells of the different types of connective tissue follow: (1) production of intercellular substances, (2) storing fat (adipocytes), and (3) production of the various blood cells, which in turn have specific functions (e.g., phagocytosis of bacteria and production of antibodies). The intercellular substance of chondrocytes and osteocytes (cartilage and bone) are connective tissues specialized for the support of the body. **Cartilage**, **bone**, and **blood** are elements of connective tissue that will be described in separate chapters.

Ordinary Connective Tissues

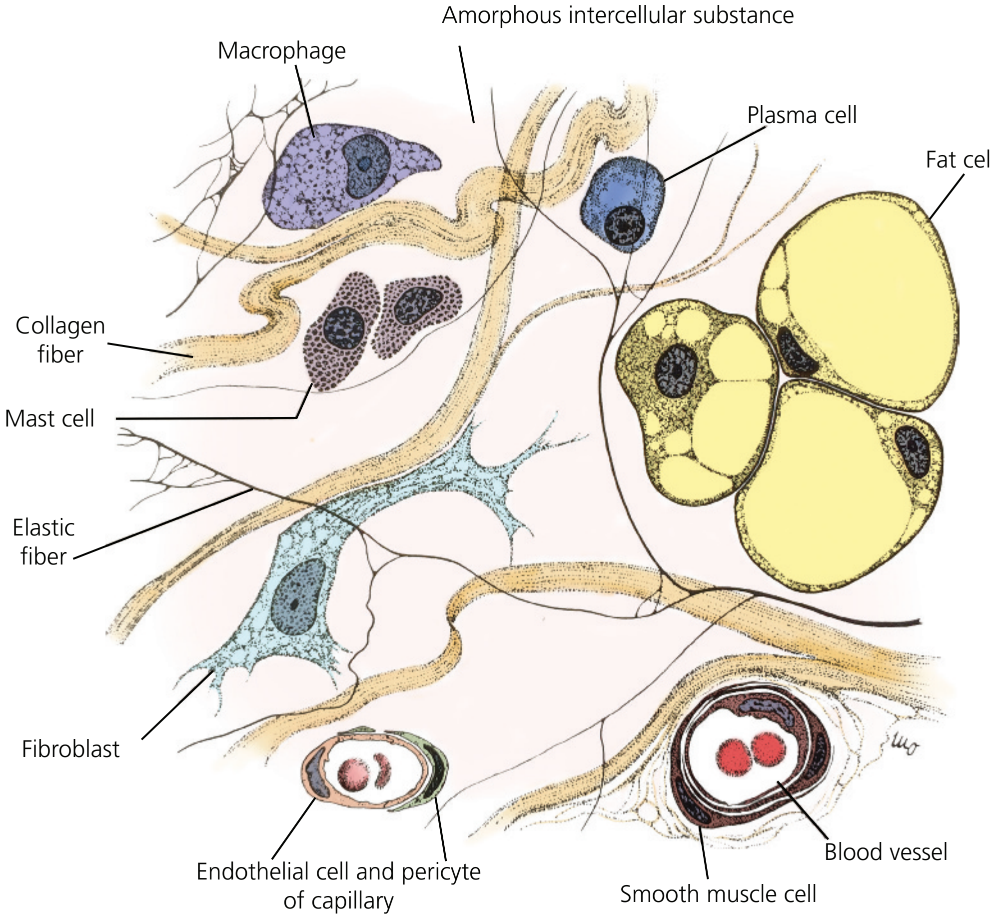
Ordinary connective tissues connect other tissues and are classified as either loose or dense.

Loose connective tissue contains a variety of different cell types. Loose connective tissue is widely distributed in the body, where it makes up the subcutaneous tissue or superficial fascia. It penetrates between organs to fill space and bind structures together. Because of its loose nature, it allows for movement of muscles relative to one another. **Fibroblasts** are the cells that produce the intercellular substance of ordinary connective tissue. When less active during adult life, fibroblasts are often referred to as **fibrocytes**.

Important intercellular substances of loose connective tissue are (1) collagenous or white fibers, (2) elastic or yellow fibers, (3) reticular fibers, and (4) amorphous ground substance.

Collagenous fibers appear as wavy ribbons. They are strong and inelastic and are composed of collagen, a family of closely related proteins. **Elastic fibers** are long cylindrical threads or flat ribbons. They tend to regain their original shape after being stretched. They are found in the walls of elastic arteries and are mixed with other tissues wherever elasticity is needed. **Reticular connective tissue fibers** are fine and highly branched. They make up part of the framework of endocrine and lymphatic organs and also form networks where structures are adjacent to connective tissue, as found along the blood vessels, in basement membranes, and around nerve, muscle, and fat cells. Like collagenous fibers, they are inelastic. The above fibers are imbedded in **amorphous** (without form) **ground substance**. The viscosity of amorphous ground substance varies from fluids to gel. *Figure 1-12* illustrates cells and fibers that might be seen in a microscopic section of loose connective tissue.

Dense connective tissues contain essentially the same fiber elements as loose connective tissues. There are two types, **dense regular** and **dense irregular**. The regularity relates to the arrangement of the fiber elements. In dense regular connective tissue, the fibers (especially collagenous fibers) are



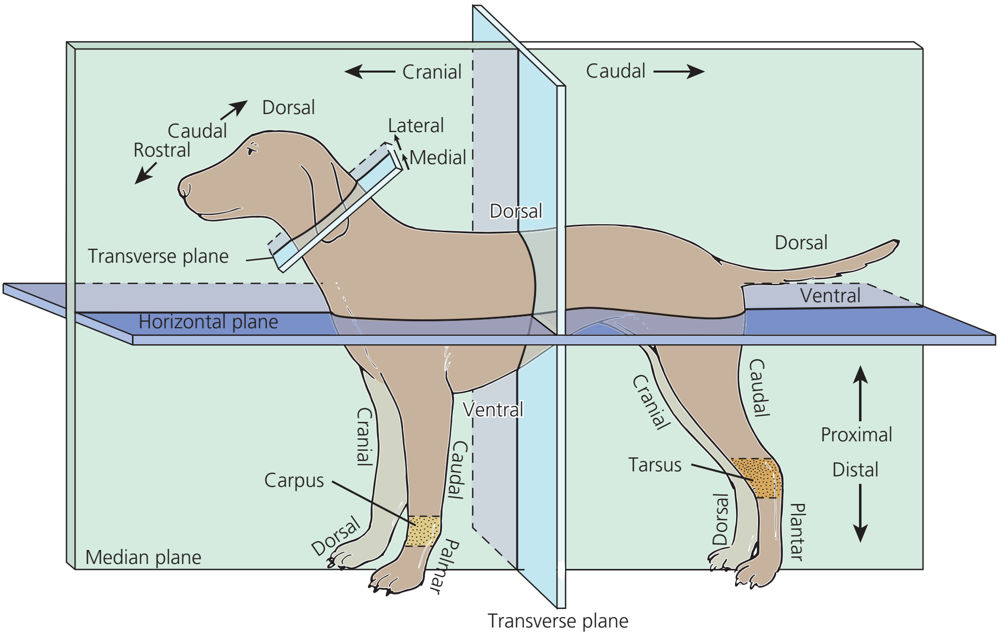
■ **FIGURE 1-12** Fibers and cells of loose connective tissue. Mast cells are usually found close to small blood vessels and have granules containing potent inflammatory mediators (e.g., histamine). Macrophages are phagocytic and plasma cells are the source of circulating antibodies (immunoglobulins). Pericytes are intimately associated with blood capillaries and venules, providing a potential source of new fibroblasts and smooth muscle cells. (From Cormack DH. Ham's Histology. 9th edn. Philadelphia, PA: JB Lippincott Company, 1987.)

arranged in parallel bundles forming tendons. In ligaments, the collagenous fibers are not as regularly arranged and may be mixed with elastic fibers. The ligamentum nuchae in the necks of grazing animals has a predominance of elastic fibers. In dense irregular connective tissue, the collagenous fibers are interwoven and compacted to form a dense matting. This type is found in the dermis of the skin. The dermis of the skin is used in the production of leather. It is treated with tannic acid after the epidermis is removed.

Cartilage, bone, and blood are other elements of connective tissue that will be described separately in respective chapters.

■ DIRECTIONAL TERMS AND PLANES

1. **Know the definitions of the directional terms and planes, and visualize the application of these as shown in *Figure 1-13.***



■ **FIGURE 1-13** Directional terms and planes as applied to four-footed animals. The stippled areas represent the carpus and tarsus on the forelimbs and hindlimbs, respectively.

Throughout this book, descriptive terms will be used when referring to the location of body parts. These frames of reference are in relation to the animal itself and apply regardless of the position or direction of the animal.

Definitions of the terms that follow are illustrated in *Figure 1-13* and apply to quadrupeds (four-footed animals).

1. **Cranial** is a direction toward the head. The lungs are cranial to the intestines (closer to the head).
2. **Caudal** is a direction toward the tail. The intestines are caudal to the lungs (closer to the tail).
3. **Rostral** and **caudal** are terms for direction within the head to mean toward the nose (rostral) or toward the tail (caudal). The cerebrum is rostral to the cerebellum.
4. The **median plane** is one that passes through the body craniocaudally (from head to tail). It divides the body into equal right and left halves.
5. A **sagittal plane** is any plane parallel to the median plane and, except for the midsagittal plane (which is another name for the median plane), it would be either to the right or to the left of the median plane.
6. A **transverse plane** is at right angles to the median plane and divides the body into cranial and caudal parts. A cross-sectional view of the body or part would be made on the transverse plane.
7. A **horizontal plane** is at right angles to both the median and the transverse planes and would divide the body into dorsal (upper) and ventral (lower) segments.
8. **Dorsal** pertains to the back or upper surface of an animal. Often used to indicate the position of one structure of the body relative to another (i.e., nearer the back surface of the body). The kidneys are dorsal to the intestines.
9. **Ventral** pertains to the undersurface of an animal and, as with dorsal, is often

used to indicate the position of one structure relative to another. The intestines are ventral to the kidneys.

10. Medial relates to the middle or center; nearer to the median or midsagittal plane. The lungs are medial to the ribs.
11. Lateral is opposite to the meaning of medial (i.e., away from the median plane). The ribs are lateral to the lungs. A lateral radiographic (X-ray) view is one with the animal on its side and the film in the sagittal plane.
12. Superficial pertains to the surface or to a structure situated near the surface. The skin is superficial to the muscles.
13. Deep refers to a structure situated at a deeper level in relation to a specific reference point. The femur is deep to the quadriceps muscles.
14. Proximal, when referring to part of a limb, artery, or nerve, means it is nearest the center of the body or the point of origin. The femur is proximal to the hoof.
15. Distal means relatively farther from the center of the body. The hoof is distal to the femur.
16. Palmar refers to the caudally facing surface of the forelimb distal to the carpus (joint connecting the radius, ulna, and carpals). Dorsal refers to its opposite cranially facing side.
17. Plantar refers to the caudally facing surface of the hindlimb distal to the tarsus (also known as the hock; joint connecting the tibia, fibula, and tarsals). Dorsal refers to its opposite (cranial) side.
18. Prone refers to a position in which the dorsal aspect of the body or any extremity is uppermost. A radiograph from this position with the film on the ventral aspect is identified as a dorsal–ventral view.
19. Supine refers to a position in which the ventral aspect of the body or palmar or plantar aspect of an extremity is uppermost. A radiograph from this position with the film on the dorsal aspect is identified as a ventral–dorsal view.

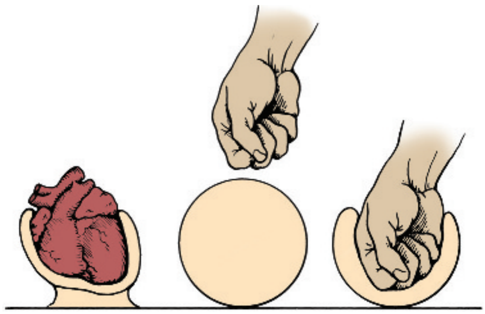
BODY CAVITIES

1. What are the subdivisions of the ventral body cavity?
2. Differentiate between visceral and parietal pleura.
3. What is the mediastinal space?
4. What structures occupy the mediastinal space?
5. Differentiate between the abdominal and pelvic cavities with regard to the structures contained in each.
6. What is the peritoneum?
7. Differentiate among omentum, mesentery, and ligaments.

A median plane view would show two main body cavities, the dorsal and ventral, and each has its subdivisions. The dorsal cavity contains the brain in its cranial cavity and the spinal cord in its vertebral cavity. The ventral cavity is subdivided by the diaphragm into the thoracic cavity cranially and the abdominal and pelvic cavities (collectively known as the abdominopelvic cavity) caudally.

Thoracic Cavity

The thoracic cavity is divided into two lateral chambers. Each chamber is lined by a serous membrane called the pleura and is termed a pleural cavity. The right and left lungs occupy their respective cavity and are enveloped by visceral pleura, which is continuous with the parietal pleura (mediastinal, costal, and diaphragmatic). The envelopment occurs during embryonic development. An analogy is that of pushing one's fist into a partially inflated balloon, as shown for the heart in *Figure 1-14*. The space between the two lungs is known as the mediastinal space or mediastinum (*Figure 1-15*). It is a partition between the two pleural cavities. The heart, thoracic parts of the esophagus, trachea, vessels, and nerves are contained in the mediastinum, which is bounded

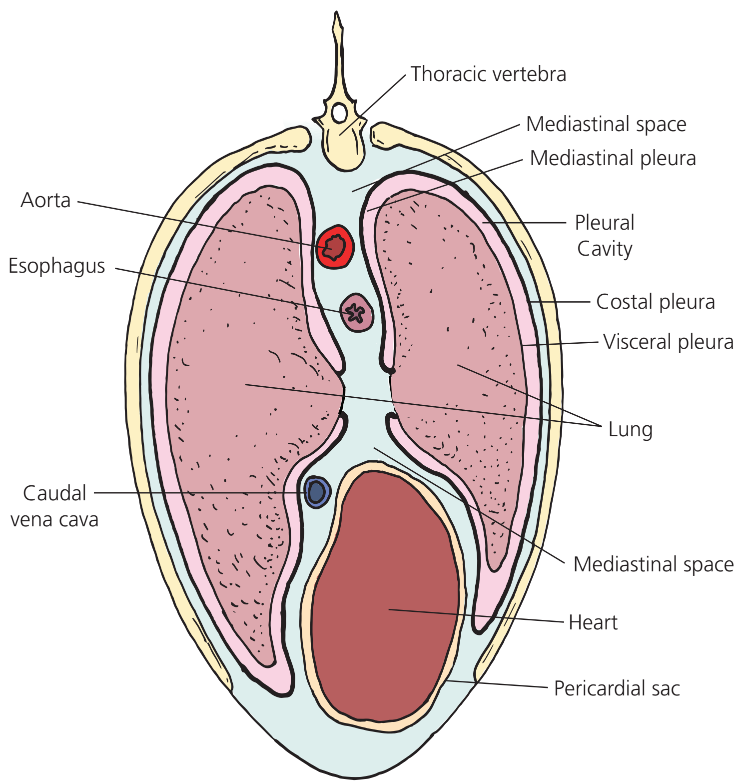


■ **FIGURE 1-14** Invagination of the serous membrane to form outer (parietal) and inner (visceral) layers **(A)**. Development proceeded similar to a fist being pushed into a balloon **(B** and **C)**. (From Frandson RD, Wilke WL, Fails AD. Anatomy and Physiology of Farm Animals. 7th edn. Ames, IA: Wiley-Blackwell, 2009.)

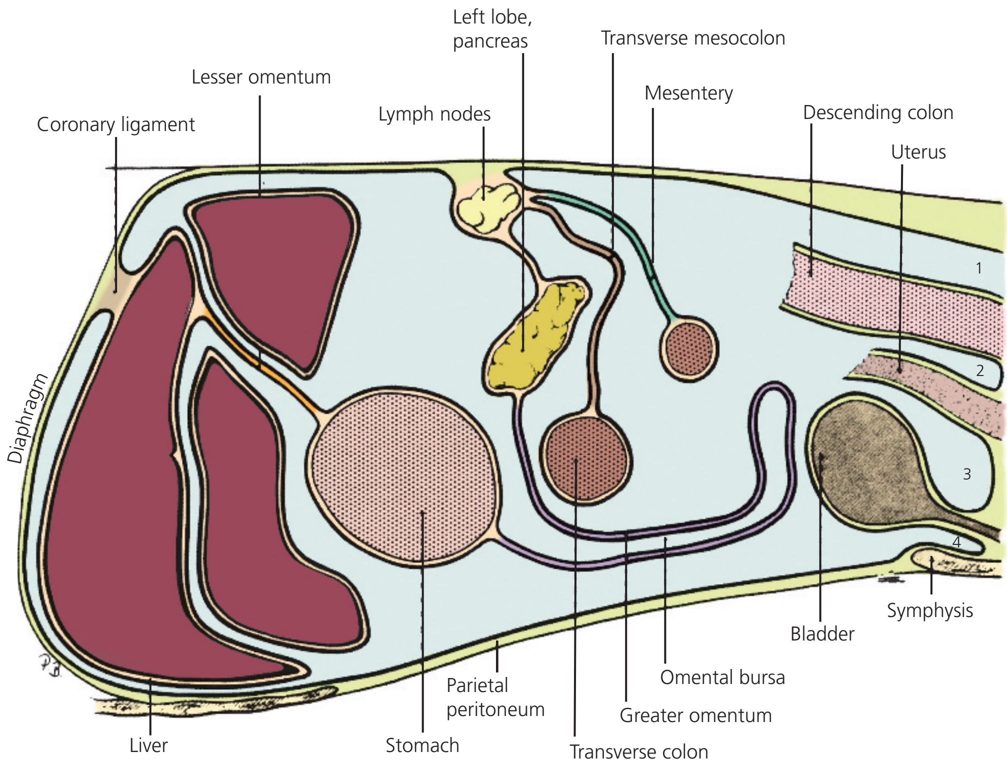
laterally by mediastinal pleura. The **mediastinal pleurae** are the parietal pleurae that cover the sides of the partition between the two pleural cavities and the **costal pleurae** line the walls of the thorax. In general, the partition completely separates the right and left pleural cavities for all of the domestic animals except the dog and horse.

The Abdominopelvic Cavity

The abdominal cavity contains the kidneys, most of the digestive organs, and parts of the internal reproductive organs in both sexes. The pelvic cavity contains the rectum (terminal part of the gastrointestinal tract) and the internal parts of the urogenital system not otherwise found in the abdominal cavity. A serous membrane similar to that surrounding the heart and lungs is also found in the abdominopelvic cavity and is known as peritoneum.



■ **FIGURE 1-15** Schematic transverse plane of the equine thorax. The thoracic portions of esophagus, aorta, caudal venae cavae, and the heart are shown in the mediastinal space.



■ **FIGURE 1-16** Schematic sagittal plane of the abdominal cavity showing the peritoneum and its connecting folds. (From Evans HE, deLahunta A. Guide to the Dissection of the Dog. 8th edn. St Louis, MO: Elsevier, 2017.) 1. Pararectal fossa. 2. Rectogenital pouch. 3. Vesicogenital pouch. 4. Pubovesical pouch.

The Peritoneum

The peritoneum lines the abdominal cavity and extends into the pelvic cavity. The abdominal organs begin development in a subserous (outside of the peritoneum) location, near the body wall. During development the organs enlarge and migrate into the abdominal cavity. They carry the peritoneum before them (introversion) and folds are formed that suspend them from the wall (*Figure 1-16*). The connecting folds are termed omenta, mesenteries, and ligaments. They contain a varying amount of connective tissue, fat, and lymph glands, and provide a pathway for vessels and nerves of the organs. An **omentum** is a fold that passes from the stomach to other viscera (soft structures). A **mesentery** is a fold that attaches the intestine to the dorsal wall of the abdominal cavity. **Ligaments** are folds that pass between viscera, other parts of the digestive tube, or connect them with the abdominal wall. The coronary ligament (see *Figure 1-16*) is a sheet of peritoneum that passes between the diaphragm and the liver around the caudal vena cava.

■ SUGGESTED READING

Cormack DH. Ham's Histology. 9th edn. Philadelphia, PA: JB Lippincott, 1987.
Evans HE, deLahunta A. Guide to the Dissection of the Dog. 8th edn. St Louis, MO: Elsevier, 2017.
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SELF EVALUATION – CHAPTER 1

THE CELL, ITS STRUCTURE AND FUNCTIONS

1. The Golgi apparatus is associated with:
   a. cell reproduction.
   b. energy production.
   c. packaging materials for transport.
   d. protein synthesis.

2. The endoplasmic reticulum:
   a. is entirely separate from the nucleus.
   b. has agranular locations associated with protein synthesis.
   c. has granular locations with ribosome attachments and is associated with protein synthesis.
   d. has an internal fluid with the same composition as that found in the cytoplasm.

3. Which one of the organelles is the site of the citric acid cycle?
   a. Mitochondria
   b. Lysosomes
   c. Centrosome
   d. Endoplasmic reticulum

ENERGY PRODUCTION

4. The aerobic stage of energy production from carbohydrate, lipid, and protein catabolism involves:
   a. acetyl-Co A.
   b. NAD and FAD.
   c. the citric acid cycle.
   d. all of the above.

5. The electron transfer chain is located in the:
   a. endoplasmic reticulum.
   b. mitochondria.
   c. nucleus.
   d. Golgi apparatus.

6. In the electron flow in the electron transfer chain:
   a. ATP is synthesized from ADP (oxidative phosphorylation).
   b. NADH and $FADH_2$ are oxidized.
   c. oxygen is consumed and metabolic water is produced.
   d. all of the above.

FUNCTIONS OF DNA AND RNA

7. A chromosome is:
   a. the same as a gene.
   b. a large molecule of DNA.
   c. a large molecule of RNA.
   d. the histone portion of DNA.

8. At which stage of mitosis is the nuclear envelope reconstructed?
   a. Telophase
   b. Prophase
   c. Anaphase
   d. Metaphase

9. Mitosis:
   a. is a phenomenon of cell division in which each cell after division has a haploid chromosome number.
   b. is the division of somatic cells in which nuclear division precedes cytoplasmic fission.
   c. is the division of reproductive cells (oocytes and spermatozoa) in which each cell after division has a diploid chromosome number.
   d. concludes with the anaphase stage.

10. The sequence of bases on one strand of DNA is TGCCAT. What would be the sequence of bases of its complementary strand within a DNA double helix?
    a. ACGGTA
    b. CATTGC
    c. GTAACG
    d. TGCCAT

11. During replication of DNA:
    a. the double helix is not split and a new double helix forms by its side.
    b. the double helix is split and each nucleotide chain is identified as the new chromosome.

c. the double helix is split and each nucleotide chain becomes paired with a new complementary strand, forming two double-helix chromosomes.
d. the duplicated attached chromosomes are called centromeres.

12. The synthesis of protein:
a. occurs in the cytoplasm and is accomplished by RNA molecules.
b. occurs in the nucleus and is accomplished by DNA molecules.
c. occurs within the endoplasmic reticulum.
d. has nothing to do with the DNA.

13. During the synthesis of protein:
a. only one tRNA is involved in its synthesis.
b. tRNA is synthesized by the Golgi apparatus in the cytoplasm.
c. tRNA enters the nucleus with its attached amino acid for the nuclear synthesis.
d. tRNAs, specific for each of 20 amino acids, move to the cytoplasm to pick up respective amino acids and carry it to the mRNA, where it is fitted into the code for a specific protein molecule.

EMBRYOLOGY

14. Meiosis:
a. is the same as mitosis except that it occurs in reproductive cells, the oocytes and spermatozoa.
b. begins after fertilization of the oocyte by the spermatozoa.
c. results in a reduction of chromosome numbers by one-half (haploid or n) while still in the reproductive systems of the male and female.
d. happens beyond fertilization and during the formation of a new individual.

15. The nervous system develops from the germ layer known as:
a. ectoderm.
b. mesoderm.
c. endoderm.
d. hypoderm.

16. The coelom is the forerunner of:
a. skeletal, smooth, and cardiac muscle.
b. the pericardial, pleural, and abdominopelvic cavities.
c. the skin and all of its derivatives.
d. the placenta.

TISSUES

17. Epithelial tissues are derived from:
a. ectoderm.
b. endoderm.
c. mesoderm.
d. both a and b.

18. Epithelium that appears to consist of many layers but actually only has one layer is known as:
a. stratified squamous.
b. transitional.
c. simple columnar.
d. pseudostratified columnar.

19. Glands with cells that accumulate secretory products in their cytoplasm and then die and disintegrate are known as:
a. apocrine glands.
b. merocrine glands.
c. holocrine glands.
d. pep glands.

20. Mucous membranes:
a. line body cavities and cover the surfaces of related organs.
b. line the hollow organs and cavities that open on the skin surface of the body.
c. are represented by pleura, pericardium, and peritoneum.
d. both a and c.

21. Tissues that produce intercellular substances (e.g., cartilage and bone), store fat, and produce various blood cells are known as:
a. connective tissues.
b. epithelial tissues.
c. nervous tissues.
d. muscle tissues.

22. Collagenous or white fibers, and elastic or yellow fibers:
    a. are intercellular substances produced by fibroblasts.
    b. are found in loose connective tissue.
    c. are found in dense connective tissue.
    d. a, b, and c.

DIRECTIONAL TERMS AND PLANES

23. Within the head, rostral means:
    a. toward the nose.
    b. the same as cranial.
    c. toward the tail.
    d. the same as caudal.

24. A sagittal plane is:
    a. one that divides the body into cranial and caudal parts.
    b. any plane parallel to the median plane.
    c. one that would divide the body into upper (dorsal) and lower (ventral) segments.
    d. equipped with jets.

25. The part of a limb, artery, or nerve that is nearest the center of the body or point of origin is referred to as:
    a. proximal.
    b. palmar.
    c. distal.
    d. superficial.

26. The position in which the dorsal aspect of the body or any extremity is uppermost is known as:
    a. supine.
    b. upside.
    c. prone.
    d. downer.

BODY CAVITIES

27. The mediastinum:
    a. is located in the abdominal cavity.
    b. contains the heart, thoracic parts of the esophagus, trachea, vessels, and nerves.
    c. is bounded by peritoneum.
    d. contains the lungs.

28. A mesentery is a connecting fold of the peritoneum that:
    a. attaches the intestine to the dorsal wall of the abdominal cavity.
    b. passes from the stomach to other soft structural viscera.
    c. passes between viscera other than parts of the digestive tube or connects them with the abdominal wall.
    d. separates the abdominal cavity from the pelvic cavity.

29. The serous membrane that lines the wall of the thoracic cavity is:
    a. parietal pleura.
    b. parietal peritoneum.
    c. visceral pleura.
    d. visceral peritoneum.

30. Omentum refers to a peritoneal fold:
    a. passing from the stomach to other soft structure viscera.
    b. passing between viscera other than parts of the digestive tube.
    c. that attaches the intestine to the dorsal wall of the abdominal cavity.
    d. in the thoracic cavity.