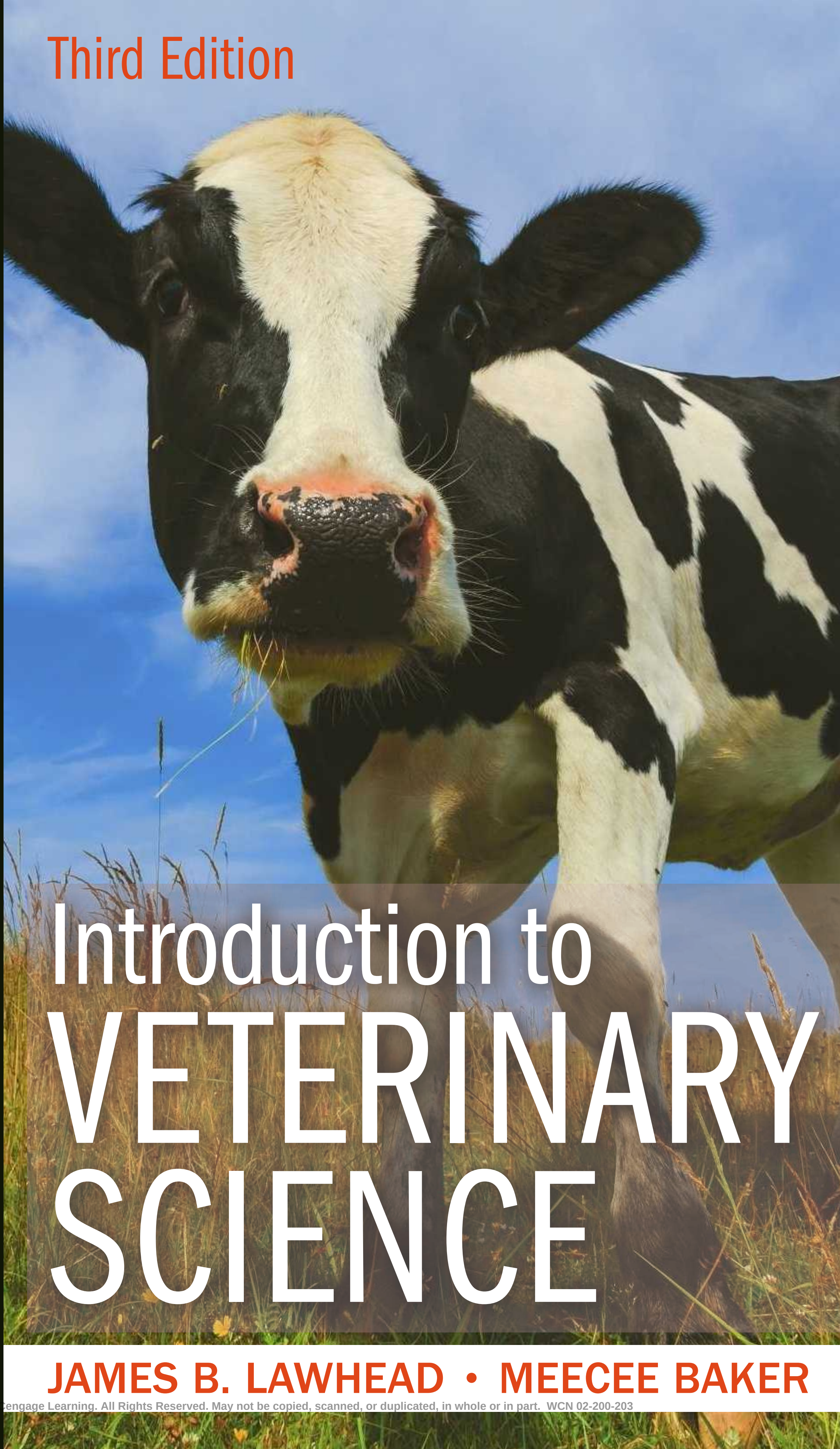

Third Edition

Introduction to VETERINARY SCIENCE

JAMES B. LAWHEAD • MEECEE BAKER

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Introduction to
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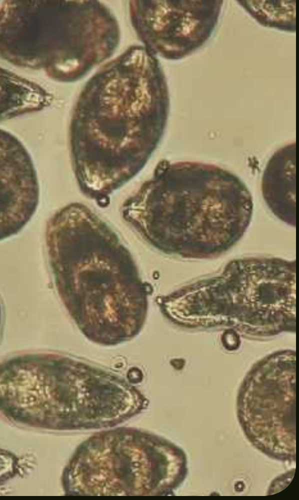

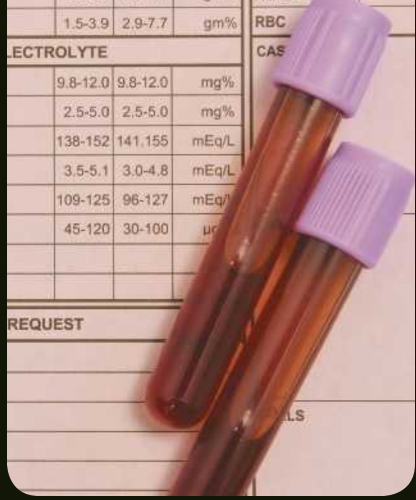

Introduction to VETERINARY SCIENCE

Third Edition

JAMES B. LAWHEAD, V.M.D.
MEECEE BAKER, PH.D.

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Dr. Baker dedicates her efforts in producing this text to her daughter, Elizabeth "Libby" Baker-Mikesell.

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Unit II ■ Nutrition

Unit III ■ Diseases

Unit IV ■ Surgery

Unit V ■ Professionalism and Careers

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PREFACE

Agriscience programs vary nationwide and most have undergone extensive curricular changes within the past decade. Many include advanced placement-type coursework, such as veterinary science. While teaching agricultural education at Greenwood High School in Millerstown, Pennsylvania, Dr. Baker searched for materials to be used in a new veterinary science course. After a futile hunt, and hearing similar concerns from other instructors, Dr. Baker teamed with Dr. Lawhead, a practicing veterinarian who served the local area where she taught, in an effort to author a veterinary science text that was both student and teacher friendly.

The authors believe that two of the most useful features in this book are the "A Day in the Life" of a veterinarian, coupled with the "Clinical Practice" chapter features. These two elements tie the real-life work of a veterinarian, which can have less than desired outcomes, with the technical and, sometimes, dry and difficult text material. Therefore, the next time a student says, "I want to be a veterinarian," a venture into *Introduction to Veterinary Science* will provide the learner with a realistic preview of both veterinary work and the academic rigor needed to achieve success in the profession.

Simply put, the goals of this text are to afford learners a base knowledge of veterinary science by moving through topics ranging from the cell to surgery, and to provide a view of the practice of veterinary medicine through the eyes of an experienced practitioner. Chapters 1 and 2 begin the text with a comprehensive investigation of cells and tissues. Following chapters examine the musculoskeletal, circulatory, respiratory, renal, digestive, reproductive, nervous, endocrine, and immune systems. The basic physiology learned in the beginning of the text is then applied in concluding chapters covering nutrition, species differentiation in nutrition, principles and prevention of infectious disease, disease classification, zoonotic diseases, disease diagnosis, and surgery.

NEW TO THIS EDITION

- Additional hands-on activities that use easy-to-find materials have been added to the chapters. These new activities will help instructors reinforce student learning using a variety of applications.
- The new safety chapter provides guidelines to help teachers ensure student safety in the classroom and field laboratories, while another new chapter further explores veterinary careers.
- Technical material has been further explained by the author, Dr. James Lawhead. These expanded and updated explanations will help students grasp more advanced material.
- Additional photos and figures bring the veterinary practice into the classroom, helping to keep students engaged.
- The new edition discusses the most current technology used in veterinary practice, providing a look into recent advances in the field of veterinary medicine.

EXTENSION TEACHING/LEARNING MATERIALS

Instructor's Companion Website

The Instructor Resources are now available on the companion website. Updated for the third edition, this robust suite of teaching resources includes the following components to help minimize instructor prep time and engage students:

- **Instructor's Guide to Text—**The Instructor's Guide provides answers to the end-of-chapter questions and additional material to assist the instructor in the preparation of lesson plans.
- **PowerPoint—**Chapter outlines with images for each textbook chapter.
- **Computerized Test Bank in Cognero—**Hundreds of modifiable questions for exams, quizzes, in-class work, or homework assignments, in an online platform.
- **Image Gallery—**Hundreds of images from the textbook that can be used to easily customize the PowerPoint outlines.

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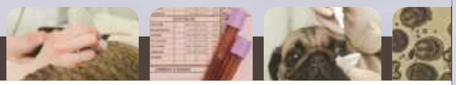
Each chapter in the textbook begins with clear educational objectives to be learned by the student in the reading, a list of important key terms, and an introduction overview of the chapter content.

CHAPTER 1



Basic Cell Biology

Objectives

Upon completion of this chapter, you should be able to:

- Explain the molecular makeup of cells.
- Identify the basic structures of the cell and their corresponding functions.
- Review the basic function of the cell.
- Describe the process of protein synthesis.
- Discuss mitosis and its clinical significance in diseases such as cancer.
- Detail meiosis in mammalian reproduction.
- Connect cellular parts and function to clinical veterinary practice.

Key Terms

anesthetize	glucose	metabolism	active transport
antibiotics	diabetes	anabolism	endocytosis
cancer	glycogen	catabolism	benign
lipid	enzymes	homeostasis	malignant
hydrophilic	antibodies	diffusion	pathologists
hydrophobic	exocytosis	osmosis	

Introduction

The cell is the basic structure of animal life. However, the cell contains other structures and molecules. Cells conduct many functions and are also able to reproduce. Animals not only have millions of cells that comprise the body but also many different cell types. The combination of these cell types makes an animal function. This chapter will discuss the structure of cells, and how they work.

Chapter 4 The Circulatory System | **55**

A Day in the Life
ADR—Ain't Doin' Right...

I remember the day in veterinary school when our stethoscopes arrived. The air filled with excitement as we listened to our own heartbeats. This instrument became a necessary tool in everyday life as I began to examine animals. I must admit I felt cool walking around the hospital in a white lab coat with a stethoscope draped around my neck! It seems like yesterday, even though more than a few years have passed.

Several months ago I examined a cow that was ADR—ain't doin' right. As I walked into the pen, I could see she obviously wasn't feeling well at all. She appeared quite droopy, had lost a lot of weight, and had developed a swelling under her jaw. During the physical, I listened to her heart. It sounded like the noise from a washing machine in midcycle. The heart made a sloshing sound with every beat. Using the stethoscope, I diagnosed **hardware disease**. The cow had eaten a piece of metal that migrated from the stomach and lodged close to the heart. The location and structure of the heart provided me with the information necessary to interpret the symptoms of this disease. Hardware disease is often found during my appointed rounds. The next diagnosis is not.

This week, Dr. Deppen and I were both doing evening small animal appointments at the office. It was snowing heavily and we were hoping to finish at a reasonable hour. Dr. Deppen was seeing Lucky, a 12-year-old Schnauzer mix that had a history of having what the owners thought was a seizure. She detected that the dog's heart rate was too slow and the rhythm was very irregular. I had a chance to listen to the dog's heart as well and agreed that we should do more tests to detect the underlying problem.

The author James Herriot portrayed veterinary work in his best-selling collection of stories, *All Creatures Great and Small*. Times have changed considerably since Herriot practiced. Much more information and sophisticated medicines and techniques are now readily available. Still, I cannot possibly be an expert on all animals. Last year our office received a call from a local school. The sixth grade class mascot, Sonic the hedgehog, had a sore foot. In this case, my experience with hedgehogs was limited to reading just one obscure

Photograph courtesy Richard Musselman.

FIGURE 4–1 A hedgehog.

journal article. I had never even met one in real life. Therefore, I advised the teacher of my lack of experience but agreed to examine Sonic.

Sonic arrived at the office in a cage (Figure 4–1). He looked just like a miniature porcupine. Because hedgehogs are nocturnal animals, Sonic was apparently taking his afternoon nap when he arrived at the office. I disturbed him as I tried to examine his leg. Sonic jumped and snorted in an attempt to scare me. To be honest, it worked! His prickly quills were quite sharp. My assistant and I then put on thick leather gloves and proceeded with the examination. Sonic countered with another protective measure. He rolled himself into a tight ball, so tight his legs were completely hidden. I referred to the journal article for help.

Following the recommendations, I anesthetized Sonic with an inhalant anesthetic. We placed him in the large clear mask. The anesthetic was slowly delivered with every breath. Finally Sonic relaxed enough so I was able to have a more thorough look. Once Sonic's leg was exposed, the problem was quite obvious. The rags that Sonic used as a nest had tattered edges with loose strings. One of these strings had wrapped tightly around his foot and stopped the circulation. The foot had turned dark and was oozing. All mammals rely on circulation to maintain their bodies. What happened to Sonic's foot when the blood supply was stopped?

Each chapter features "A Day in the Life" of a veterinarian vignette that relays James Herriot–type stories with relevance to clinical practice and the real-life work of a veterinarian.

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Chapter 3 The Musculoskeletal System | **41**

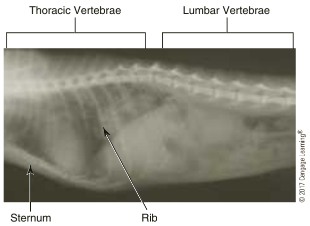

FIGURE 3–13 Radiograph of a cat, showing the thoracic and lumbar spine. Ribs and sternum are also visible.

attach to these vertebrae, forming a sling that supports internal organs.

The sacrum, a group of three sacral vertebrae, fuses to support the pelvis (Figure 3–14). In addition, the sacrum articulates with the last lumbar vertebra and the first caudal vertebra. The sacrum then joins with the pelvis, allowing the hind limbs to support the weight of the body. This connection can be damaged. The pelvis may split away from the sacrum when dogs and cats are hit by cars (HBC). During this type of accident, fracture of the pelvis itself is also common. Very painful lameness often results from a split pelvis or pelvic fracture. Many of these fractures heal if the animal's activities are restricted. In severe cases, surgeries may be required.

The final group of vertebrae is called caudal. These small vertebrae comprise the tail. As mentioned, the numbers of vertebrae vary among species and within a species. The typical dog has 20 caudal vertebrae, but this can range from 6 to 23.

The appendicular skeleton includes the bones of the forelimbs and hind limbs. A study of this part of the skeleton provides a clear examination of comparative anatomy. Although the same anatomic terms are used for all mammals, great differences exist in the numbers and sizes of bones in the mammalian appendicular skeleton. For instance, a dog has four or five toes, whereas a horse has only one.

The forelimb, or thoracic limb, does not have a bony connection to the axial skeleton. The scapula, or shoulder blade, lies flat against the rib cage (Figure 3–15). The scapula connects to the axial skeleton with a group of muscles. This attachment allows the scapula to move over the rib cage. This rotation ranges as high as 25 degrees in animals such as cats while running. This flexibility is also useful in cats as they land after a jump. As the cat falls, it extends its front legs fully at both the scapula and the elbow. As the front feet hit the ground, the elbow flexes and the scapula rotates. The cat makes this very coordinated act look quite graceful. Clinically, this is of significance when cats fall from extreme heights. In large cities, this happens often as cats tumble from balconies or windows of tall buildings. In **high-rise syndrome**, the falling cat rarely breaks a leg; however, it will often break its lower jaw. The high speed of the falling cat forces the jaw to contact the ground.

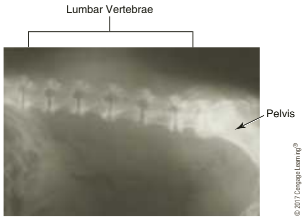

FIGURE 3–14 Radiograph of the lumbar spine of a dog. A portion of the pelvis is also visible. This dog is showing an age-related change called spondylosis. In spondylosis, bone spurs are formed that can eventually bridge between vertebrae.

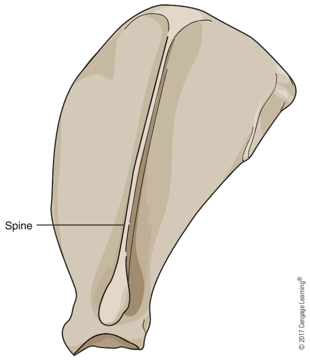

FIGURE 3–15 The scapula.

Each chapter contains combinations of charts, illustrations, photographs, radiographs, and the like that help to illustrate and enhance the concepts presented.

Chapter 1 Basic Cell Biology | **5**

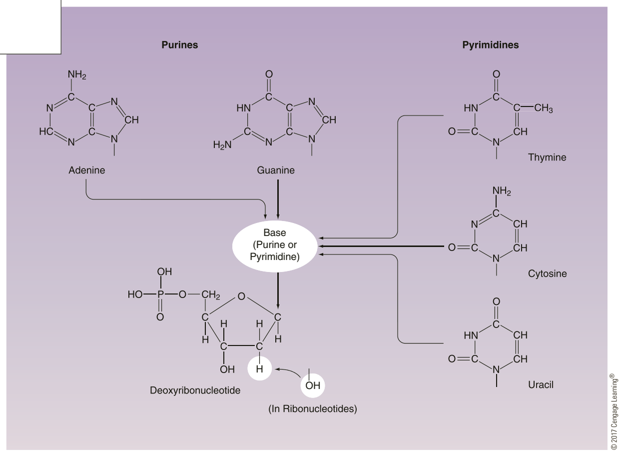

FIGURE 1–5 Chemical structure of a nucleotide.

allowing veterinarians to diagnose what specific organism is causing the sickness.

Nucleic acids provide plans for the differing construction of proteins. Nucleic acids are fabricated with a series of nucleotides. The nucleotides are made up of a five-carbon sugar, a phosphate group, and a nitrogen-containing base (Figure 1–5). Ribonucleic acid (RNA) claims ribose as its sugar, whereas deoxyribonucleic acid (DNA) has deoxyribose as its sugar. There are four different bases for RNA and DNA (Table 1–1).

Table 1–1 RNA and DNA Bases

DNA Bases	RNA Bases
1. Adenine	1. Adenine
2. Cytosine	2. Cytosine
3. Guanine	3. Guanine
4. Thymine	4. Uracil

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Notice that the bases are the same except for thymine and uracil. The order of base combination determines what amino acids are used to make proteins. This information is stored in the cell's genetic material.

Both DNA and RNA have a backbone of sugar alternating with phosphate. The nitrogenous bases are attached to this backbone. In DNA, a double-stranded molecule is formed as the bases are loosely bonded together. The molecule has a twisted structure, which is described as a double helix (Figure 1–6). The bases join, specifically, thymine to adenine and cytosine to guanine. Later in the chapter, a process of transcription will be described, in which the sequence of DNA nitrogenous bases is converted to a molecule of RNA. In this situation, adenine in the DNA molecule bonds to a uracil base of RNA. The sequence of nitrogenous bases is used to define the amino acids used in protein synthesis. A group of three nitrogenous bases is the code for a specific amino acid. The order of the nitrogenous bases makes up the genetic code of the animal. Each gene provides the code for one peptide chain.

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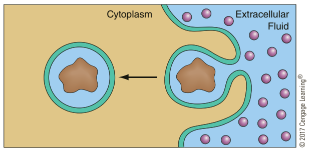

FIGURE 1–12 Endocytosis: A large particle is engulfed by the cell membrane and brought into the cytoplasm within a vacuole.

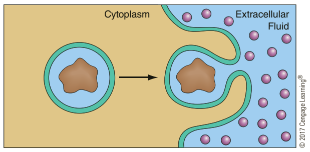

FIGURE 1–13 Exocytosis: A membrane-bound sac joins with the cell membrane to release the particle.

(Figure 1–12). During endocytosis, the cell membrane wraps around the particle, pinches off, and moves into the cytoplasm as a vacuole. Lysosomes then join with the vacuole, providing the enzymes necessary to break down the particle. The smaller fragments produced are then released into the cell.

In cells producing protein, the opposite process occurs. In exocytosis, a membrane-bound sac containing the protein joins with the cell membrane and releases it into the ECF (Figure 1–13). These sacs are produced within the Golgi apparatus. In intestinal cells, fat droplets can be taken into the cell through endocytosis. The vacuole is transported across the cell and released into the bloodstream by exocytosis.

PROTEIN SYNTHESIS

Objective

- Describe the Process of Protein Synthesis

As mentioned previously, every cell contains all the genetic material of the animal. The expression of certain genes produces specific proteins that allow cell specialization. Protein synthesis begins within the nucleus on the basis of the DNA structure. During transcription, information within the DNA is transferred to a strand of messenger RNA (mRNA) that moves into the cytoplasm.

An enzyme called RNA polymerase binds to DNA, causing a separation of the double-helix strands (Figure 1–14). This pulling apart exposes a gene. The enzyme begins at a specific series of bases (thymine, adenine, cytosine) called a promoter. The RNA polymerase moves along the length of the DNA molecule, creating a complementary strand of RNA. The RNA bases are added in the specific order that bonds to the bases of the DNA. The corresponding bases were discussed earlier in the chapter. This process continues until the polymerase reaches a terminator series of bases (adenine, thymine, thymine). The mRNA is released and the DNA helix reconnects.

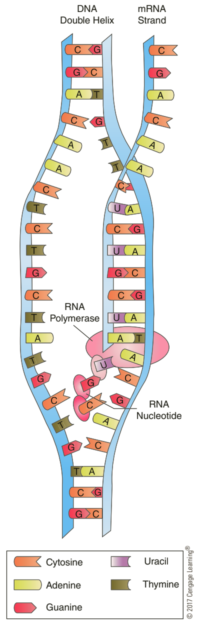

FIGURE 1–14 Transcription of mRNA: RNA polymerase separates the strands of DNA and creates a strand of mRNA coded by the nucleotides of the DNA molecule.

cat from that of a horse. Having muscles closely associated with the skeleton provides movement of the bones at a joint. The movement of bones allows locomotion and function of the animal.

The strength of bones also protects more fragile tissues. The rib cage gives protection to the heart and lungs, whereas the skull protects the delicate brain. Bone acts as a reservoir for calcium and phosphorus. In times of need, the minerals are moved from the bone and sent into the bloodstream. Excess minerals can be stored in the bone. Calcium plays an essential role in muscle contraction and enzyme activity. Phosphorus is necessary for energy metabolism within the cell. Bone, in response to several hormones, maintains a tight regulation on the blood level of these minerals. These hormones, calcitonin and parathyroid hormone, will be discussed in much greater detail in Chapter 10.

The long bones are present in the legs (and arms in humans). The femur and humerus are classified as long bones. They have a dense outer shell and a hollow shaft. Bone marrow is made in this hollow center, the medullary cavity. Bone marrow in turn produces blood cells.

BONE STRUCTURE

Objective

- Detail the Structure of Bone

Splitting a long bone along its length shows the typical structure of bone (Figure 3–3). The outer shell is composed of dense or compact bone. The term *cortical bone* is also used for this region. The greater the forces placed on a bone, the thicker this layer will be. In the femur, this compact bone is thickest in the middle of the shaft, where greatest strain occurs.

Within compact bone lies a more loosely arranged bone, called spongy or cancellous bone. Spongy bone is found within the long bones but not inside the flat bones of the skull or pelvis. It only fills the ends of these long bones. Spongy bone is made up of tiny spicules and plates of bone. The spicules look random but are actually arranged to maximize strength. The spongy arrangement keeps the weight of the bones much lighter than that of a solid bone of the same dimension. The medullary cavity is located in the hollow center of the shaft. The bone marrow lies within the medullary cavity and the spaces of the spongy bone. As mentioned earlier, bone marrow produces blood cells.

Bones are covered with a thin connective tissue called the periosteum. The periosteum blends into tendons and ligaments, binding them to the bone. The periosteum has an extensive blood and nerve supply. Hence trauma to the periosteum is quite painful. The portion of bone within the joint is covered with cartilage and not by periosteum. This articular cartilage

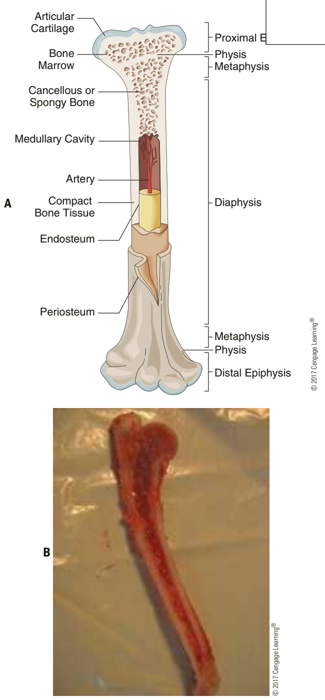

FIGURE 3–3 A. Illustration of bone structure. B. Photograph of the internal structure of bone.

provides protection as the bones move against one another within a joint. The open spaces within bone are covered with a similar connective tissue, the endosteum. Both the periosteum and endosteum provide cells necessary for the repair of damage.

Each chapter is further enhanced by the addition of repeat objectives to aid in student comprehension.

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88 | **Unit 1** Comparative Anatomy and Physiology

SUMMARY

Being able to identify respiratory structures and their associated functions, from the nose to the lungs, allows veterinarians to diagnose and treat such disease conditions as pneumonia and roaring. Moreover, respiratory rate provides a key piece of information to practitioners when assessing the overall health of animals. The status of the respiratory system affects the breathing and therefore the total health of animals.

REVIEW QUESTIONS

1. Define any 10 of the following terms:

   respiration
   palpated
   endotracheal tube
   inspiration
   expiration
   cyanosis
   pneumonia
   pleural friction rub
   contagious
   roaring
   heaves
   bronchodilators

2. True or False: Mucus lines the epithelial tissue in the nostrils.
3. True or False: The cartilage rings of the trachea are shaped like an **O**.
4. The ________ is the common area shared by the nose and throat.
5. The human larynx is sometimes called the ______ .
6. The trachea branches into two ________ .
7. Gas exchanges occur in the smallest openings of the respiratory system. These openings are called the ________ .
8. The muscles between the ribs are called the _____.
9. Name the reflex action that occurs when there is an irritation in the nose.
10. What substance lines the lungs, making them easier to inflate?
11. What controls the rate of respiration?
12. What is the normal respiration rate for a dog?
13. What plays a more significant role in the control of respiration, oxygen, or carbon dioxide?
14. What medical tool is used to evaluate breathing?
15. What species can develop a condition referred to as roaring?

ACTIVITIES

Materials needed for completion of the activities:

stethoscope
balloons
Y-shaped polypropylene connecting tubes

1. Use the stethoscope to listen to normal lung sounds. Have the "patient" take deep, slow breaths. The patient should breathe quietly, not making noise through the nose and mouth. The stethoscope can detect these noises. Listen to different areas on the chest, from both the front and the back.
2. Take two identical balloons and inflate them to different sizes. Slip a balloon onto an end of **Y**-shaped polypropylene connecting tubes. Do not release the balloons yet. Plug the third opening of the **Y** piece. Hypothesize what will happen when the balloons are released. Will the large balloon deflate and fill the smaller balloon to equalize the size? Or will the smaller balloon deflate into the other balloon? Surfactant prevents this problem from occurring between alveoli. Even though the alveoli may be of different sizes, the pressure in each is similar. Without it, the small alveoli would deflate.
3. Observe the respiratory rates of classmates and pets or livestock. Compare to the norr listed in Table 5–1.

A chapter summary highlights the topics that have been presented, and the end of each chapter is also followed by a series of review questions and student activities.

Chapter 21 Careers and Decision Making in Veterinary Science | 355

Courtesy of Dr. Cathy Hanlon.

FIGURE 21–3 Dr. Hanlon working with a sedated raccoon that had been captured in a live trap.

Courtesy of Dr. David Sweet.

FIGURE 21–4 Dr. David Sweet, with assistance of registered veterinary technician Michele Antoch, examines a surgical incision on a dog.

methods for prevention of rabies, and responds to questions about rabies from other public health professionals and the public.

Veterinary Surgeon

Dr. David Sweet graduated in 1989 from the University of Pennsylvania School of Veterinary Medicine. Following his graduation, Dr. Sweet pursued further training as an **intern** at the University of Pennsylvania and a surgical residency at the North Carolina State University. Following that training, Dr. Sweet accepted an instructorship at Washington State University and returned to the University of Pennsylvania as an assistant professor. During his training, Dr. Sweet met the rigorous qualifications necessary to become a **diplomate** in the American College of Veterinary Surgeons. This honor earned by Dr. Sweet distinguishes him as a surgical specialist.

Dr. Sweet works at a **referral practice**. The center employs veterinary specialists in many fields, including surgery. The veterinary practice provides a service that allows private practitioners to refer difficult cases for more specialized treatment. Dr. Sweet performs both soft tissue and orthopedic surgery (Figure 21–4). He performs many complicated and difficult surgeries. As with all veterinarians, he attends continuing education conferences to learn new procedures and information.

EDUCATIONAL REQUIREMENTS FOR VETERINARY CAREERS

Objective

- Explain the Educational Requirements for a Variety of Veterinary Careers

Veterinary technicians must complete either a two-year associate degree or four-year bachelor of science degree program. Further, they must pass a state licensing exam. The number of institutions offering such coursework has grown significantly over the past several years. **Veterinary assistants** are not required to complete any formal classes. However, increasing numbers of technical schools and community colleges offer veterinary assistant programs.

Both technicians and assistants help the veterinary practice by performing a wide range of tasks (Figure 21–5). These individuals may greet patients, keep records, bill clients, and restrain animals, as well as feed, exercise, and provide basic health care for patients. The responsibilities vary from employer to employer with technicians performing more technical duties. Numbers of available jobs for veterinary assistants and technicians will continue to grow with the demand for veterinarians.

Level of degree separates veterinary assistants from veterinary specialists. Almost 30 programs grant degrees in veterinary specialties. Most of these programs deliver master's and doctorate degrees, although a few award associate and bachelor's degrees. Specialists may provide such supportive services as nutrition counseling, ration balancing, or radiology expertise to veterinary clinics. Conversely, other specialists may be employed in academia, where they perform research or extension duties in veterinary-related

The new chapter on careers investigates occupations in veterinary science, including veterinary technicians, veterinary assistants, private practitioners, and veterinary specialists.

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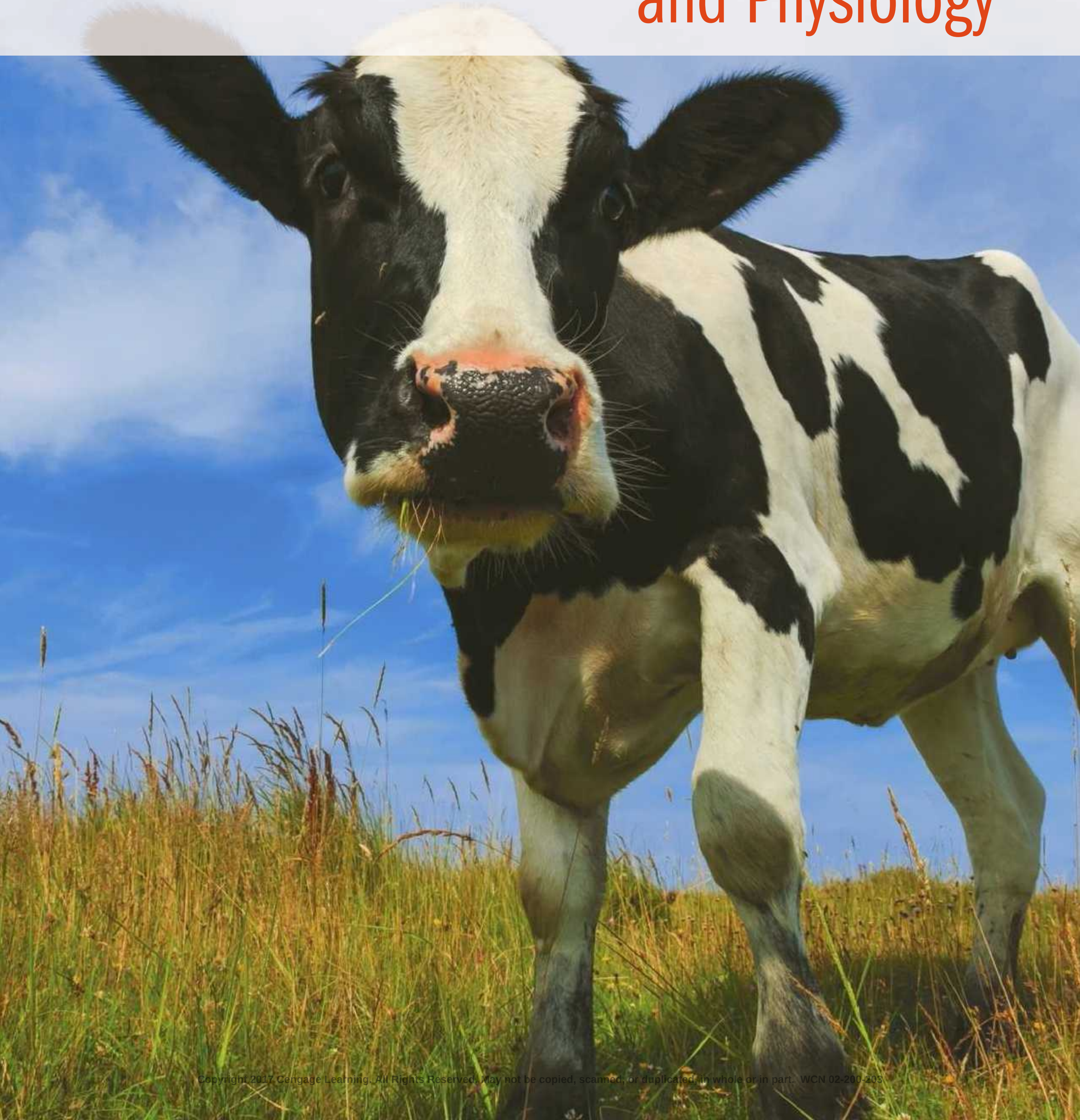
Unit I

Comparative Anatomy and Physiology



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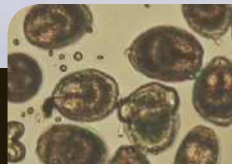
CHAPTER 1



Basic Cell Biology

Objectives

Upon completion of this chapter, you should be able to:

- Explain the molecular makeup of cells.
- Identify the basic structures of the cell and their corresponding functions.
- Review the basic function of the cell.
- Describe the process of protein synthesis.
- Discuss mitosis and its clinical significance in diseases such as cancer.
- Detail meiosis in mammalian reproduction.
- Connect cellular parts and function to clinical veterinary practice.

Key Terms

anesthetize
antibiotics
cancer
lipid
hydrophilic
hydrophobic
glucose
diabetes
glycogen
enzymes
antibodies
exocytosis
metabolism
anabolism
catabolism
homeostasis
diffusion
osmosis
active transport
endocytosis
benign
malignant
pathologists

Introduction

The cell is the basic structure of animal life. However, the cell contains other structures and molecules. Cells conduct many functions and are also able to reproduce. Animals not only have millions of cells that comprise the body but also many different cell types. The combination of these cell types makes an animal function. This chapter will discuss the structure of cells, and how they work.

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A Day in the Life

There Just Never Seems to be a Typical Day . . .

I headed to the office with the thought of doing only cow work on this particular day. However, those plans were short lived. Shortly after I arrived at work, two nervous owners walked through the door with their Labrador retriever. Poor Jake had just been run over by the owner's car! Amazingly, Jake was doing very well, although he was a bit excited. Apart from a couple of cuts on his jaw, he was ready to go home and play.

Then, at my first farm call of the day, the farmer wanted me to look at his dog, Millie. Millie had a grapefruit-size lump under her jaw. The lump felt like it was full of fluid. I asked him to bring Millie to the office so I could work on her there. I finished my farm calls and headed back to the small animal clinic.

Once there, I **anesthetized** Millie and made an incision into the skin. Pus flowed from the lump (Figure 1–1). I flushed the large pocket left behind and started Millie on a course of **antibiotics**, drugs that fight bacterial infections. Although I do not know why it started, I do know Millie was fighting an infection with her body's cells.

Next I had the opportunity to remove a tumor from Penny, a 12-year-old cocker spaniel. Last week I gave Penny a physical examination and administered blood tests. Penny appeared healthy, and we elected to do surgery. The surgery went well, and I was able to remove the entire lump.

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FIGURE 1–1 Draining an abscess on the side of the face of an anesthetized cat.

In private practice, cells affect me every day. Today I saw Millie's cells attacking the bacteria in her neck. Penny, on the other hand, had **cancer**-causing cells dividing uncontrollably. To understand how mammals work and how to treat them, I first had to learn how cells function.

CELL MAKEUP

Objective

- Explain the Molecular Makeup of Cells

Cells and their structures are composed of molecules. Biochemistry is the study of these molecules in living creatures. One goal of this chapter is to identify the differing types of molecules and their properties.

Lipids or fats combine hydrogen, carbon, and oxygen in a form that is poorly dissolvable in water (this is why fat floats to the top of water). Fat consists of a molecule of glycerol and three fatty acid molecules (Figure 1–2). Fats are stored in the cells of the body as a source of high energy.

Phospholipids are similar but have only two fatty acid groups and a phosphate group (PO_4). This is significant because one end of the molecule is attracted to or soluble in water (**hydrophilic**) and the other end is repelled by water (**hydrophobic**). These characteristics of phospholipids are important in the structure of the cell membrane.

Carbohydrates supply energy and provide structure within the cell. Monosaccharides are the simplest of these molecules. They possess the basic structure of $(CH_2O)_n$ (Figure 1–3). In this formula, n describes the number of carbon atoms in the molecule. The genetic material in the cell has the five-carbon sugars ribose and deoxyribose. **Glucose** (blood sugar), a six-carbon sugar, is used for energy in the cells. The amount of glucose in blood is routinely monitored. If there is too much or too little glucose in the blood, the animal will not function normally. In **diabetes**, the blood sugar increases to very high levels, but the animal does not utilize it properly. Diabetes requires treatment to lower the blood sugar.

Polysaccharides are composed of many monosaccharides. One example of a polysaccharide is starch, such as **glycogen**, which is used to store energy within the cell. Glycogen is made when monosaccharides are taken into the cell and then assembled into a long chain. Polysaccharides can be joined with protein molecules to form glycoproteins, which assist in building the cell structure.

Proteins play a key role in the structure and function of cells. Proteins make up 50% of the dry weight of animals. Proteins are large molecules of many amino acids. (Twenty-two different amino acids are used to

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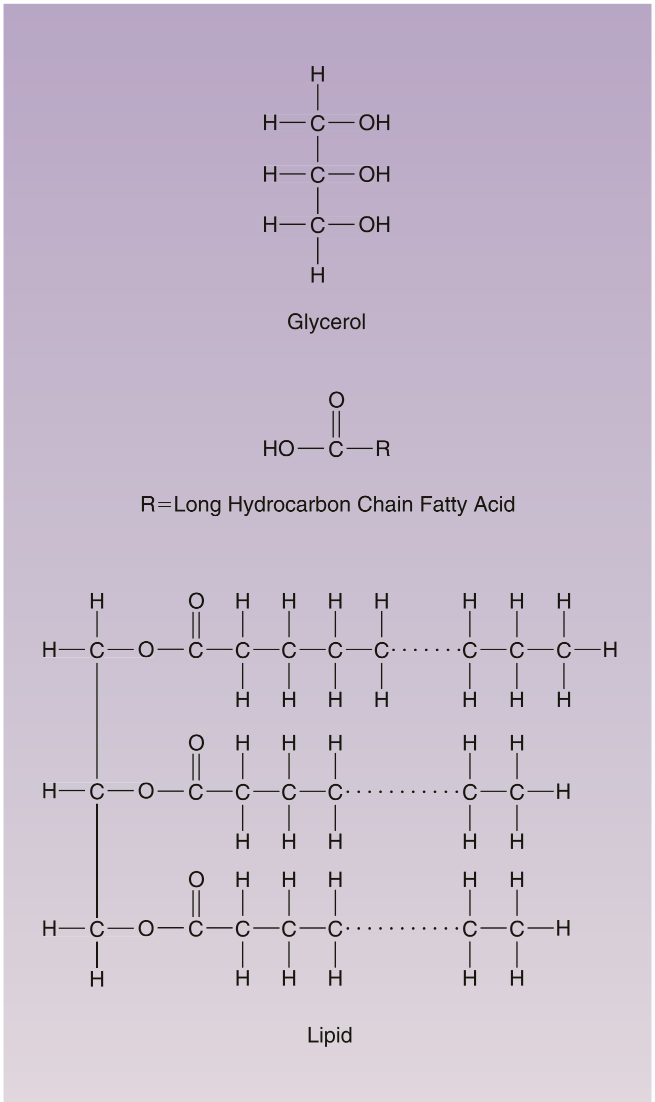

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FIGURE 1–2 Chemical structure of glycerol, a fatty acid, and a typical lipid.

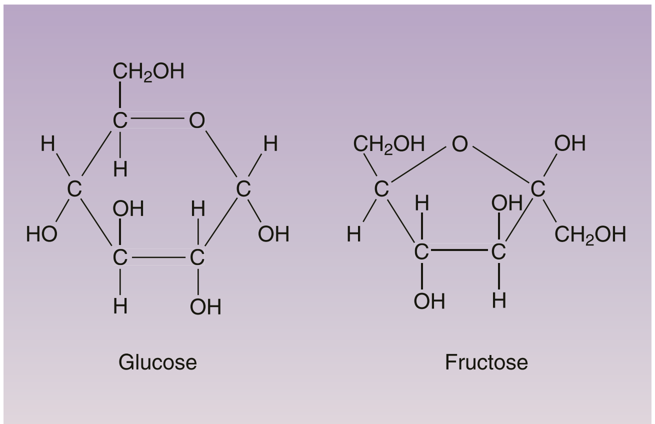

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FIGURE 1–3 Chemical structure of selected sugars.

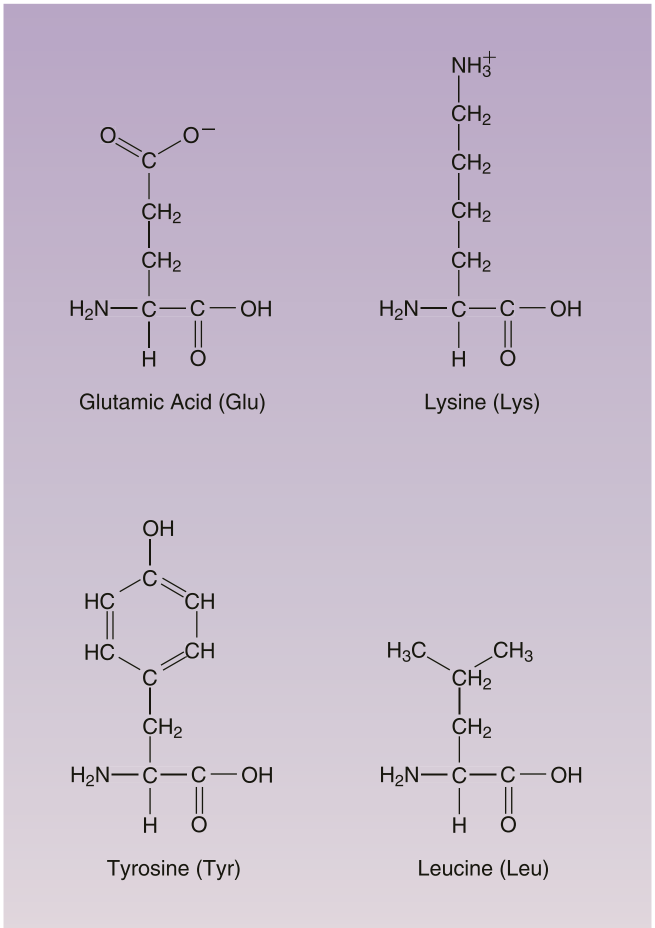

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FIGURE 1–4 Chemical structure of selected amino acids.

make proteins; Figure 1–4.) A single protein can include 200 to 300 of these amino acids. It was mentioned earlier that proteins could be joined to sugars. They may also be joined with lipids and phosphate groups. Protein molecules are not only very large but also quite complex molecules. Chemical bonding between amino acids will fold the amino acid chains into a three-dimensional structure. This complex structure is essential for the function of certain protein molecules.

Proteins have many functions in cells. Muscle is largely composed of protein that is specially arranged to allow cells to contract and move. Further, **enzymes** are protein molecules that speed the chemical reactions in the body (i.e., enzymes act as catalysts). Proteins also add strength to many of the structures in the body. Proteins are found within the cell membrane and are commonly found in the intercellular matrix of tissues. Protein can bind with other molecules to aid in their transport in the bloodstream. In addition, proteins found in blood help to carry oxygen, stop bleeding, and fight off infection. These infection-fighting proteins are called **antibodies**. In practice, antibodies specific to different diseases are measured in the blood, thus

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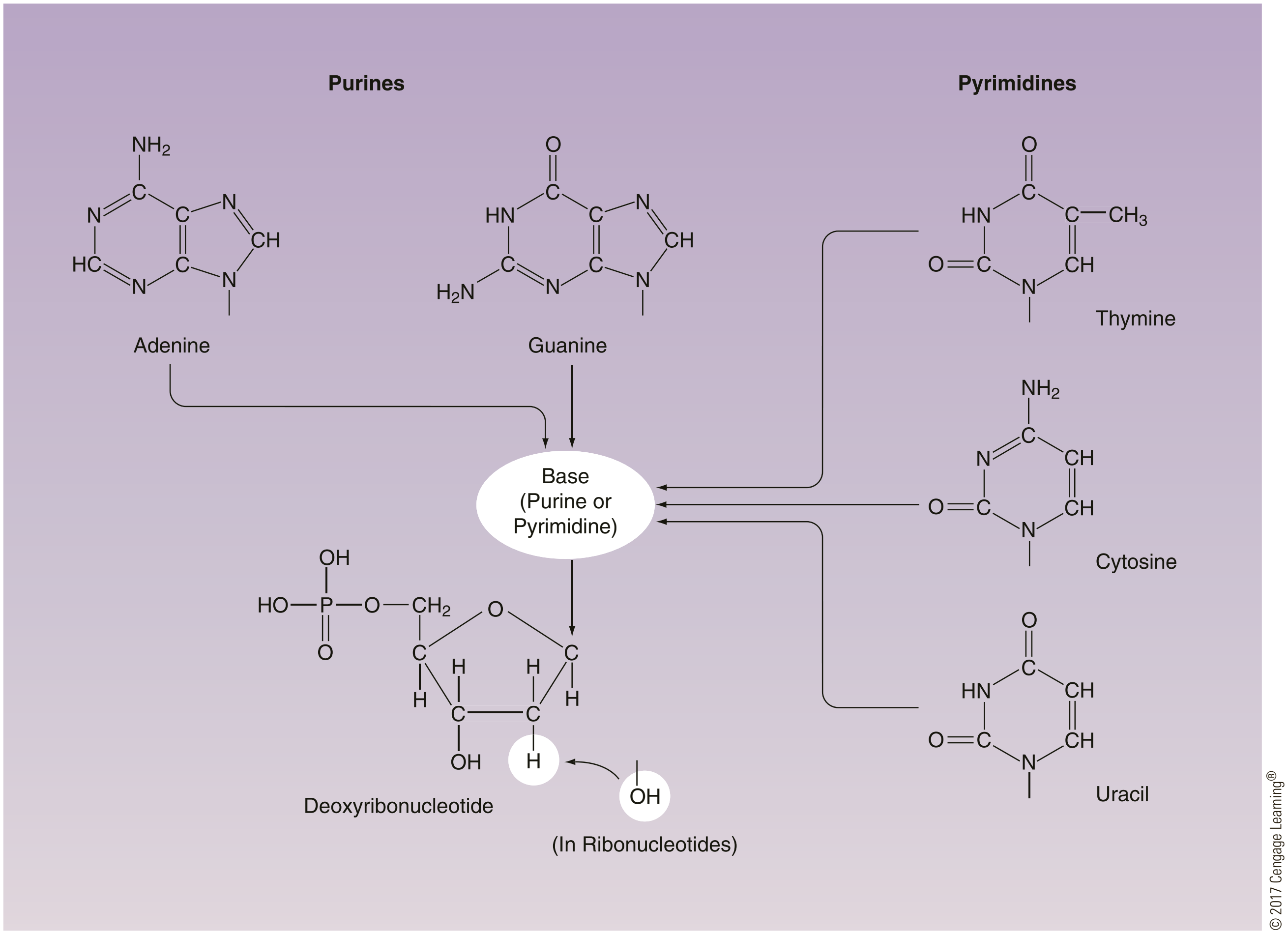

FIGURE 1–5 Chemical structure of a nucleotide.

allowing veterinarians to diagnose what specific organism is causing the sickness.

Nucleic acids provide plans for the differing construction of proteins. Nucleic acids are fabricated with a series of nucleotides. The nucleotides are made up of a five-carbon sugar, a phosphate group, and a nitrogen-containing base (Figure 1–5). Ribonucleic acid (RNA) claims ribose as its sugar, whereas deoxyribonucleic acid (DNA) has deoxyribose as its sugar. There are four different bases for RNA and DNA (Table 1–1).

Table 1–1 RNA and DNA Bases

DNA Bases	RNA Bases
1. Adenine	1. Adenine
2. Cytosine	2. Cytosine
3. Guanine	3. Guanine
4. Thymine	4. Uracil

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Notice that the bases are the same except for thymine and uracil. The order of base combination determines what amino acids are used to make proteins. This information is stored in the cell's genetic material.

Both DNA and RNA have a backbone of sugar alternating with phosphate. The nitrogenous bases are attached to this backbone. In DNA, a double-stranded molecule is formed as the bases are loosely bonded together. The molecule has a twisted structure, which is described as a double helix (Figure 1–6). The bases join, specifically, thymine to adenine and cytosine to guanine. Later in the chapter, a process of transcription will be described, in which the sequence of DNA nitrogenous bases is converted to a molecule of RNA. In this situation, adenine in the DNA molecule bonds to a uracil base of RNA. The sequence of nitrogenous bases is used to define the amino acids used in protein synthesis. A group of three nitrogenous bases is the code for a specific amino acid. The order of the nitrogenous bases makes up the genetic code of the animal. Each gene provides the code for one peptide chain.

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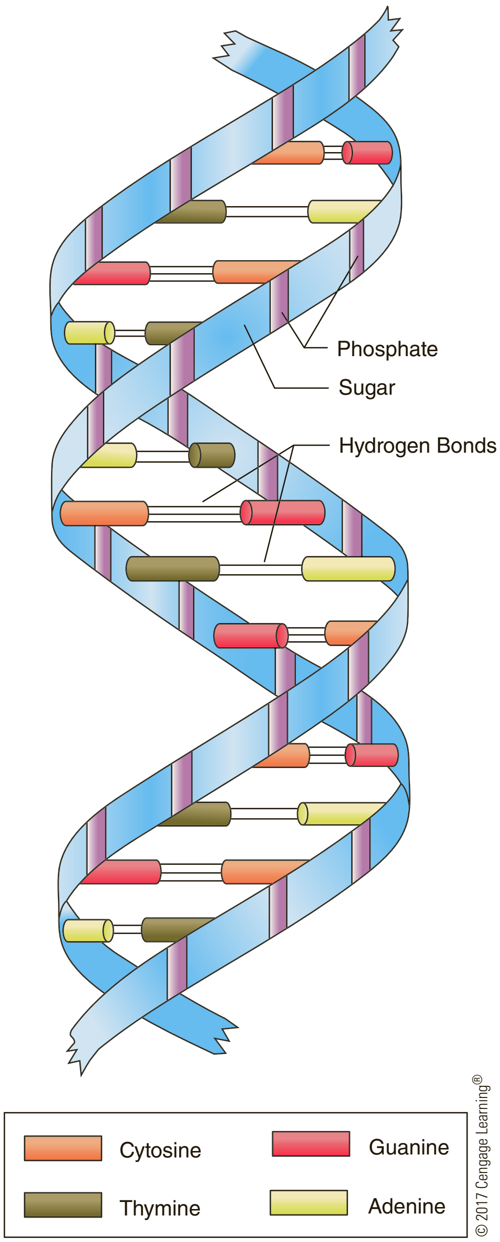

FIGURE 1–6 DNA structure: The structure is described as a double helix. Phosphate and sugar groups make up the two strands. The strands are joined by hydrogen bonds between two nitrogenous bases.

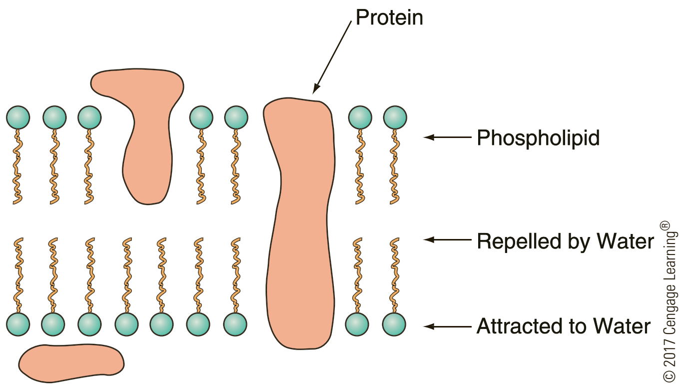

FIGURE 1–7 Illustration of cell membrane. The cell membrane has a double layer of phospholipid. In addition, protein molecules are present on and within the phospholipid layers.

CELL STRUCTURE

Objective

- Identify the Basic Structures of the Cell and Their Corresponding Functions

Many cell types exist. These cells not only look different but function differently as well. Nevertheless, many features are common among cells. Specialized structures within the cells are called organelles. These organelles are present in most but not all cells. Red blood cells, for example, lack a nucleus.

The cell membrane (or plasma membrane) is common to all cells. It serves as the boundary that keeps the inside of the cell contained. The cell membrane is so fine that it cannot be seen with a normal light microscope. The cell membrane is about half protein and half lipid (phospholipid type). One end of phospholipids is attracted to water, whereas the other end is repelled by water. The cell membrane, which is surrounded by water on both sides, has two layers of lipid in its wall (Figure 1–7). The ends of the lipid that are attracted to water face outward. Protein is also included in the membrane, both between the lipid molecules and on the surface. The position of the protein molecules is not firmly established; rather, the molecules are mobile within the membrane. Cholesterol, another molecule in the cell membrane, provides stabilization of the membrane.

Cell membranes are semipermeable, meaning they allow certain substances but not others to pass. Some molecules, such as water, are able to pass through easily. The specialized proteins in the cell membrane influence which molecules are able to pass readily. In addition, the intrinsic membrane proteins can act as receptors. These receptors can process a signal from the extracellular fluid to influence the cell's interior (e.g., a hormone can trigger a reaction within the cell). Other molecules, such as proteins, starches, and some ions, are unable to pass.

Many of the organelles within the cell are also surrounded by a membrane. The basic structure remains the same for all the membranes. The specifics of the makeup differ, depending on function.

Cell contents are divided into the nucleus and the cytoplasm. *Cytoplasm* generally describes the organelles and fluid in the cell. A nucleus comes as a standard part of most cells (with a few exceptions such as the red blood cell; Figure 1–8). The nucleus contains the genetic material (i.e., DNA) of the cell, which controls cellular activities by coding for protein synthesis. The DNA in the nucleus is called chromatin. As the cell divides, the chromatin clumps into chromosomes. Identical DNA is passed to all daughter cells. All the cells in the body have the same chromatin. However, cells take on different roles by using certain areas of the chromatin more than others.

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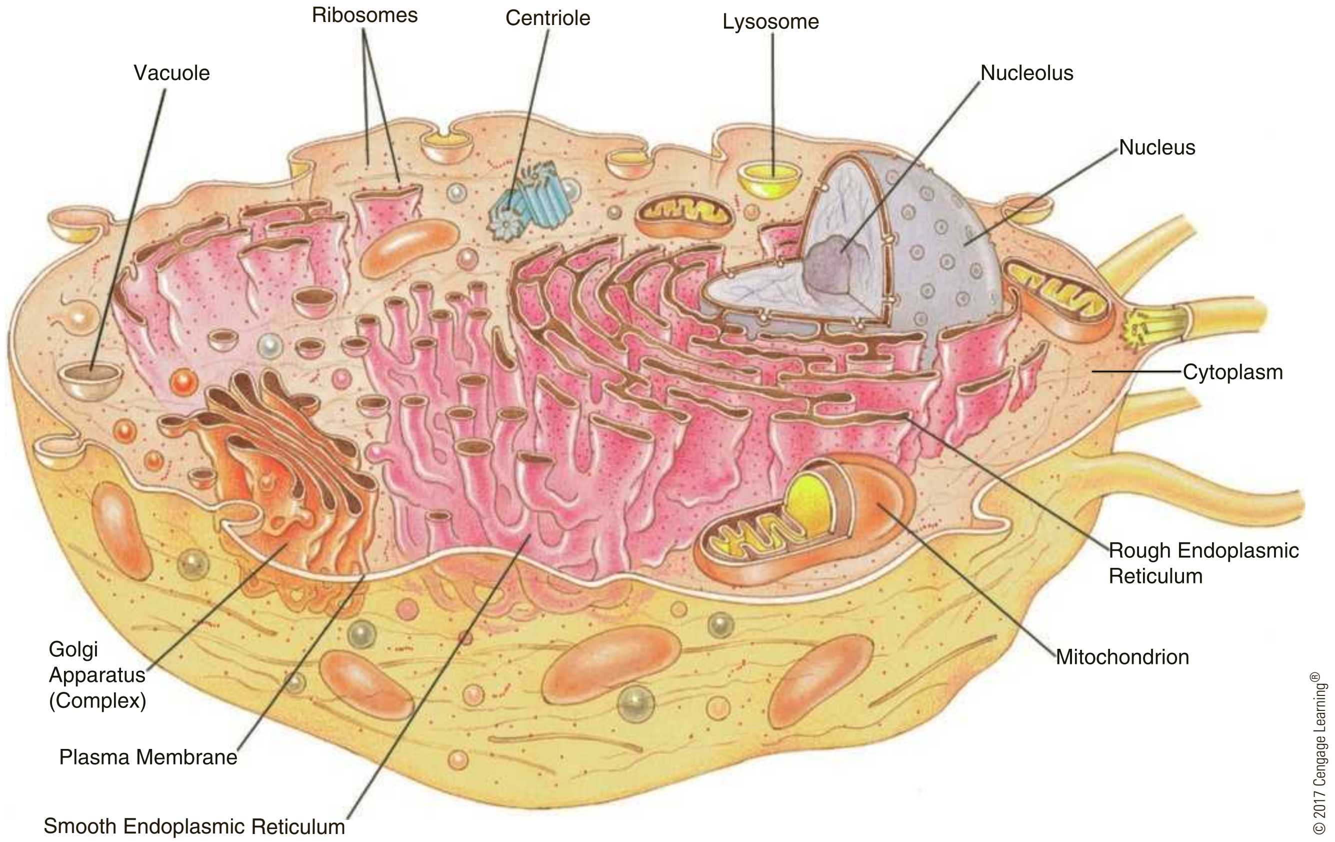

FIGURE 1–8 Illustration of cell structure.

A membrane made of two lipid bilayers surrounds the nucleus. This membrane is often joined to other organelles, such as the endoplasmic reticulum and ribosomes. Such a close association helps the nucleus control cell function.

In cells not dividing, a nucleolus is often seen in the nucleus. The nucleolus produces RNA that forms the ribosomes, which in turn produce protein. Cells with large nucleoli actively produce protein.

Ribosomes are small granular-like structures that can be found in the cytoplasm. They contain roughly 60% RNA and 40% other protein. Ribosomes manufacture the protein used in the cell. Growing cells require large amounts of protein and, therefore, have a greater number of ribosomes. The specific proteins produced by a cell are governed by the nucleus.

The endoplasmic reticulum (ER) is a collection of folded membrane. This membrane attaches to the membrane of the nucleus. The ribosomes often line this membrane, giving it a bumpy appearance and therefore its name, rough endoplasmic reticulum (RER). Protein produced by the ribosomes is then deposited into the RER. These proteins can be further changed in the RER. This protein may be used by the cell or moved to the surface of the cell for secretion. The protein is moved through the membrane in a process called **exocytosis**, which will be discussed later in the chapter.

Smooth endoplasmic reticulum (SER) has no ribosomes attached. This form is not as common. Some liver cells contain a large amount of SER. The SER in these cells produces glycogen and lipids, and removes toxins.

The Golgi apparatus is formed with large amounts of folded membrane that looks similar to SER. The Golgi apparatus produces polysaccharides and special protein sacs called lysosomes. Protein produced in the RER is moved to the Golgi apparatus. The Golgi apparatus then changes the protein and collects it in the lysosomes. These sacs are pinched from the Golgi apparatus and then moved to the surface of the cell and released.

The proteins contained in the lysosomes are enzymes (remember, enzymes are molecules that help speed chemical reactions in the body). Lysosomes contain enzymes that help to break down other molecules. Varying enzymes match differing molecules. The membrane surrounding lysosome prevents the enzymes from attacking other parts of the cell.

Lysosomes are used to digest food taken in by the cell and to destroy cell structures no longer needed. In Millie, the dog with the abscess, her white blood cells were using lysosomes to destroy bacteria. Cells that die in the body are eliminated when enzymes within lysosomes are released into the cytoplasm. This process of autolysis makes room for replacement cells.

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Mitochondria are small rod-shaped organelles found in varying numbers in cells. The more active the cell, the more mitochondria are present. Mitochondria have a double membrane, similar to the cell membrane. The outer membrane is smooth and forms the shape of the mitochondria. The inner membrane is highly folded. These shelflike infolded ridges are called cristae.

The role of mitochondria is well defined. The mitochondria convert food substances into energy that can be used by the cell. Mitochondria contain the enzymes necessary for this process. Because of this role, mitochondria are called the powerhouses of the cell. The mitochondria are found within cells at their areas of highest activity.

CELL FUNCTION

Objective

- Review the Basic Function of the Cell

The cell constantly reacts to its environment. **Metabolism** describes all the reactions going on in cells. Metabolism can be categorized into two main types. **Anabolism** describes reactions in which smaller molecules are combined into larger ones. The joining of amino acids to form proteins serves as an example. **Catabolism**, the opposite, occurs when large molecules are broken down into smaller ones. The breaking down of glycogen to release energy is an example of catabolism.

A liquid called extracellular fluid (ECF) surrounds living cells. The ECF supplies cells with all the products necessary for their functions. ECF is derived from blood. The outermost skin cells are not covered in liquid; however, they are no longer living.

Other cells exposed to the surface, such as those of the eye, need moisture. In the eye, tears produced by glands act as the source of moisture and nutrients. The eyelids help to sweep the tears across the surface of the eye. Certain breeds of dogs, such as the pug, have eyes that bulge from the eye socket. The bulging can be so severe that the eyelids cannot keep the surface of the eye moist with tears. This results in a disease condition on the surface of the eye. Artificial tears are often used to keep the surface moist.

Table 1–2 summarizes the makeup of ECF. Water is the major component of ECF. Oxygen passes to the cells through the ECF. Conversely, carbon dioxide passes from the cells through it. There are many inorganic ions in the ECF. Some ions, macrominerals, are present in large amounts. Trace minerals are present in much smaller amounts. Both macrominerals and trace minerals are essential for cellular function. Many of the trace minerals are needed for enzymes to function. Organic compounds, including the lipids, proteins, and carbohydrates, are also delivered by the ECF. Metabolism produces waste products, which must be removed from the cells. These waste products are eliminated by the ECF. Without elimination, the waste products actually become toxic to the cell.

Table 1–2 Components of the Extracellular Fluid

1. Water
2. Dissolved gases: oxygen, carbon dioxide
3. Inorganic ions Macrominerals: sodium, potassium, chloride, phosphate, calcium, bicarbonate Trace minerals: copper, zinc, manganese, cobalt, selenium, fluoride, iron
4. Organic compounds (carbon-containing compounds): proteins, amino acids, lipids, carbohydrates, vitamins
5. Hormones: compounds produced by glands to influence metabolism of cells
6. Waste products

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Many of the products in ECF must be maintained at constant normal concentrations. Cells will be unable to function properly if there is too much or too little of certain products. Glucose provides an excellent example. Small puppies can become low in blood sugar if they have too many parasites robbing them of nutrients. When the sugar in ECF becomes too low, the cells do not have adequate energy. The puppy can become weak or, in severe cases, develop a seizure. **Homeostasis** is the maintenance of ECF. Homeostasis allows maintenance of normal concentrations of molecules in spite of a wide variety of external conditions.

Cells must be able to obtain products from the ECF. It is not enough that the chemicals just exist in the ECF; there must be means for their exchange with the cell. Table 1–3 summarizes the mechanisms by which materials are exchanged across the cell membrane. The first mechanism is a process called **diffusion** (Figure 1–9), in which molecules move from higher to lower concentrations. Because molecules are always moving, there is a greater chance that they will move toward areas of lower concentration. This movement continues until the concentrations are equalized.

The cell membrane does not allow totally free diffusion. Diffusion is influenced by the size of the molecule, its charge, and its ability to dissolve in lipid. In general, the smaller the molecule, the more easily

Table 1–3 Mechanisms of Cellular Exchange

1. Diffusion
2. Osmosis
3. Active transport
4. Endocytosis
5. Exocytosis

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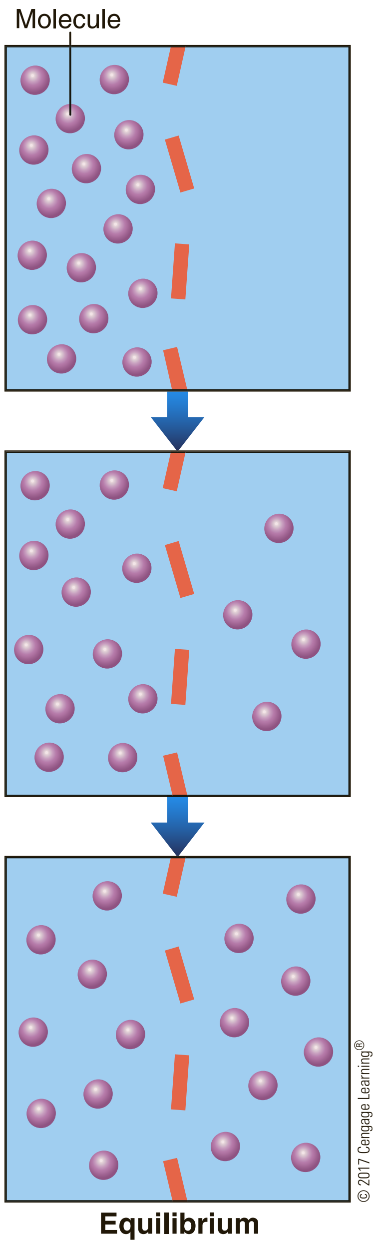

FIGURE 1–9 Diffusion: Random movement of molecules allows equalization of concentrations across a membrane.

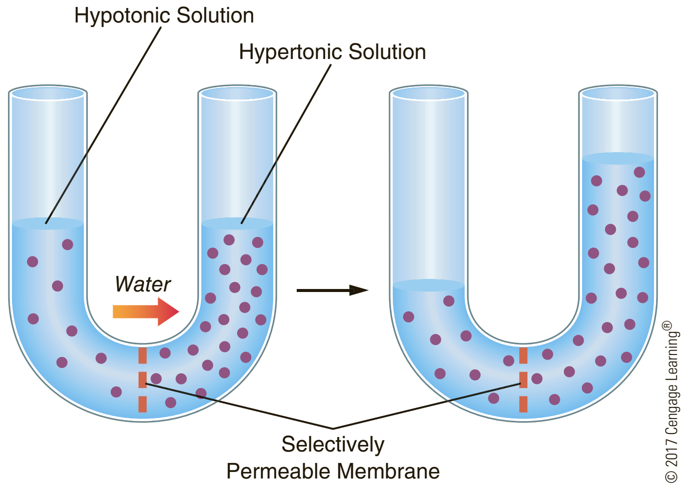

FIGURE 1–10 Osmosis: The semipermeable membrane prevents the passage of large molecules. In this situation, water moves across the membrane to equalize the concentration.

the diffusion occurs. Some large molecules such as proteins are unable to diffuse through the membrane and must be transported in other ways.

As previously learned, the property of allowing only certain molecules to diffuse through the membrane is called semipermeability. This characteristic sets the stage for a special type of diffusion, called **osmosis**. A solvent (in the following case, water) moves across the membrane to equalize the concentration; however, the molecules dissolved in the water (called solutes) cannot pass through the membrane (Figure 1–10). This process can be observed in red blood cells when they are placed in a concentrated solution. The water from the cell moves outward into the solution. Microscopically, the red blood cells can be seen to shrink.

In certain situations, a cell may require a higher concentration of a molecule than is found in the ECF. For example, red blood cells have higher levels of potassium than the surrounding fluid. Diffusion constantly attempts to equalize the concentrations (e.g., potassium continually diffuses from the cell). In this case, the potassium is pumped back into the cell, and the higher concentration is maintained. This process is referred to as **active transport** (Figure 1–11). Active transport requires the cell to burn energy and use enzymes to aid the process. Many different cell types perform the function. Another example occurs in intestinal cells, which transport glucose into the bloodstream, where it is present at higher levels.

Large molecules, such as proteins, must be moved through the membrane in a process called **endocytosis**

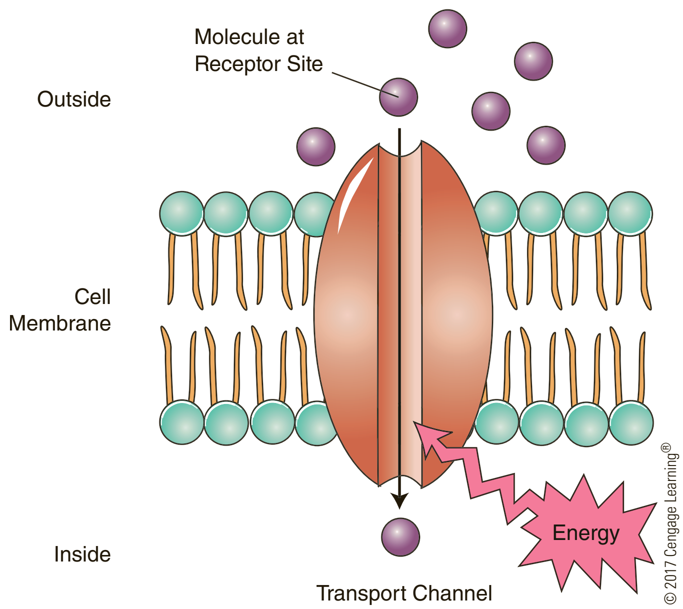

FIGURE 1–11 Active transport: Energy is used to actively pump molecules into a region of higher concentration.

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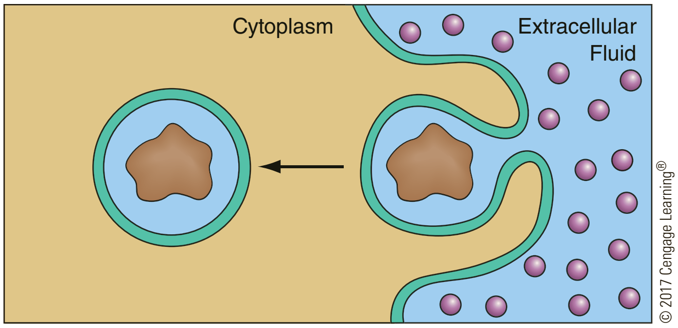

FIGURE 1–12 Endocytosis: A large particle is engulfed by the cell membrane and brought into the cytoplasm within a vacuole.

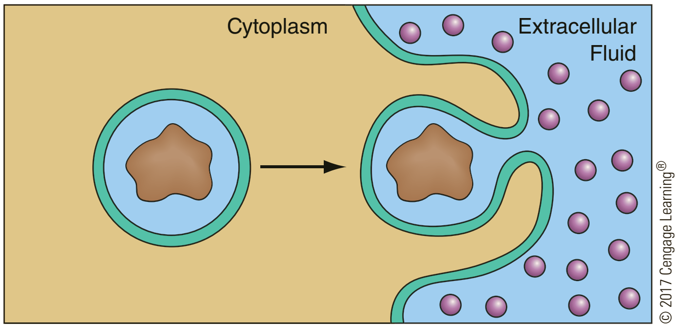

FIGURE 1–13 Exocytosis: A membrane-bound sac joins with the cell membrane to release the particle.

(Figure 1–12). During endocytosis, the cell membrane wraps around the particle, pinches off, and moves into the cytoplasm as a vacuole. Lysosomes then join with the vacuole, providing the enzymes necessary to break down the particle. The smaller fragments produced are then released into the cell.

In cells producing protein, the opposite process occurs. In exocytosis, a membrane-bound sac containing the protein joins with the cell membrane and releases it into the ECF (Figure 1–13). These sacs are produced within the Golgi apparatus. In intestinal cells, fat droplets can be taken into the cell through endocytosis. The vacuole is transported across the cell and released into the bloodstream by exocytosis.

PROTEIN SYNTHESIS

Objective

- Describe the Process of Protein Synthesis

As mentioned previously, every cell contains all the genetic material of the animal. The expression of certain genes produces specific proteins that allow cell specialization. Protein synthesis begins within the nucleus on the basis of the DNA structure. During transcription, information within the DNA is transferred to a strand of messenger RNA (mRNA) that moves into the cytoplasm.

An enzyme called RNA polymerase binds to DNA, causing a separation of the double-helix strands (Figure 1–14). This pulling apart exposes a gene. The enzyme begins at a specific series of bases (thymine, adenine, cytosine) called a promoter. The RNA polymerase moves along the length of the DNA molecule, creating a complementary strand of RNA. The RNA bases are added in the specific order that bonds to the bases of the DNA. The corresponding bases were discussed earlier in the chapter. This process continues until the polymerase reaches a terminator series of bases (adenine, thymine, thymine). The mRNA is released and the DNA helix reconnects.

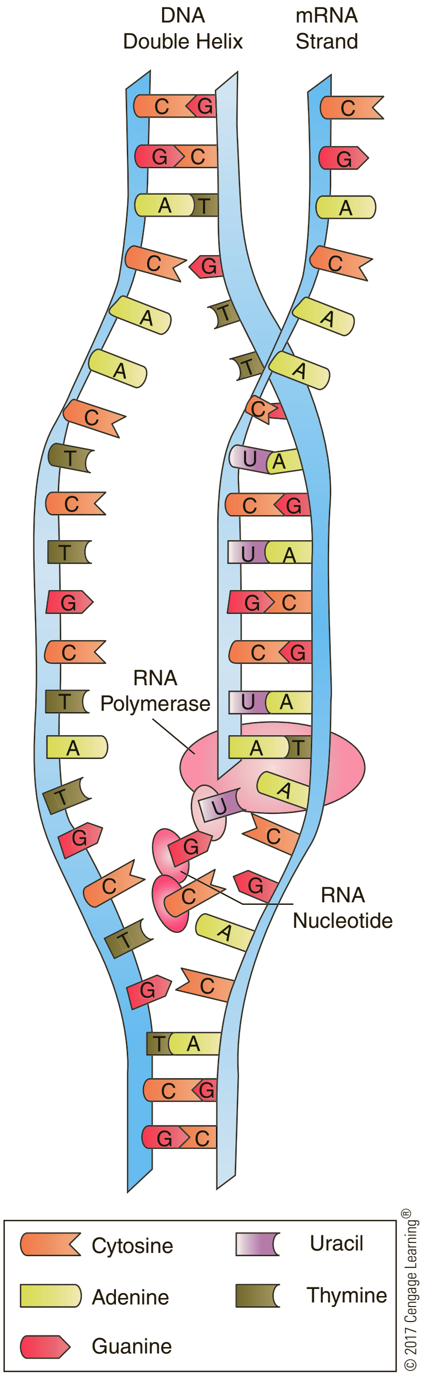

FIGURE 1–14 Transcription of mRNA: RNA polymerase separates the strands of DNA and creates a strand of mRNA coded by the nucleotides of the DNA molecule.

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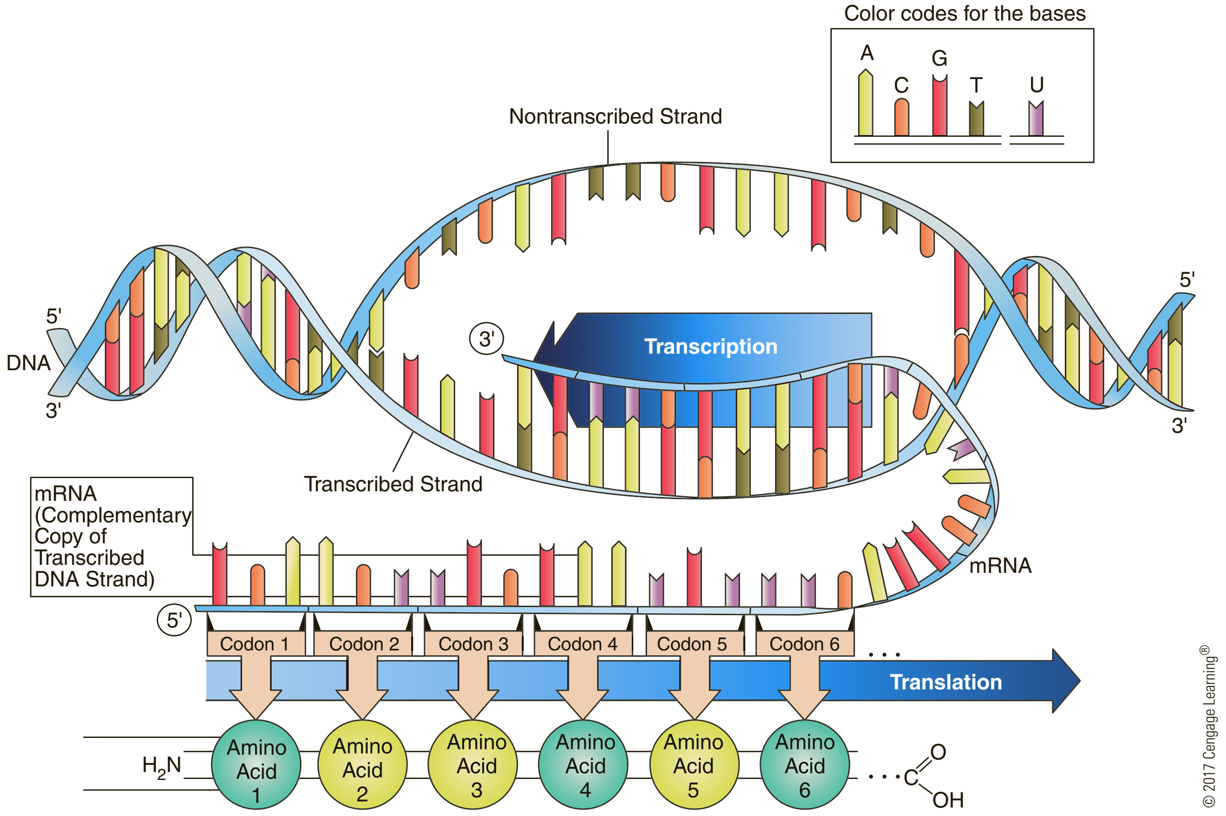

FIGURE 1–15 Translation: The mRNA created in transcription is used to code the amino acid sequence in protein formation.

Translation, which occurs in the ribosomes, is the process in which the code of bases in the mRNA is converted to a series of amino acids. Each series of three bases in the mRNA is a codon (Figure 1–15). The codon provides the signal for a specific amino acid. The molecule of mRNA is bound by ribosomes. A molecule of transfer RNA (tRNA) that contains the three complementary bases (anticodon) attaches to the mRNA. Each molecule of tRNA carries the amino acid specific to the codon. Enzymes on the ribosome allow release of the amino acid from the tRNA. A peptide bond is created between adjacent amino acids. This process is repeated along the length of the mRNA molecule, creating a polypeptide. The proteins created may be used within the cytoplasm or processed further within the endoplasmic reticulum.

MITOSIS AND CANCER

Objective

- Discuss Mitosis and its Clinical Significance in Diseases Such as Cancer

Cells must reproduce. In mitosis, the cells divide, producing two identical cells. Mitosis is necessary for the growth and maintenance of the animal. Cell division is controlled by a number of factors present within the cell and the extracellular fluid. The rate of cell division is adapted to the needs of the animal. Some cells, such as the epithelia lining the intestinal tract, divide frequently to maintain the integrity of the layer. Other cells, such as skeletal muscle, do not divide in an adult.

When these normal controls break down, the cells can begin to undergo frequent mitosis. Uncontrolled mitosis results in cancer. New cells are produced more quickly than needed, resulting in an accumulation or mass of cells in a region. This mass of rapidly dividing cells is called a tumor.

In a nondividing cell, the genetic material is called chromatin. In this form, the chromatin is loosely arranged in the nucleus. The individual chromosomes cannot be seen with a light microscope. These cells are described as being in the interphase. In this stage, the cell is in the process of doubling its DNA. The steps of division are broken down into four phases (Table 1–4). The phases are identified to help understand the

Table 1–4 Stages of Mitosis

1. Interphase
2. Prophase
3. Metaphase
4. Anaphase
5. Telophase

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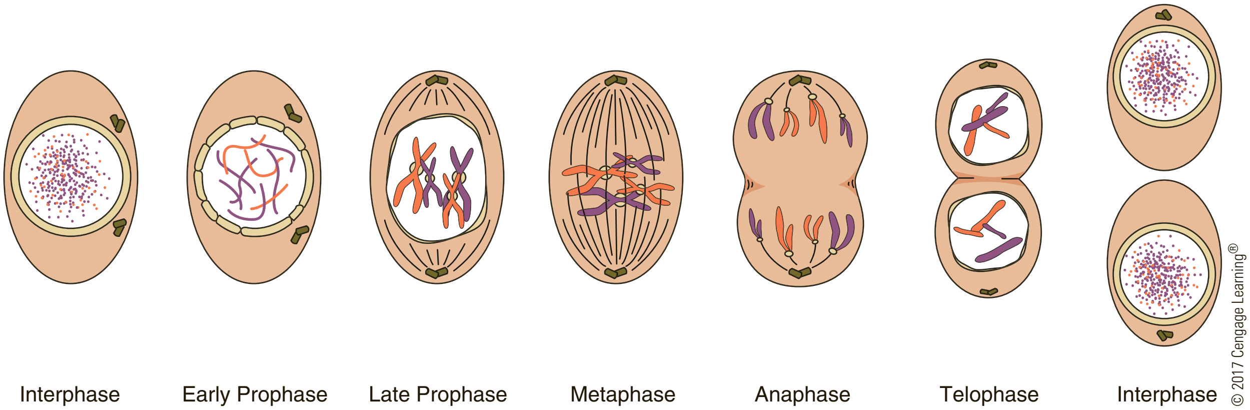

FIGURE 1–16 Mitosis. *Interphase:* Cell in its normal state, as the chromosomes begin to replicate. *Prophase:* The chromatin thickens and becomes visible, taking on an X shape. The nucleoli and nuclear membrane begin to disappear. *Metaphase:* The spindle forms between two centrioles. The chromosomes align on the spindle. *Anaphase:* Chromosomes split at the centromeres, with each half moving to opposite ends. *Telophase:* The nucleus reforms and a groove divides the two new cells.

process. However, actual cell division is a continuous process, as seen in Figure 1–16.

Prophase begins as the chromatin thickens into visible chromosomes. This is the first time that the individual chromosomes can be seen with a light microscope. Along with this process, the nucleoli and nuclear membrane begin to disappear. At this point, the chromosomes show the doubling that occurred during interphase. The chromosomes have an **X** shape. The two identical halves, or chromatids, are joined at a small point called the centromere. Two small organelles, the centrioles, separate and move to opposite ends of the cell.

In metaphase, a spindle is formed between the two centrioles. This is a collection of microtubules that stretch between the two centrioles. The chromosomes move to the center of the cell and align themselves on the spindle.

As anaphase begins, the chromosomes split at the centromere. At this point, the chromosomes are still on the spindle. Each chromatid begins to move outward. The centromere portion moves first, giving the chromosome a V shape. The chromosomes move to opposite ends of the cell.

Telophase is basically the reverse of prophase. The chromosomes become loosely organized into chromatin. The nuclear membrane and nucleoli return. A groove then forms down the center of the cell. This groove deepens until two identical cells are produced in a process called cytokinesis.

Mitosis is essential in maintaining the population size of cells in the body. The number of cells is established on the basis of the frequency of mitosis, the differentiation of cells, and cell death. An increase in cell number can occur if the rate of cell division increases or the rate of death decreases. In certain instances, a combination of these two changes has a cumulative effect.

The rate of cell division is controlled by soluble factors found in the extracellular fluid surrounding the cells. These factors can either stimulate cell division or inhibit it. Other factors found in the ECF help to control cell death in a process called apoptosis. A classic example of this balance occurs in the cells that line the gastrointestinal tract. Cells at the base of the lining divide frequently at a rate that balances with the cells undergoing apoptosis and death at the surface of the lining. The programmed cell death is designed to occur whenever there is significant cell damage such as mutations.

Different cells divide at varying rates. Cells found in certain areas such as the bone marrow and linings of the gastrointestinal tract have stem cells that actively divide on a regular basis. Other cells found in organs such as the liver, kidney, and pancreas do not routinely divide. However, following injury or disease, these cells can become activated into frequent mitosis to allow repair of the organ. A few specialized cells such as nerve and muscle cells have very limited or no ability to divide.

MAMMALIAN REPRODUCTION

Objective

- Detail Meiosis in Mammalian Reproduction

Mammals rely on sexual reproduction for species survival. In sexual reproduction, a sperm cell and egg cell join to form the new embryo. In this process, half of the genetic material is provided by each of the cells. Meiosis is the division in which the resulting cells contain only half of the genetic material.

There are two cell divisions during meiosis, with only one doubling of the chromatin. The final result is the formation of four cells, each with half the number of chromosomes. Just as in mitosis, meiosis divides into phases (Figure 1–17).

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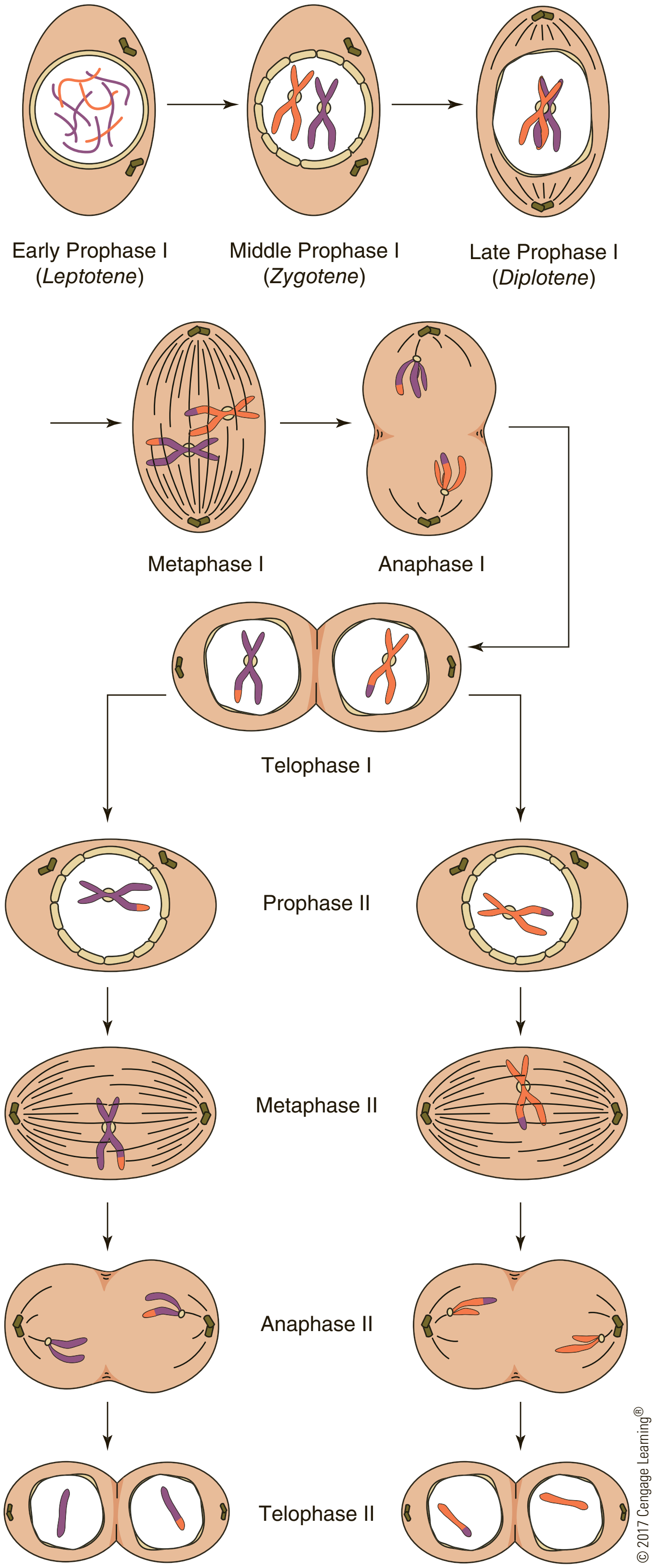

FIGURE 1–17 Meiosis: A two-division process. *Prophase I:* Homologous chromosomes align in the center of the cell. The homologues exchange segments of genetic material. *Metaphase I:* Similar to the step in mitosis, except that the homologues will separate into opposite cells. *Anaphase I:* The chromosomes move to opposite ends of the cell. *Telophase I:* The cell is divided into two daughter cells, each with half of the chromosome numbers of the original cell.

The second division of meiosis is similar to mitosis. The net effect of meiosis is the formation of four cells, each with half of the original number of chromosomes.

Prophase I: Mammals should have an even number of chromosomes. The chromosomes come in pairs, and each member of a pair is called a homologue. Before prophase I, the homologue of each pair replicates and is formed by two strands (or chromatids). The chromatids are joined by a centromere. Prophase I is very complex. The basic process allows the homologues to pair up near the center of the cell. In this arrangement, the homologues are joined at several points. At these points, an exchange of DNA fragments occurs.

Metaphase I: This step is very similar to mitosis. The nuclear membrane and nucleoli begin to disappear. The paired chromosomes move into alignment on the spindle. The important distinction in meiosis is that the homologues align themselves where they will be divided into opposite cells.

Anaphase I and Telophase I: In anaphase, the chromosomes begin to move to opposite ends of the cell. In this step, the centromere does not split. Rather, the pairs of chromosomes are divided.

The length of interphase between the two divisions is variable, and may even be zero (i.e., this phase may not occur at all). The two cells produced enter into the second division. The second division of meiosis is basically the same as mitosis. In this division, the chromosomes align on the spindle, separate at the centromere, and send one strand to each new cell. The stages are named just as they are in mitosis. The final result of meiosis is the formation of four cells, each with half the number of chromosomes of the original cell.

Meiosis allows genetic material to be provided from each parent. The exchange of genetic material between homologues in prophase I produces variability in each cell. Offspring acquire traits from each parent. With the variation, no two sperm or egg cells will provide the same genetic material.

Twinning can result in two animals having the same genetic makeup. Identical twins occur when an embryo splits. Each half then develops into a new embryo. The resulting offspring begin life with identical chromosomes. Even identical twins, however, do not appear completely identical. There is variation in the way the genes are expressed.

CLINICAL PRACTICE

Objective

- Connect Cellular Parts and Function to Clinical Veterinary Practice

In clinical practice, the appearance of cells is often evaluated. A biopsy takes tissues or cells from an animal for microscopic review. This procedure allows

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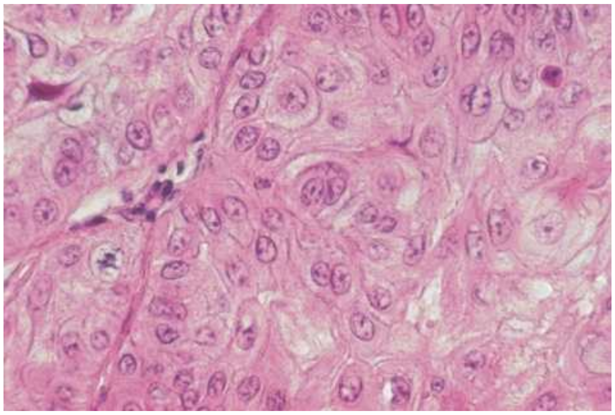
diagnosis. In tumors, the cells divide without normal control. This leads to a mass in the tissue or in an organ. Tumors are divided into two major groups, **benign** and **malignant**. Benign tumors are localized to one area, have a well-defined margin, and do not spread to other parts of the body. Malignant tumors are more likely to invade surrounding tissues and spread to other parts of the body. For example, cells from a tumor may break away and move into the bloodstream or lymph vessels and then settle into a new location. The spread of a tumor from its primary location is called metastasis. The word *tumor*, or *neoplasm*, can be used to describe either a benign or malignant mass. The term *cancer* is typically used in reference to a malignant tumor. With biopsy, cells are evaluated to determine the type of tumor that is present. Penny's tumor was submitted for biopsy. Fortunately, the **pathologists** (who interpret and diagnose changes in cells and tissues) found the tumor to be benign and did not find any tumor cells at the margins of the sample. This was great news for Penny, and we were optimistic that her tumor would not cause any more problems.

Tumors develop because the cells are growing rapidly and dividing without normal control. Changes that occur in DNA allow a tumor cell to divide, independent of the inhibitory and stimulating control of normal growth factors. The tumor begins from a single defective cell. Further division can allow even further mutations that influence some other aspect of the cell cycle. For example, tumor cells lose susceptibility to factors that control apoptosis. Normal cells require attachment to other cells and surrounding matrix. Cancer cells develop the ability to replicate without this attachment. This feature is critical to allow for metastasis with cells spread from the original tumor being able to replicate at a new location.

Many features of cancer can be predicted with this information. In cancerous cells, there is often a large nucleus with many nucleoli. The chromatin is often clumped and visible. There are many more cells involved in the process of cell division than in normal tissue. Furthermore, many of the dividing cells have an abnormal spindle. Only with an understanding of the normal cell cycle can we interpret these abnormal findings (Figure 1–18).

Bottle jaw is a term used to describe an accumulation of fluid within the tissues under the jaw. Edema describes excess fluid within a tissue. In bottle jaw, it is described as pitting edema, because finger pressure into the tissue creates a "pit" that only slowly resolves. Bottle jaw occurs in severely parasitized sheep. Parasites within the intestinal tract consume such a large amount of protein that the animal is unable to maintain normal protein levels within the bloodstream. The walls of the smallest blood vessels (capillaries) act as a semipermeable membrane. They do not allow the protein within the blood to freely move to the extracellular fluid. Water, on the other hand, is able to move freely in either direction. Osmosis occurs across the walls of the capillaries. With normal blood protein levels, a balance is reached between the extracellular fluid and the liquid portion of blood. As protein levels decline, there is less osmotic pressure to keep water within the blood vessels. As protein continues to decline, water accumulates within the tissues. In sheep with severe parasitism, the most common site for this fluid accumulation to occur is below the jaw.



Photograph courtesy Dr. Arthur Hattel, Pennsylvania State University.

FIGURE 1–18 Photomicrograph (high power) of cancer (squamous cell carcinoma) in the skin of a horse. There is variation in the shape and size of the nucleus and cells. Many mitotic figures can also be seen.

Sadie, a nine-year-old Papillon, presented with a distended abdomen. Previous workup by a specialist had discovered a kidney problem that allowed protein to leak into the urine. Table 1–5 shows that Sadie's total protein had dropped below normal. This was primarily due to the decrease in albumin. Sadie's liver was unable to make albumin quickly enough to replace what was lost. As a result, Sadie developed ascites, an accumulation of free fluid within the abdomen (Figure 1–19). On presentation, Sadie weighed four pounds, and more than one half pound of fluid was

Table 1–5 Blood Results for Sadie, a 9-Year-Old Spayed Female Papillon

	Sadie	Reference Range
Total protein	3.4 g/dl	5.2–8.2
Albumin	1.0 g/dl	2.2–3.9
Globulin	2.4 g/dl	2.5–4.5

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FIGURE 1–19 Photograph of Sadie showing her abdomen distended with ascites.

drawn from the abdomen. This lowered the pressure on her internal organs and provided immediate relief. The low protein level meant the ascites would rapidly recur. To slow this progression, Sadie was given a solution of hetastarch into her bloodstream. Hetastarch is a very large molecule that increases osmotic pressure within the bloodstream, helping to slow the recurrence of ascites. The hetastarch slowly leaves the blood and thus provides only a temporary benefit. The goal in this case is to improve the osmotic pressure until a more permanent cure can be found.

Diffusion and osmosis are used therapeutically in the process of dialysis. Dialysis is a treatment option in kidney failure. As will be discussed later in the text, the kidneys serve to maintain fluid and electrolyte balance within the body. In addition, the kidneys function to remove many forms of soluble waste products. Ethylene glycol found in certain antifreeze products is extremely toxic to the kidneys. Unfortunately, pets often find the antifreeze palatable (i.e., tasty) and will ingest enough to severely damage the kidneys.

When the kidneys do not function adequately, toxins increase in the bloodstream, and many electrolyte levels become imbalanced. The complete process of dialysis is quite complex and requires extensive monitoring to be done correctly. Urea will be used as an example to describe the function of diffusion in dialysis. Urea is a breakdown product in the metabolism of protein. The kidneys normally excrete the urea into the urine. With kidney failure the urea level increases in the bloodstream and acts as a toxin.

In peritoneal dialysis, an electrolyte solution is infused into the abdomen through a catheter. Urea is able to diffuse across the membrane that lines the abdomen. Because there is no urea within the infused electrolyte solution, the urea diffuses from the higher concentration within the bloodstream into the solution. The solution is then removed from the body, effectively reducing the level of urea in the bloodstream. Dialysis must be repeated to remove the urea that is subsequently produced. Dialysis is used to maintain the animal in the hope that the kidneys will recover from the toxic effect.

Understanding cellular function is essential for sound veterinary practice. Although there is great similarity among all mammals, there are species differences. This chapter has discussed enzymes and their importance in cellular function. Cells contain enzymes that break down medication (that is why medicines must be given more than once). Furthermore, differences between animals can lead to reactions to medications. Cats possess much less of certain enzymes that break down many medications. Acetaminophen (Tylenol), a common over-the-counter pain reliever, has been proved quite safe for use in humans. Because of the differences in the enzymes between species, this product is very dangerous for cats. As little as half a tablet designed for adult humans can make a cat sick. Cellular detail seems far removed from a complete animal. However, the details of cells guide treatment of animals in clinical practice.

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SUMMARY

Successful students of veterinary science begin their study by mastering the understanding of cells. A thorough knowledge of cellular makeup, including structures and functions, will help veterinary students build a strong foundation of information, based on which a more comprehensive investigation of body processes can start. Moreover, knowing how cellular activities such as meiosis take place gives a more complete understanding of the reproductive system, which in turn can help veterinarians assist producers in making financial decisions concerning their livestock. Similarly, another cellular activity, mitosis, can result in cancer if uncontrolled. Here again, veterinary practitioners rely on their cellular understanding to assist in diagnosis and treatment of that dreaded disease. The examination of cells sets the groundwork for the study of veterinary science.

REVIEW QUESTIONS

1. Define any 10 of the following terms:

   anesthetize
   antibiotics
   cancer
   lipid
   hydrophilic
   hydrophobic
   glucose
   diabetes
   glycogen
   enzymes
   antibodies
   exocytosis
   metabolism
   anabolism
   catabolism
   homeostasis
   diffusion
   osmosis
   active transport
   endocytosis
   benign
   malignant
   pathologists

2. True or False: Fats easily dissolve in water.
3. True or False: Larger molecules diffuse more readily than smaller molecules.
4. True or False: Smooth endoplasmic reticulum (SER) contains ribosomes.
5. All cellular reactions are collectively called ________.
6. Extracellular fluid (EFC) surrounds all living cells and is derived from ________.
7. Too much blood sugar indicates which disease?
8. How many different types of amino acids are used to make proteins?
9. Give another name for the cell membrane.
10. Where is chromatin found within a cell?
11. Do mammals have an even or odd number of chromosomes?
12. Do enzymes function identically in all species?
13. How might cancer cells differ from a normally dividing cell?
14. List five mechanisms of cellular exchange.
15. List the four stages of mitosis.

ACTIVITIES

Materials needed for completion of activities:

several beakers
assorted fats, such as cooking and motor oil
water
food coloring
heat source
eggs
dissecting pins

1. Does fat really float as explained in the cellular molecular component section? Assemble several beakers of water. Add drops of assorted fats, such as cooking and motor oil. Observe the results.
2. Pretend the classroom is a cell, with the walls being the cell membrane. Your instructor will assign you a cellular part. Review your function within the cell

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and your relationship to other cell parts (other students). Present your information to the group.

3. Add one drop of food coloring to a beaker of water. Observe for evidence of diffusion. Does heat influence diffusion? Investigate by trying the activity with water samples of varying temperature.
4. Using a small dissecting pin, pick away the shell at the air sac end of an egg. Leave the inner shell membrane intact. Place the egg under water in a beaker. Watch osmosis cause the inner shell membrane to rupture.
5. Several interactive quizzes can be found online to assist students in learning the processes of mitosis and meiosis. Investigate these options as a means of further study.
6. Research the latest treatments available for canine cancers. Report the findings to classmates. Advancing technologies continually give new hope to owners whose pets are diagnosed with cancer.
7. Students can self-test for pitting edema of the foot or ankle by pressing a thumb against the skin and watching to see how quickly the depression resolves. If any concerns regarding pitting arise, medical attention should be sought.

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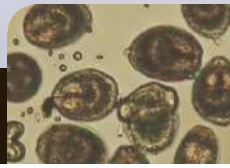
CHAPTER 2



Tissue Types and Functions

Objectives

Upon completion of this chapter, you should be able to:

- Describe the properties, locations, functions, and varieties of epithelial tissues.
- Describe the properties, locations, functions, and varieties of connective tissues.
- Describe the properties, locations, functions, and varieties of muscle tissues.
- Describe the properties, locations, functions, and varieties of nerve tissues.
- Link knowledge of tissues to clinical practice.

Key Terms

tissue
organs
displaced abomasum
foot-and-mouth disease (FMD)
epithelial tissues
basement membrane
integument
keratin
tendons
ligaments
adipose tissue
myofiber
rigor mortis
porcine stress syndrome
hypocalcemia
sweeny
central nervous system
peripheral nervous system
neurons
tying up, or Monday-morning disease
Horner's syndrome

Introduction

In the previous chapter, learners examined the cell, the basic unit of life. Cells develop specialized structure and function. A collection of cells, organized for a particular function, is called a **tissue**. Collections of tissues are then arranged into **organs**. Mammals have four basic tissue types: epithelial, connective, muscle, and nerve.

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A Day in the Life
Some Days Seem Relatively Easy . . .

It was a beautiful day in early June. Farmers were busy making hay and planting the last of their crops. On hectic days like this, the last people farmers want to call are veterinarians, but sometimes they have no choice. The welfare of their cattle still takes priority despite the pressures of spring planting. I received a call from a farmer who had a cow that was not doing well.

A **displaced abomasum** (cows have four stomachs, the fourth being the abomasum), a common circumstance in dairy cows, often occurs shortly after a calf has been born. This condition, abbreviated DA, is called twisted stomach in lay terminology. In this disease, the stomach fills with gas and is pulled upward. Instead of lying in the normal position at the bottom of the abdomen, gas pulls the abomasum up toward the animal's side. Cows with this problem do not eat well and, therefore, are not very productive.

Several procedures exist to correct displaced abomasums. The simplest procedure is to roll the cow. In this process, the gas that pulls the stomach upward is used to pull it back into place by rolling the cow from the right side to the left. This procedure is often effective in correcting the problem but does not keep the stomach in place. Recurrence is common after using this technique. Rolling works best in a cow that has other problems to be corrected at the same time. For example, a cow may develop a DA secondary to an infected uterus. The infection makes the cow stop eating well and predisposes her to the DA. Along with rolling the cow, antibiotics are administered to treat the infection. The hope is that by eating well, the stomachs are full of feed, which will help prevent recurrence.

Another technique involves rolling the cow onto its back. A blind stitch is then used to fasten the stomach to the body wall. The gas in the stomach is used to hold the abomasum against the body wall. Either a large needle or a trocar (a metal tube over a sharp metal rod) is used to place suture material into the abomasum. The success rate is higher than the simple rolling technique, and it is relatively quick to perform. The disadvantage of this procedure is that the exact location of the attachment to the stomach cannot be determined.

Several surgical procedures are available to correct a DA as well. The method that I use most commonly utilizes a surgical approach into the lower part of the abdomen (Figure 2–1). I make an incision into the abdomen to identify all the areas of the abomasum. This is the most time-consuming procedure (and therefore the most expensive), but in my experience, surgery has the highest success rate. The farmer elected surgery for this cow.

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FIGURE 2–1 A Holstein cow, shown following surgery to correct a displaced abomasum.

With the farmer's help, I rolled the cow onto her back and tied her to a gate. I then used a local anesthetic before making an incision into the cow's abdomen. The abomasum was then sutured to the body wall and the remaining layers closed. Once this procedure is completed, the cow in question will not get another displaced abomasum.

Friends called because their dog had just tangled with a groundhog. Remmy, a small 12-pound Jack Russell terrier with a big attitude, had attacked the groundhog that was invading his yard. I do not know how badly the groundhog was injured before it escaped, but Remmy had several bite wounds on his neck and face. The bite of the groundhog had torn the skin of his cheek away from the underlying tissues, and now a pocket of blood was forming. I also commonly see bite wounds when a larger dog attacks a smaller dog. In these cases, the tissue structure guides my treatment.

Several years ago, a foot-and-mouth disease outbreak in the United Kingdom quite stimulated the conversation. Many farmers became concerned about the risk to their operations in Pennsylvania. The disease seemed so far away until one of my clients became concerned about European visitors. She had friends coming to visit from Germany, and wondered about the risks of inviting them stay at her farm. Fortunately, because the foot-and-mouth disease had not spread to Germany, the risk was extremely low. However, **foot-and-mouth disease (FMD)** is a highly contagious viral disease that attacks **epithelial tissues**. Veterinarians have to be aware of such reportable diseases and understand how the disease affects tissues.

continues

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A Day in the Life continued

Knowledge of tissues affects my everyday life as a veterinarian. In the previously described surgery, I had to know what tissues I would encounter, along with their properties and functions. For example, I needed to know about nerve tissue to use anesthetic to avoid causing pain to the cow. Moreover, my surgical incision passed through epithelial, connective, and muscle tissue. Each of these tissue layers required special handling procedures.

EPITHELIAL TISSUES

Objective

- Describe the Properties, Locations, Functions, and Varieties of Epithelial Tissues

Epithelial tissues are collections of cells packed together in sheets. The sheets line the body's surface and openings. These tissues also cover all the openings of the intestinal, reproductive, and urinary tracts. In addition, they line tubes in the body, such as blood vessels and the heart.

Epithelial tissues perform multiple functions. Skin, an important epithelium, offers defense in many forms. Skin protects the body from trauma, the sun's ultraviolet light, extremes of temperature, drying, and bacterial invasion. The cells lining the respiratory, intestinal, urinary, and reproductive tracts also provide protection. Specialized cells in the respiratory tract have cilia on their surface. These cilia, tiny motile filaments on the surface of the cell, are able to move particles from the large airways. For example, dust or bacteria is moved upward so it can be coughed from the airway.

Epithelial tissues produce a variety of secretions. Tears and saliva help to moisten and protect the epithelium. In the airways, mucus secretions help to trap the particles mentioned in the previous paragraph. Also, urine and sweat are forms of epithelial excretion. In addition, the mammary system is lined with epithelial cells that secrete milk. Dairy cows have very well-developed mammary systems that produce large volumes of milk.

Epithelial cells can absorb materials in a highly selective manner. Cells lining the intestines, lungs, and kidneys all take in materials from the surrounding fluids. Cells lining the blood vessels provide points of exchange for materials from the blood and extracellular fluid (ECF).

Along with keeping substances from entering the body, the epithelial cells conserve materials within the body. These cells help to prevent excessive loss of fluid and nutrients from the ECF.

Specialized cells within the epithelial tissues provide sensory input. The retina in the eye is a very specialized epithelial layer that is essential in transmitting the visual input to the central nervous system. The tongue has receptors for taste, touch, and temperature, providing sensory information about the environment. The senses of smell and hearing are also aided by specialized epithelial tissue.

Every epithelial lining has an underlying connective tissue layer. A **basement membrane** is a collection of fibers that ties the epithelial layer to the underlying connective tissue. The epithelium itself has no direct blood supply. Therefore, the connective tissue not only provides support for the epithelium but also supplies nutrients and removes wastes. The blood supply within the connective tissue allows these functions. Nutrients supplied by the blood diffuse through the basement membrane into the epithelium. Likewise, waste products created by cell metabolism are removed via the underlying blood supply.

Epithelial tissues are classified based on the shape of the cells and the number of layers (Figure 2–2). The epithelial tissue may be categorized as follows: (1) simple, with one cell layer; (2) stratified, with multiple layers; and (3) transitional, with multiple layers (the shape of the cells can change). Descriptive terms also identify the shape of the cells: (1) squamous (very flat), (2) cuboidal (cube shaped), and (3) columnar (more tall than wide).

The two most appropriate terms are then combined to describe the epithelium. Simple squamous epithelium contains a single layer of flat cells. These cells can be so thin that the nucleus forms a bulge in the surface of the cell. Simple squamous epithelium is found where there is need for exchange across the border. Blood vessels are lined with simple squamous epithelium, allowing for transfer of fluids, nutrients, gases, and wastes. This smooth flat epithelium offers little resistance to the flow of blood through the vessels. Likewise, the small air spaces of the respiratory system have a similar lining, which provides for the exchange of oxygen and carbon dioxide. Simple squamous epithelium is quite fragile and only exists in protected areas.

Simple cuboidal epithelium consists of a single layer of cells that are almost square when observed from the side. This type of epithelium is often associated with secretion or absorption. Simple cuboidal epithelium is found in many exocrine and endocrine glands, including the thyroid, pancreas, and salivary glands. Many of the tubules of the kidney are also lined with simple cuboidal epithelium. Typically, it is found in tubules that are only responsible for transport.

Endocrine glands secrete hormones that are distributed to other regions of the body via the bloodstream.

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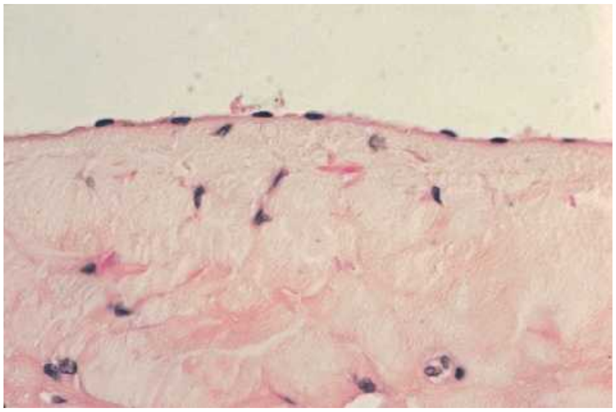

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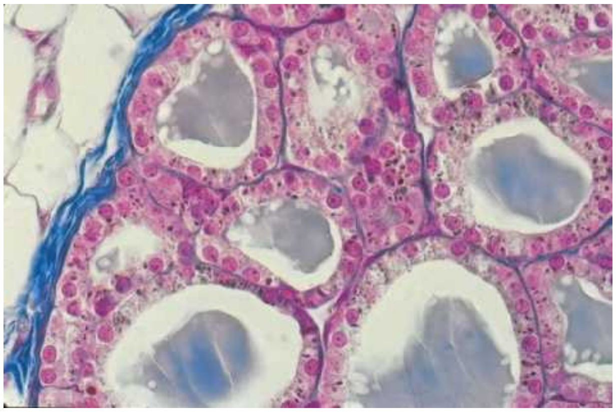

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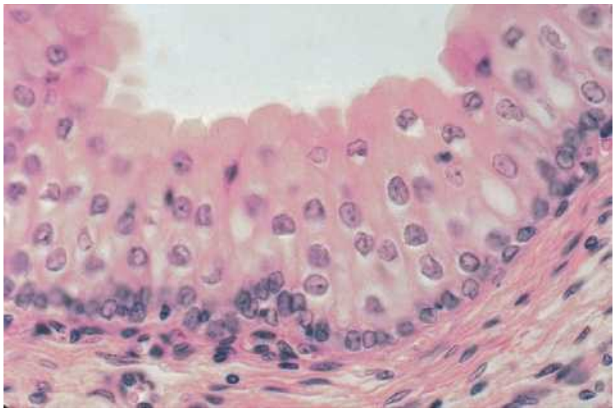

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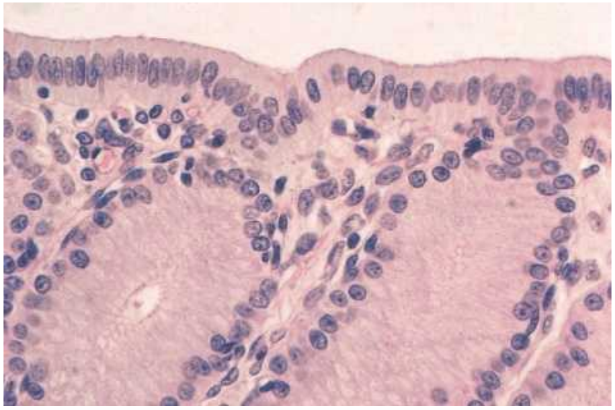

Photomicrograph courtesy William J. Bacha, PhD, and Linda M. Bacha, MS, VMD.

FIGURE 2–2 Types of epithelial cells. A. Simple squamous epithelium covering the outer layer of the esophagus in a pig (note the very flat, dark blue nuclei of the cells). B. Simple cuboidal epithelium lining the openings within the thyroid gland of a cat. C. Simple columnar epithelium lining the uterus of a dog. D. Stratified squamous epithelium from the lip of a sheep. This sample was taken on the mucous membrane side of the lip. This epithelium has a large number of layers. E. Transitional epithelium from a duct within the kidney of a pig. The cells become much flatter, allowing the duct to distend.

Hormones regulate the function of other organs. Endocrine glands release the product directly into the bloodstream without having internal ducts or tubules. The thyroid, adrenal, and pituitary glands are all examples of endocrine glands.

Exocrine glands have ducts that transport their secretions to impact more local areas. Therefore, the secretions produced do not enter the circulation. Examples of exocrine glands are sweat, mammary, and salivary glands.

Simple columnar epithelium contains a single layer of cells that are taller than they are wide. The nuclei of columnar cells are aligned near the base of all these cells. This type of epithelium (often associated with secretion or absorption) can be found in many glands, the stomach, and the intestines. In locations such as the intestinal tract, the simple columnar epithelium has a surface covered with microvilli. Microvilli or brush border are tiny finger-like projections of the cell membrane that tremendously increase the surface area of the cell and, in turn, the efficiency of absorption. Stratified cuboidal and columnar epithelium also exist in certain glands and ducts.

Skin provides the classic example of stratified squamous epithelium, with many layers of very flat cells (Figure 2–3). All these cells originate from a basal layer of cells that appear more cuboidal. The basal layer cells continually divide and move outward and undergo changes. The cells begin to lose cytoplasm and the nucleus, becoming much flatter. The cells in the outer layers have an increased amount of keratin, a structural

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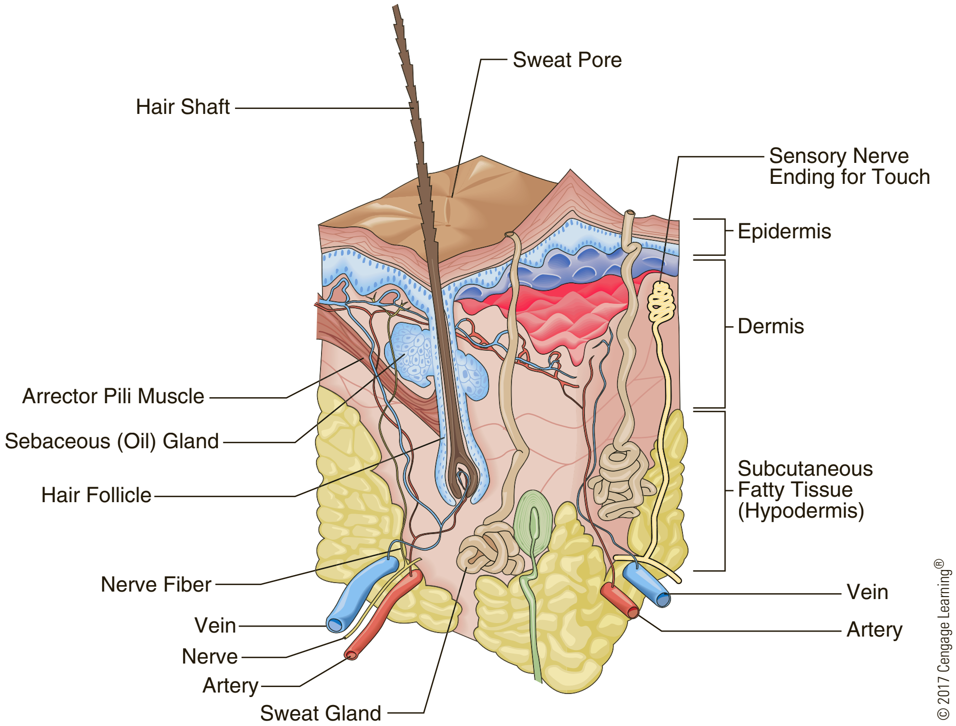

FIGURE 2–3 A. The structure of skin. The skin is composed of the epidermis and dermis. B. Photomicrograph of the specialized skin found in the foot pad of a cat.

protein. These cells are described as cornified. The outermost layer is covered in dead squamous cells that are constantly being shed. Stratified squamous epithelium is found in regions of mechanical stress. Other regions of stratified squamous epithelium are found in the mouth, esophagus, vagina, and rectum. The thickness of the layer depends on the stresses in the area. In human terms, the skin on the sole of the foot has a thick layer, adding protection, relative to an area such as the back. Specific regions facing repeated friction or trauma will become even thicker, developing a region called a callus. For example a person doing physical labor will develop calluses on the palms of the hand.

Transitional epithelium remains specific to the urinary tract. This epithelium possesses the ability to stretch. In its relaxed state, the epithelium appears to have at least six or seven layers of cells. As the urinary bladder fills, the epithelium stretches, allowing storage of urine. With the bladder full, the epithelium seems to be only a few cells thick. In addition to its ability to stretch, transitional epithelium prevents exchange of fluid between the urine and the underlying tissue.

The **integument**, or skin, performs many important functions. As generally discussed with epithelium, skin offers a two-way barrier over the body. Skin keeps damaging agents out of the body and fluids and nutrients in the body. Specialization of the skin (hair, fur, and sweat glands) helps animals to maintain a stable body temperature. During sun exposure, the skin is responsible for the synthesis of vitamin D, which is essential in calcium control. Moreover, the pigment in skin helps to protect the body from damaging ultraviolet radiation. Clinically, this is important in animals with little skin pigment. Gray horses have a much higher incidence of malignant melanoma than darkly pigmented horses. With time, the accumulated sun exposure causes highly malignant melanoma tumors to develop in the skin. As a sensory organ, skin detects pain, pressure, and temperature, thus adding further means of protection. Furthermore, skin's flexibility allows for movement.

Clinically, the skin provides the first visible impression of an animal's health. Many diseases are evident by the appearance of the skin. For example, fleas commonly cause hair loss and skin sores. Many other parasitic, nutritional, and endocrine diseases affect the appearance of the skin.

As described earlier, the skin consists of the epidermis and the underlying dermis. The epidermis is a stratified squamous epithelium. The cells originate from the basal layer and move outward. The outermost cells of the epidermis are dead and continually shed from the surface. A basement membrane separates the epidermis from the underlying dermis. The dermis is a connective tissue layer that contains blood vessels, nerves, and glands. Another layer of connective tissue, called the hypodermis, then supports the skin, epidermis with dermis. (Note the relationship with the term hypodermic needle, which allows injection to layers

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beneath the skin.) The hypodermis has a large percentage of fat, which provides a layer of insulation from extremes in external temperatures. This layer of fat also functions as a shock absorber. Connective tissues are discussed more thoroughly later in this chapter. Connective tissues are mentioned at this point to aid in the understanding of their close connection with the epithelium.

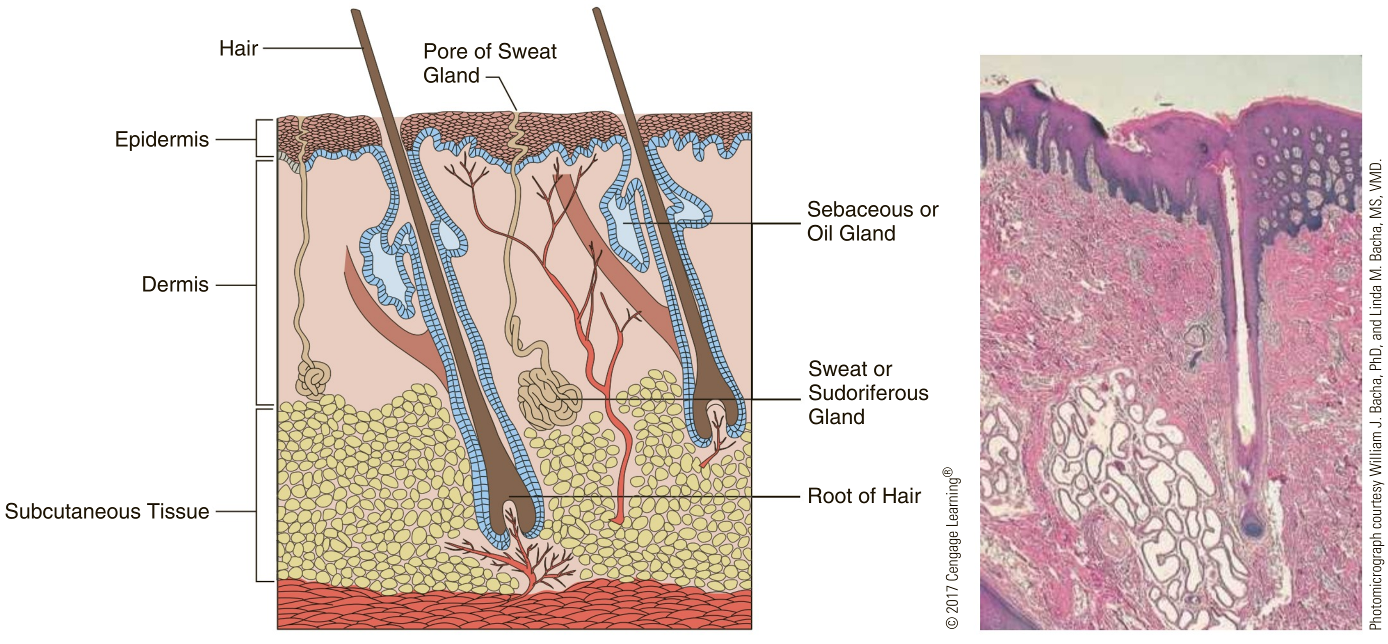
The foot pads or digital pads of dogs and cats are extremely thickened and hardened specialized areas of the skin. This thickened skin resists physical trauma. A pad of fat found under this skin acts as a cushion for the foot.

Hair serves as another modification of the epidermis. Hair provides insulation, protection, and sensation. The hair originates from a follicle in the dermis (Figure 2–4). The shaft of the hair is made of epithelial cells, much like the outer layers of the epidermis. Growth occurs as cells are attached to the base of the hair. Compound follicles exist where multiple hairs exit one opening in the skin. Each hair has its own follicle. Typically, there is one long primary hair with multiple finer and shorter secondary hairs in one compound follicle. Shedding is a process in which hairs are lost during a cycle of growth, loss, and replacement. Shedding is influenced by genetics and environmental temperatures. Breeds of dogs have significant variation in the amount of hair shed.

The benefit of insulation occurs because air is trapped among the hairs. In addition, dark coat colors help absorption of heat on exposure to sunshine. The arrector pili muscle is attached to the connective tissue around the hair follicle. When contracted, this muscle makes the hair stand upright. In cold weather, this process is used to improve the insulation effect of hair. Dogs also use this as a signal of aggression or fear. Many dogs make the hair stand on their backs when showing aggression. Approach these dogs with caution!

Claws and hooves are regions of modified epidermis. **Keratin**, a specialized protein, is deposited in the cells, giving the typical hardness and durability. The claws of dogs and cats surround the last bone of the toe. A rich blood supply surrounds the bone and subsequently nourishes the claw. Hooves have a similar anatomy. A section of the equine foot shows how the last bone of the foot is actually suspended within the hoof (Figure 2–5). The laminar corium has a rich blood supply and connective tissue that supports and nourishes the hoof wall. Growth of the hoof starts from the coronary band, where additional cells are deposited.

Horns have a similar structure to claws and hooves. The center of the horn, a bone, extends from the skull. This bone communicates with the sinus of the skull. When a cow is dehorned in a manner designed to prevent regrowth, an opening to the sinus is created. If not removed, horns continue to grow throughout the life of the animal. Blood in the surrounding tissue feeds the horn. The horn material, called keratinized epithelium, is similar to a hoof. The keratin makes the epithelium hard and durable.



A B

FIGURE 2–4 A. Hair follicles and surrounding structures. B. Photomicrograph of a region of thin skin in a pig, showing a section through a hair follicle and a nearby sweat gland.

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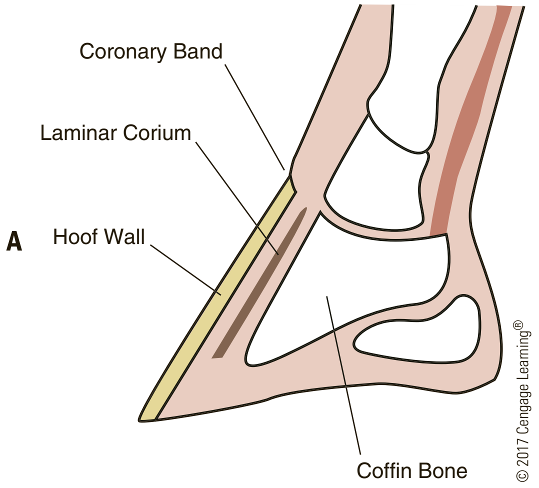

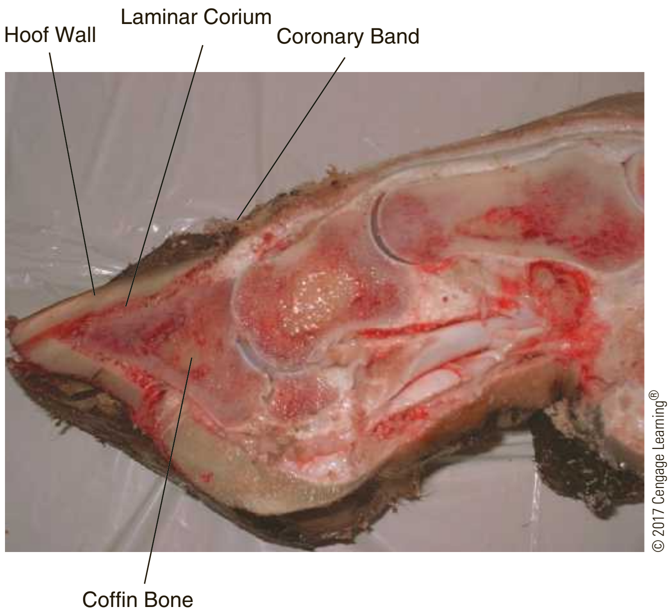

FIGURE 2–5 A. The structure of the equine foot. The laminar corium suspends the bone of the toe (coffin bone) within the hoof and nourishes the hoof wall. Growth of the hoof originates from the coronary band. B. Photograph shows the internal structure of a cow's foot.

CONNECTIVE TISSUES

Objective

- Describe the Properties, Locations, Functions, and Varieties of Connective Tissues

Tendons, fat, blood, cartilage, and bone are all examples of connective tissue. These tissues share the common features of specialized cells embedded in large amounts of extracellular material. This extracellular material, the matrix, is produced and deposited by the connective tissue cells. The matrix includes both extracellular fiber and a ground substance. The appearance of the connective tissue ranges from fibrous to smooth, on the basis of the amount of each in the tissue. Connective tissues have a number of functions (Figure 2–6). As the name implies, connective tissues connect one organ or tissue to another. **Tendons** serve to connect muscles to bones. The matrix in tendons is mainly composed of a protein called collagen. Collagen is arranged in bundles of fibers, which provide great strength. **Ligaments**, another type of fibrous connective tissue, connect bones to bones. In addition to collagen, ligaments have another protein called elastin. Collagen provides strength, whereas elastin provides the ability to stretch and return. The collagen fibers in both tendons and ligaments are arranged in a tightly packed parallel manner. This type of connective tissue is described as dense regular connective tissue.

Connective tissues provide both support and protection. Bone and cartilage are two of the supporting connective tissues. (These topics are covered in detail in Chapter 3.) Just as in other connective tissues, bone and cartilage are cellular tissues with a large amount of matrix. Cartilage lacks blood vessels and is nourished by the surrounding fluid. This feature limits the thickness of cartilage and the speed at which it can heal. Hyaline cartilage provides a durable contact surface between the bones of a moveable joint. In addition, hyaline cartilage is found in the rings that support the shape of the trachea and within the growth plates of bones in immature animals. The densely packed fibers and ground substance produce a very resistant tissue but one that is more flexible than bone.

Elastic cartilage has more elastic fibers than hyaline cartilage, making it more flexible. Elastic cartilage is found in regions where repeated movement occurs. Examples include the earflap and the epiglottis, which protects the opening to the larynx.

Bone has functions similar to those of cartilage, but the matrix is mineralized. This mineral gives bone its characteristic hardness. Bones give the body its shape, allow for movement, and protect internal organs. In contrast to cartilage, bone does have blood vessels. The vessels provide nourishment for the bone cells.

Connective tissues support organs and hold tissues together. For example, connective tissue holds muscles together and attaches the skin to underlying tissues. This type of tissue quite obviously appeared in the DA surgery discussed at the beginning of the chapter. After incising the skin, the connective tissue layers were encountered. **Adipose tissue** (fat) was also found deposited in this layer. Adipose tissue, another form of connective tissue, consists of cells filled with lipid. Adipose tissue is also found between muscles, behind the eye, within bone marrow, and in the abdomen. The number of fat cells does not change, but the amount of stored lipid does vary with the nutritional status of the animal. Fat tissue has a large blood supply which

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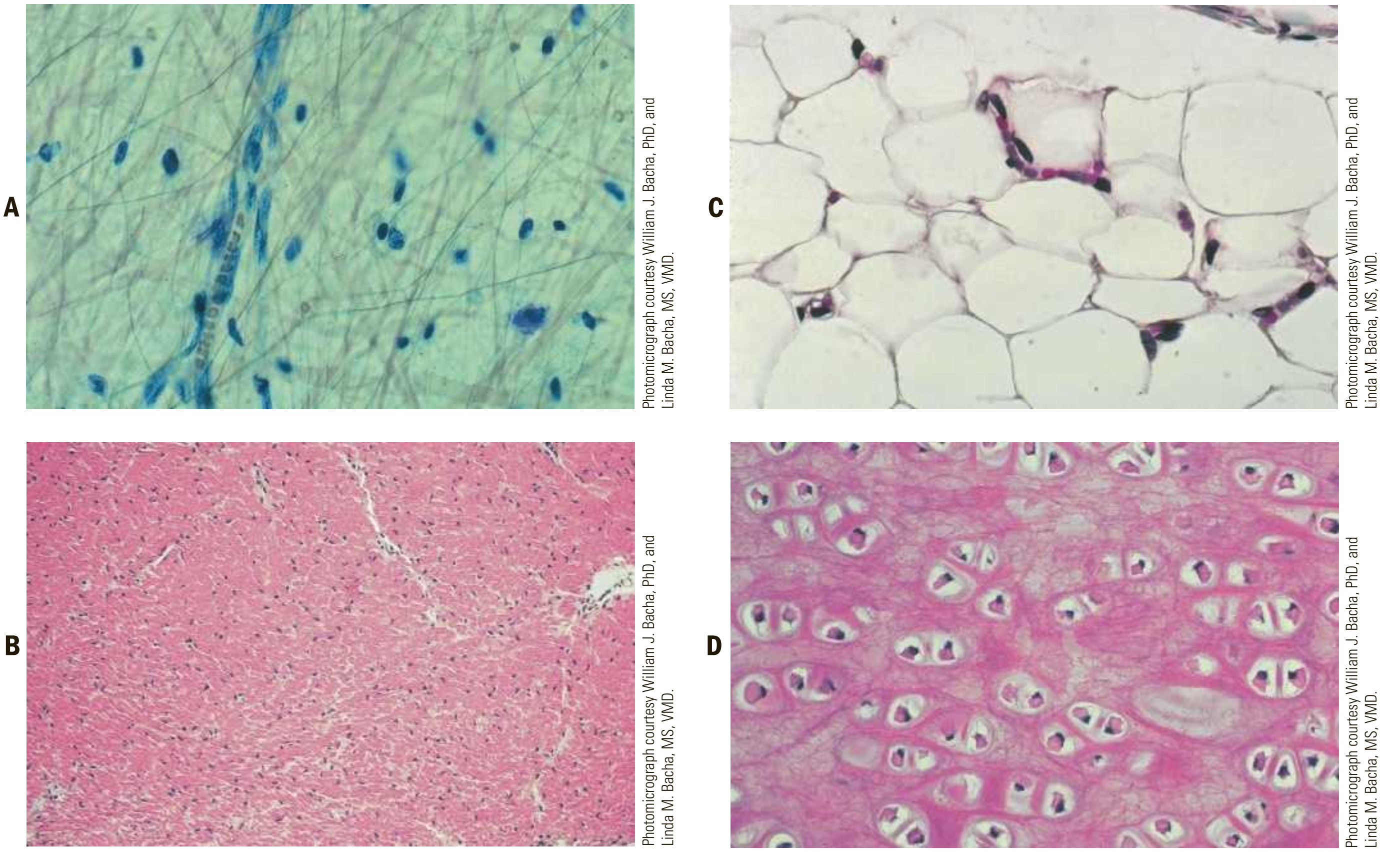

FIGURE 2–6 Types of connective tissues. A. Mesentery of a cat. The mesentery is a loosely arranged connective tissue attached to abdominal organs. This shows collagen fibers (pink) and elastic fibers (thin dark fibers). B. Densely packed elastic fibers found within a ligament of a sheep. C. Adipose tissue. The actual lipid content of the cells is no longer present. Also visible are capillaries with red blood cells. D. Cartilage found in a pig, showing the large cartilage cells, some elastic fibers, and the lightly stained matrix.

allows the stored fat to be readily accessed as an energy reserve. The fat underlying the skin provides an effective insulation against extremes in temperature.

Blood is considered a special type of connective tissue. The cells are suspended in a large volume of liquid matrix. The liquid portion of the blood is called plasma. Three formed elements are found in blood. Red blood cells transport oxygen and carbon dioxide. White blood cells fight infection. Platelets aid the blood in clotting. Further details on blood can be found in Chapter 4.

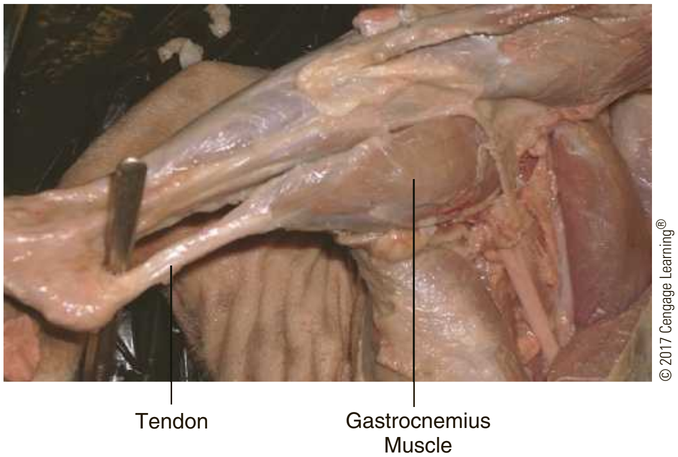

FIGURE 2–7 Photograph of the gastrocnemius tendon in a cadaver dog. This is better known as the Achilles' tendon. Note how the connective tissue surrounding the muscle blend into the tendon.

MUSCLE TISSUES

Objective

- Describe the Properties, Locations, Functions, and Varieties of Muscle Tissues

Muscles allow mammals to move. Three muscle types exist in mammals: skeletal, smooth, and cardiac. Skeletal muscle attaches to the skeleton and allows motion. The animal controls the movement of skeletal muscle with nerve signals from the nervous system. The animal can control which muscles it will move.

Smooth muscle (involuntary muscle) is located in many of the hollow organs of the body, including the gastrointestinal tract, urinary bladder, and blood vessels. The third type, cardiac muscle, is found in the heart. This type is an involuntary muscle as well. Involuntary muscle functions without the conscious thought of the animal. These muscles continue to work at all times, even while the animal sleeps.

Skeletal muscle is a striated voluntary muscle (Figure 2–7). The description of striation comes from

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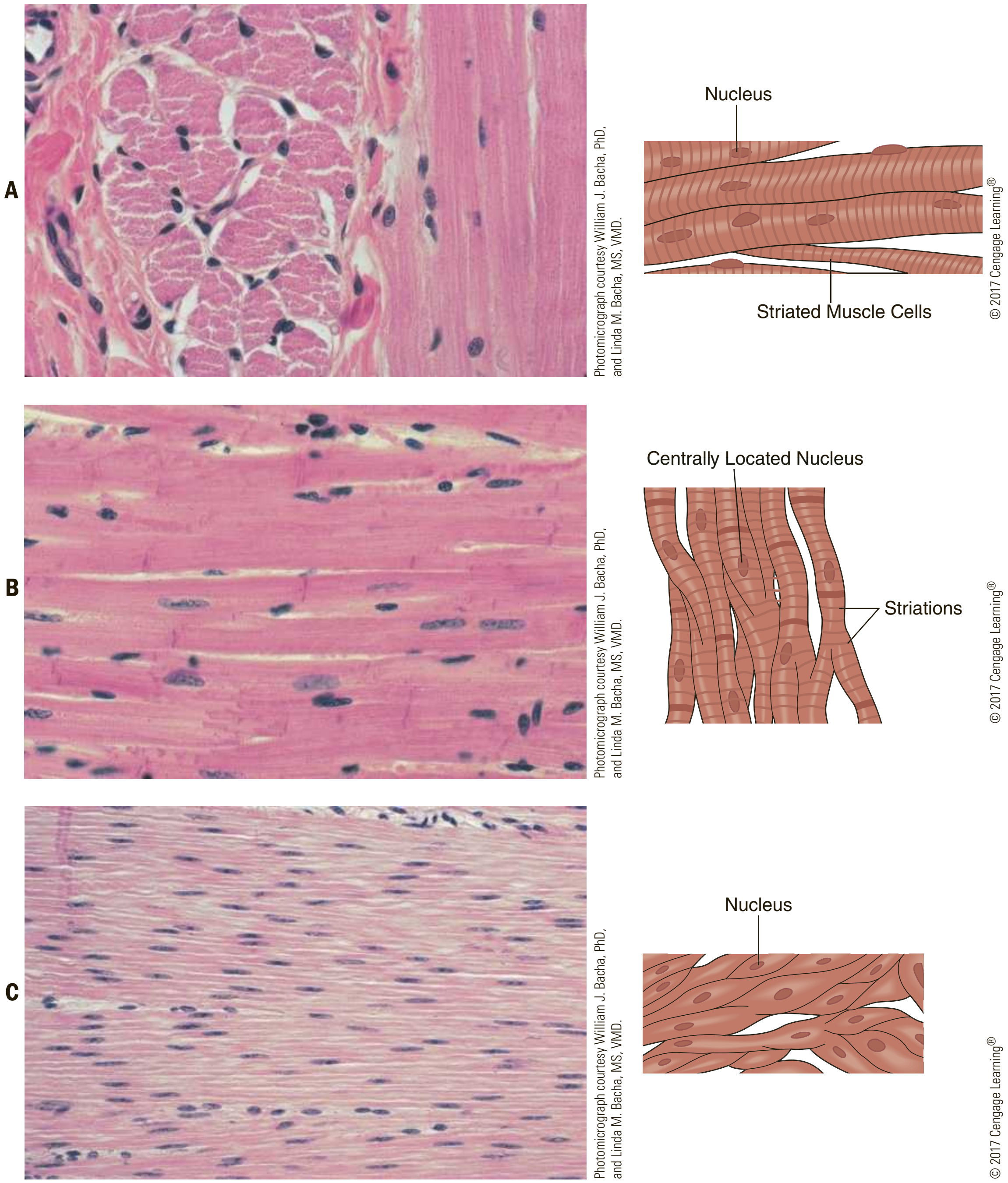

FIGURE 2–8 The three types of muscle tissues. A. Skeletal muscle from the tongue of a cat. The photomicrograph shows cells cut along their length and in cross section. B. Cardiac muscle from the heart of a goat. Note the intercalated disks that connect the cells. These structures allow the cells to act together in an organized contraction. C. Smooth muscle from the colon of a horse. Note that smooth muscle lacks the striations found in cardiac and skeletal muscle.

its appearance under the microscope. A muscle consists of thousands of muscle fibers, or muscle cells. An entire muscle cell is called a **myofiber**. This descriptive term originated because of the very long, thin, fiberlike appearance of the cell. Myofibers have several nuclei and a large number of mitochondria. Also, myofibers organize in parallel rows. They are separated by connective tissue that includes blood vessels and nerves.

The ability of a muscle fiber to contract comes from a very complicated system. Within the fiber, a highly organized system of myofilaments exists (Figure 2–8A). Two proteins, actin (thin filament) and myosin (thick filament), make up these filaments. These units are organized along the entire length of the cell. During contraction, the actin and myosin filaments slide along each other. The filaments have small bridges between them that bind and release as they slide (Figure 2–9).

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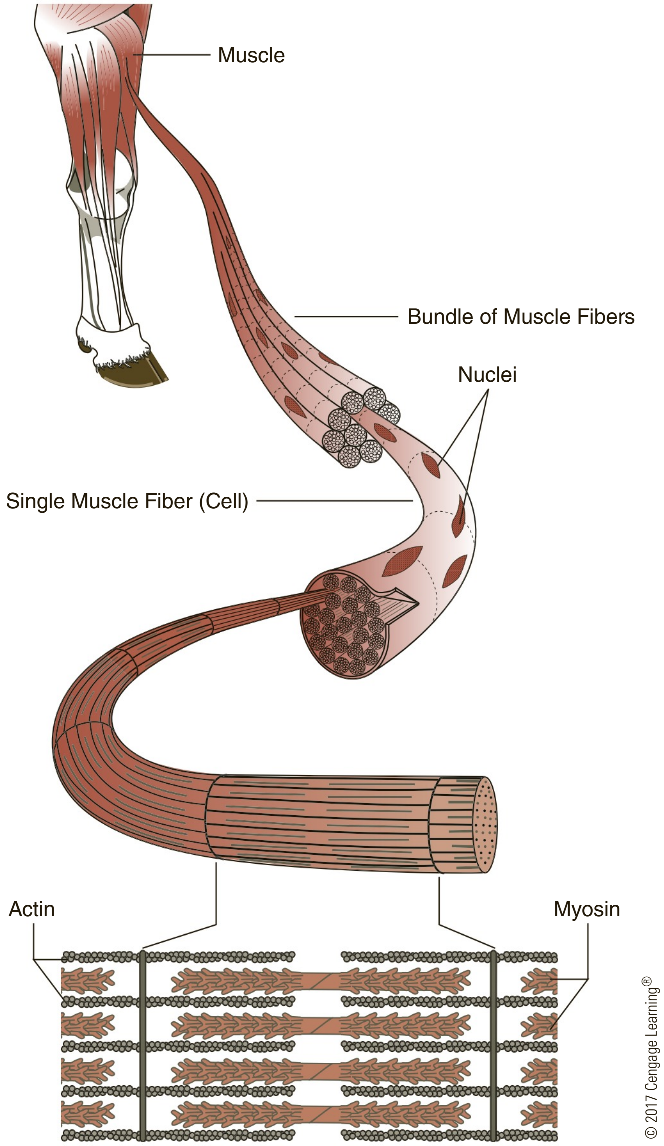

FIGURE 2–9 Muscle structure. A muscle is a collection of muscle fibers or cells. Each muscle fiber is a multinucleated cell. Actin and myosin filaments are arranged in an organized manner to allow contraction.

The contraction of a muscle fiber begins with stimulation from a nerve cell. At the neuromuscular junction the nerve cell releases acetylcholine, resulting in depolarization of the cell membrane. This change in voltage opens channels to allow a rapid flow of sodium ions across the membrane. The ion flow is propagated along the length of the muscle cell. The impulse stimulates the release of calcium that is stored in the endoplasmic reticulum. This flow of calcium ions causes the filaments to slide across each other. Energy is required for this entire process. A large number of mitochondria are present to supply the needed energy. During relaxation, the cell actively transports calcium back into the endoplasmic reticulum. This process also requires energy.

Rigor mortis (muscle stiffness) occurs after death because there is no supply of energy to pump calcium back into the endoplasmic reticulum. Without the energy, muscles cannot relax and remain stiff. **Porcine stress syndrome** (PSS) is a genetically transmitted disease in pigs in which calcium is not transported back into the endoplasmic reticulum. Therefore the muscles do not relax normally. Bouts of PSS typically occur when pigs are stressed from heat or transportation. Extreme muscling and leanness or shaking can generally identify pigs with a predisposition to this condition. In severe cases, the pig may die. These pigs enter rigor mortis rapidly, which is expected based on the lack of calcium transport. Obviously calcium plays an essential role in muscle activity. Dairy cows can develop a lack of calcium around calving time. At this point the cow dramatically increases the use of calcium for milk production. So much calcium can be excreted in the milk that calcium levels in blood and muscles become too low. This is technically called **hypocalcemia** but is commonly referred to as milk fever. A cow with milk fever becomes weak and unable to rise. Veterinarians treat milk fever with a calcium solution placed directly into the bloodstream. As the calcium transfers to the muscles, the cow responds. Within a few minutes after treatment, the affected cow often stands.

Dogs are also susceptible to low blood calcium levels following parturition. In dogs the term eclampsia is used to describe this condition, which typically occurs in small-breed dogs in the first four weeks of lactation. Initially the signs may be mild, including restlessness, anorexia, and vomiting. The signs quickly progress to muscle twitching (fasciculation), ataxia (lack of coordination), stiffness, and elevated body temperature in response to the extreme muscle activity. If calcium levels drop lower the dog will progress to seizures and even death. Once again there is rapid improvement in response to intravenous calcium solutions.

A nerve cell stimulates more than one muscle fiber. A motor unit is the collection of the nerve cell and all the muscle fibers it stimulates. Once stimulated a muscle cell contracts completely. Variation in the strength of a contraction is not within one cell, but within a number of cells that are recruited. In other words, the more cells recruited, the stronger the contraction that results. When fine control of movement is necessary, the number of muscle fibers involved per nerve cell remains small. This is seen in the muscles of the eye and larynx. Muscles engaged for gross movement, such as the upper leg, have a large number of fibers for each nerve cell. Muscles, a collection of a large number of myofibers, can partially contract. The more motor units used, the more completely the muscle contracts; conversely, the fewer motor units used, the less the muscle contracts.

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The number of muscle fibers in a muscle stays basically constant. However, muscles do get larger in response to their usage. This occurs because individual fibers add more myofilaments to become larger. When a muscle is not used, it decreases in size. This can occur from inactivity. A house pet that gets little exercise will experience a decrease in muscle size. Having a limb immobilized in a cast also causes the limb muscles to shrink. After the cast is removed, these same muscles increase in size as the limb is exercised. If the nerve supply to a muscle is damaged, the muscle also shrinks. An example of this can occur in draft horses used for pulling. A nerve in front of the shoulder can be damaged from pulling the harness. When this nerve is damaged, the muscles on top of the shoulder blade shrink. This condition is called **sweeny**.

Cardiac muscle is also striated in appearance but is involuntary in action. (Figure 2–8B). The appearance of the cardiac myofilaments is very similar to that of skeletal muscle. Moreover, the mechanism that allows for cardiac muscle contraction is identical to that in skeletal muscle. The myofibers (muscle cells) are branched in cardiac muscle and contain even more mitochondria than skeletal muscle.

Cardiac muscle cells have the unique ability to initiate their own contraction. No nerve cell stimulation is necessary for a contraction to begin. Specialized pacemaker cells are responsible for establishing the rate of contraction. However, nerve cells are present to influence the rate of contraction. The autonomic nervous system can increase or decrease the rate. As long as oxygen and glucose are provided to the cardiac muscle cells, the heart continues to beat.

For the heart to effectively serve as a pump, the cells must contract in a very organized manner. The cardiac muscle cells have a specialized connection between them. When one cell contracts, the electrical signal immediately passes to the next cell through this junction. This allows for a chamber of the heart to function as one unit.

Smooth muscle gets its name because it lacks the striated appearance of skeletal muscle (Figure 2–8C). Smooth muscle contains actin and myosin filaments, but not in the same arrangement as skeletal muscle. Each myofiber is a spindle-shaped cell, tapered at each end. In addition, each cell has one nucleus.

Smooth muscle is arranged in sheets around hollow openings such as those in the gastrointestinal tract. Contraction of this sheet of muscle may make the opening smaller. In blood vessels, this occurrence is called constriction. In an organ such as the esophagus, the contraction aids in propelling food toward the stomach. This organized contraction that propels the food is called peristalsis.

Smooth muscle contracts more slowly than skeletal muscle. Moreover, the cells are able to maintain contraction for prolonged periods without tiring. By keeping this muscle tone, the opening within an organ can be kept at the same diameter. Blood vessels may also be maintained at the same diameter for long periods. The autonomic nervous system controls the action of smooth muscle.

NERVE TISSUES

Objective

- Describe the Properties, Locations, Functions, and Varieties of Nerve Tissues

Nerves allow communication among areas of the body by receiving and transmitting electrical signals. Nerve tissue is found in the brain and spinal cord, as well as in the peripheral nerves. Together the brain and spinal cord are called the **central nervous system**. In addition, nerves extend from these areas to other locations. The **peripheral nervous system** includes all the nerves outside the brain and spinal cord.

Nerve tissue contains cells called **neurons** (Figure 2–10), which can be very large. The body of the neuron houses the nucleus and many other organelles. The axon, a hairlike extension from the cell body, carries the nerve impulse. The axon may end on other neurons or other tissues, such as muscles. The axons from many neurons are bundled together to form a nerve. The axon can be very long. In a horse, for example, some axons may be more than 2 m long. The neuron has other extensions called dendrites. An axon often ends on the dendrite of another neuron. This site of connection is called a synapse. When stimulated, the dendrite begins the nerve impulse.

The nerve impulse occurs as a flow of ions passes through the cell membrane. In a resting nerve cell, sodium ions are actively transported into the extracellular fluid. At the same time, potassium is pumped into the cytoplasm. Once stimulated, the ions flow rapidly across the membrane. Stimulation at one point then moves down the axon in a rapid progression. Afterward, the neuron prepares for the next impulse. Using microelectrodes, the nerve impulse can be measured as an electrical event.

There are three basic types of neurons:

1. Sensory neurons: These neurons have receptors that are stimulated in response to changes in the animal's environment. Once stimulated, the nerve signal transmits through the neuron back to the central nervous system. There are many types of receptors in the body. Table 2–1 lists the common receptor types. The signals from these neurons are then transmitted to motor neurons or interneurons. These neurons give feedback on changes occurring outside and within the animal.

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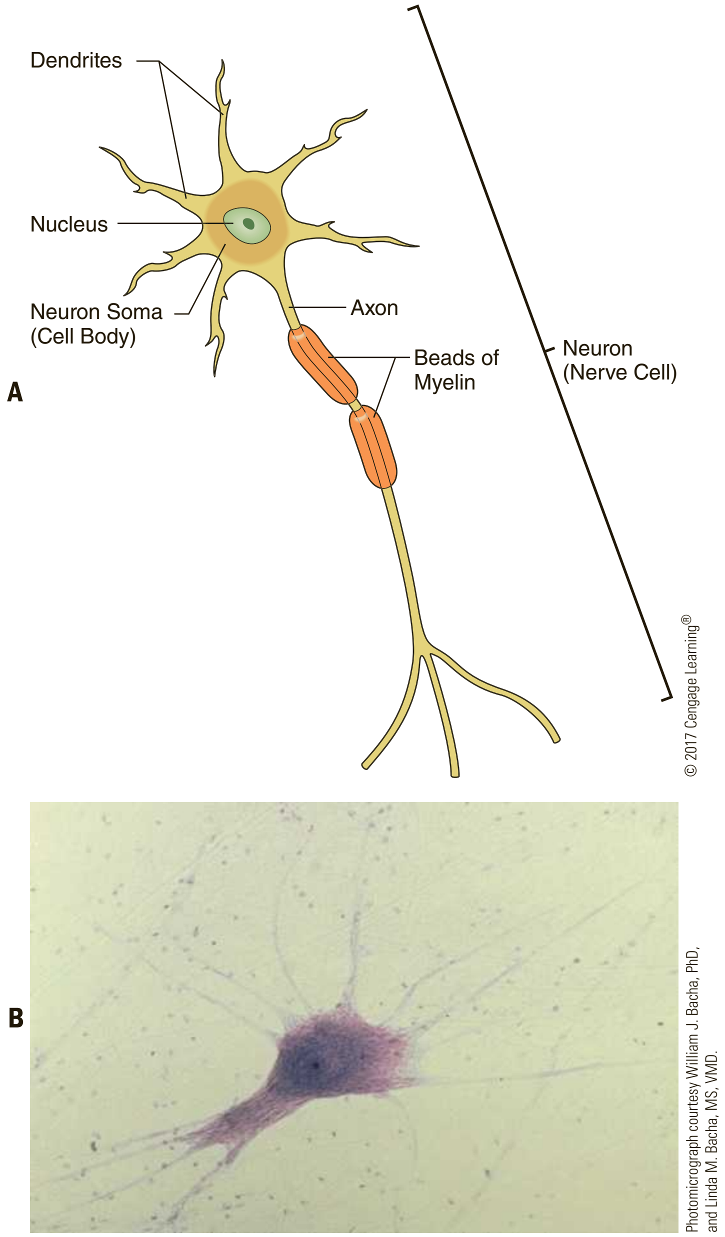

FIGURE 2–10 A. The structures of a neuron. B. Photomicrograph of a motor neuron from the spinal cord of a cow.

Table 2–1 Receptor Types

Light
Heat
Touch/pressure
Hearing
Balance
Taste
Smell
Internal chemical receptor (results in feeling thirst)

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2. Interneurons: These neurons are found within the central nervous system. Sensory neurons or interneurons stimulate them. There are a tremendous number of connections within the brain and spinal cord. The connections among all these neurons provide the pathways that allow the central nervous system to control the animal's activities.
3. Motor neurons: These neurons begin in the central nervous system and extend to a muscle or gland. When stimulated by the motor neuron, an action occurs. For example, the muscle contracts or the gland releases its secretion. A sensory neuron or an interneuron stimulates the motor neuron.

CLINICAL PRACTICE

Objective

- Link Knowledge of Tissues to Clinical Practice

Certain infectious diseases may infect specific tissue types. For example, foot-and-mouth disease selectively attacks epithelial tissue. This disease attracted international media attention when an outbreak occurred in the United Kingdom. This highly infectious disease spreads very rapidly. It commonly infects cattle, sheep, goats, and swine. FMD was last diagnosed in the United States in 1929 but has been present in other countries since then. The prior outbreak in Europe raised the concern that FMD might recur in the United States.

Although it is usually not fatal, FMD, a viral infection, causes very serious signs in affected animals. The epithelium in the mouth and tongue develops blisters. These blisters cause great pain, making the animal drool and quit eating. The epithelium around the hooves is also commonly involved, making movement painful as well. Other epithelial linings, such as those deeper in the intestinal tract, can also be infected.

This disease spreads rapidly by contact with infected animals. Humans can also transport the virus (for instance, on clothing and shoes or in the respiratory tract), which makes its spread more difficult to control. Fortunately for my client, her friends from Germany were not likely to be a source of introducing the disease into her farm. This tendency for rapid spread is the major concern of potential FMD reintroduction into the United States.

In the United Kingdom, infected and exposed animals had to be destroyed in an attempt to stop the disease. No treatment is available, although most animals eventually recover. Vaccines are available to control the spread of the disease but are not currently being used in the United States. Distinguishing between a natural infection and a vaccinated animal through a blood test can be difficult. Because the United States

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has been free of FMD for such a long time, no animals would test positive for this disease. If vaccination were started, it would be more difficult to use screening tests to monitor the incidence of the disease, because these tests may show positive in vaccinated animals. However, if FMD were to occur in the United States, vaccination might be used to stop its spread. Note that FMD is not related to hand, foot, and mouth disease, which commonly affects small children and is known to spread rapidly in preschools and day care centers.

A common problem encountered in companion animal medicine occurs when a larger dog attacks a small dog. In Remmy's case the groundhog happened to be the culprit. In these situations, the skin receives lacerations, which need repair. In addition to the lacerations, the skin may pull loose from the underlying connective tissue. The preceding discussion of tissues emphasized the significance of the connective tissue holding the skin to the underlying muscle. In a traumatic injury that causes the skin to pull loose, this bond has been destroyed.

If the torn skin is pulled back together without further repair of the connective tissue, dead space is created. Dead space, a pocket under the skin, allows tissue fluid to accumulate. This buildup of fluid often prevents complete healing. To avoid this problem, the dead space may be closed with an additional layer of sutures. Placing a drain into the dead space can also aid in repair. This drain provides an opening that allows any fluid to drain. Both these methods keep the skin in contact with the connective tissue. Over time the two tissues heal together.

Horses may be affected by a disease called **tying up, or Monday-morning disease**. This condition often occurs on a Monday after a weekend of rest, when the horse consumes a full diet. As the horse begins working or exercising, it develops severe cramping. The cramps are often so severe that damage occurs to the muscle tissue. Products from the muscle leak from the cells and eventually are cleared from the bloodstream by the kidneys. These breakdown products may damage the kidneys.

The cause of this disease process is very complex. The muscle tissue requires a great deal of energy and oxygen for the work involved. High metabolism also produces waste products that must be cleared from the cells. With the right combination of rest and diet, followed by intense exercise, normal balance is altered. The buildup of waste products results in damage to the muscle and results in tying up syndrome.

Nerves often provide signals to several muscles in one area. Damage to a nerve can be detected on the basis of the group of observable signs. **Horner's syndrome** results from damage to a nerve in the autonomic nervous system. This nerve comes through the neck and the base of the skull to control several eye functions. When damage occurs, several signs are observed, including the following: (1) The pupil is constricted; (2) the upper eyelid droops; (3) the third eyelid protrudes; and (4) the eye is sunken in the socket. When these signs are present, the animal has Horner's syndrome. These signs help to identify what nerve is damaged. Knowing this, the veterinarian can direct attention to diagnosing the underlying cause.

The integument protects the body from the environment. With long-term exposure to damaging conditions, the integument itself can become diseased. Foot rot in cattle and sheep provides an excellent example. Persistent exposure to wet and dirty conditions works to soften the skin and hoof. Combining the soft skin with trauma allows bacteria to invade the skin between the claws of the hoof. *Dichelobacter nodosus* and *Fusobacterium necrophorum* are two bacteria commonly found in the environment that colonize the skin and develop an infection, termed foot rot. This is a very painful condition that causes a distinct lameness. Typically the area between the claws of the hoof has an open infection with an accompanying distinct odor. Animals with foot rot often lose weight because they are less likely to be walking and grazing or competing for food at a feed bunk. Fortunately, the condition is responsive to topical treatment and antibiotics. Prevention revolves around keeping the environment clean and dry.

SUMMARY

In Chapter 2, four tissue types were examined: epithelial, connective, muscle, and nerve. Epithelial tissues line the body's surfaces; openings, including the intestinal, reproductive, and urinary tracts; and tubes, such as the blood vessels and the heart. Connective tissues vary in type but share the common feature of specialized cells embedded in vast amounts of extracellular material. Moreover, three types of muscle tissue exist: skeletal, cardiac, and smooth. Lastly, nerve tissues provide for communication within the body. These four tissue types allow the body to function efficiently and effectively.

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REVIEW QUESTIONS

1. Define any 10 of the following terms:
   - tissue
   - organs
   - displaced abomasum
   - foot-and-mouth disease
   - epithelial tissues
   - basement membrane
   - integument
   - keratin
   - tendons
   - ligaments
   - adipose tissue
   - myofiber
   - rigor mortis
   - porcine stress syndrome
   - hypocalcemia
   - sweeny
   - central nervous system
   - peripheral nervous system
   - neurons
   - tying up, or Monday-morning disease
   - Horner's syndrome
2. True or False: Hair is epidermal tissue.
3. True or False: Kidney damage may occur in Monday-morning disease.
4. Which of the four stomachs of a cow becomes displaced when a twisted stomach occurs?
5. What type of tissue lines the body's surface and openings?
6. What type of epithelial tissue lines the urinary tract?
7. What type of tissue is under attack in foot-and-mouth disease?
8. Name the hairlike extension from the nerve cell body that carries the nerve impulse.
9. After death, the body lacks energy to pump calcium back into the endoplasmic reticulum. Consequently, the body stiffens. Name this condition.
10. Why do light-colored horses have a higher incidence of melanoma than dark-colored horses?
11. Describe the shape of squamous cells.
12. Differentiate between tendons and ligaments.
13. List the three muscle types.
14. List two involuntary muscle types.
15. List three types of neurons.
16. Describe the functions of the three different muscle types: skeletal, smooth, and cardiac.

ACTIVITIES

Materials needed for completion of activities:

- light microscope
- slides and cover slips
- toothpicks
- iodine
- cardiac, smooth, and skeletal muscle samples
- dissecting kits
- rulers
- chicken legs
- paper plates

1. Perform a simple cheek cell scrape. After securing a light microscope, toothpicks, slides, cover slips, and iodine (or another suitable stain), prepare slides in the following manner: Scrape toothpick across the inside of the cheek. Place the scraped cells onto a slide. Place a drop of iodine on the cells, and cover with a cover slip. View under low and high power. Try to identify the epithelial cells.
2. Dissect a chicken drumstick and attempt to identify and classify connective tissue as tendons or ligaments.
3. From a local butcher shop, secure cardiac muscle (portion of the heart), smooth muscle (such as from the wall of the gastrointestinal tract or the urinary bladder), and skeletal muscle samples. Cut each sample. Compare and contrast muscle tissue types.
4. Receptors are not evenly spaced throughout the body. The pressure receptors in the skin are more common in sensitive areas, such as a finger, than on the back. Tape a toothpick to the end of a ruler, with the end sticking below the ruler. Hold a second toothpick close to the first one (Figure 2–11). Begin with the two toothpicks next to each other. Touch the toothpicks to the skin of another student. The toothpicks should contact the skin at the same time. The student being touched should not be

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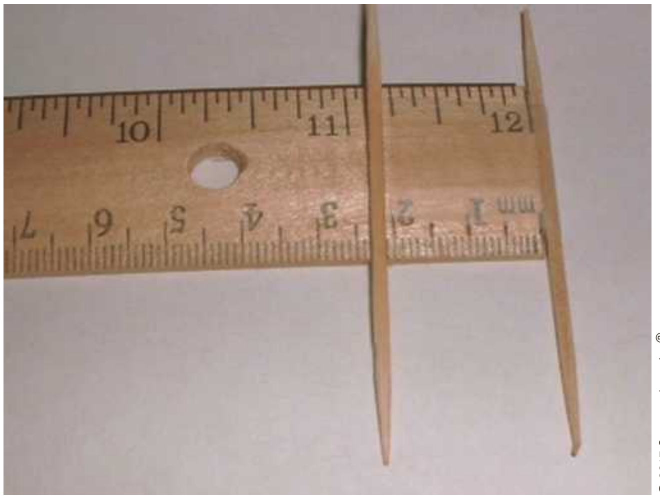
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FIGURE 2–11

able to see the contact. Move the second toothpick farther apart until the student being touched can tell that there are two contact points. Repeat this experiment at different sites on the body, such as the finger and back. Is there a difference in the distance detected between the two areas? If so, why?

5. The mission of the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (APHIS) *is to protect the health and value of American agriculture and natural resources.* Investigate the history, purpose, and current programming of the agency.
6. Research the current status of foot-and-mouth disease. Possible sources for information include the U.S. Department of Agriculture, state departments of agriculture, land grant university departments of animal or veterinary science, or the local Cooperative Extension Service.

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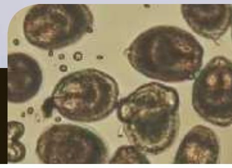

CHAPTER 3

The Musculoskeletal System

Objectives

Upon completion of this chapter, you should be able to:

- Describe the functions of the musculoskeletal system.
- Detail the structure of bone.
- Name joint types and their accompanying roles in movement.
- List the two major sections of the skeleton, name the corresponding bones, and compare species differentiation.
- Explain how bone grows and remodels.
- Relate bone and muscle groups to movement.
- Connect the academic material pertaining to the musculoskeletal system to clinical practice.

Key Terms

herd check
radiograph
orthopedic surgeon
axial skeleton
appendicular skeleton
intervertebral disk disease
high-rise syndrome
cranial drawer sign
ossification
subluxate
x-ray
radiology
simple fracture
comminuted fracture
compound (open) fracture
intramedullary pin
hip dysplasia
degenerative joint disease
joint ill

Introduction

The skeleton gives mammals shape and support. Combining bones and muscles allows movement. Bones are active tissues that adapt to changes within the animal. The skeleton, although very hard, allows the animal to adapt and grow.

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A Day in the Life

Routine Days Aren't Always Routine . . .

Today seemed predictable as far as my days go. **Herd checks** (reproductive exams and routine health maintenance work) dominated the day. Many of our dairy clients ask a veterinarian in our practice to visit once or twice a month to perform a herd check. When called for a herd check, I examine cows for pregnancy (veterinarians can detect pregnancy in cattle bred for 30 days or more) and also make sure they have recovered from calving. Keep in mind that dairy cows experience a lactation peak shortly after calving. Therefore, farmers attempt to have their cows calve every 12 to 13 months to maximize milk production. I help them accomplish this goal.

I heard a familiar bark when I pulled into my second call of the day (another herd check). Missy, a 120-pound Saint Bernard, let everyone know that I had arrived (Figure 3–1). I first met Missy after she was injured while working on the farm. Her owner had driven his pickup to cut firewood. Dutiful Missy rode along in the bed of the truck. When the truck stopped, Missy jumped off, just as she had done many times before. Unfortunately, this time Missy's right hind leg became caught and she fell.

Missy was crying in pain and not able to bear weight on her injured leg when the farmer brought her to our office. My associate, Dr. Deppen, examined her. It was obvious that the leg was very swollen and likely broken. Dr. Deppen took a **radiograph** of Missy's tibia, a bone in the lower leg.

It was apparent from the radiograph that the tibia had been broken into several pieces (Figure 3–2). We offered to refer Missy to an **orthopedic surgeon**, a veterinarian who specializes in surgery of the bones. Knowing a referral of this type can be quite expensive, the owners wondered if we could repair the bone.

Dr. Deppen and I discussed the options. We both felt that, considering the severity of the fracture, a cast or splint was not likely to be successful. Conversely, we could attempt to perform the needed surgery. I called the farmers to offer the choices at hand. I first told them that I am not an orthopedic specialist and that the fracture was quite severe. Then I explained that I could attempt the surgery. They agreed to allow me to perform the surgery, knowing that the operation might not be successful. I obviously needed a thorough knowledge of bones before I could repair them.

Photograph courtesy of Fred Brenner

FIGURE 3–1 Missy enjoying life at home.

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FIGURE 3–2 Radiograph of Missy's fractured leg.

MUSCULOSKELETAL SYSTEM FUNCTIONS

Objective

- Describe the Functions of the Musculoskeletal System

Bones furnish five basic functions: structure, leverage, protection, mineral reserves, and blood cell production. The most visible function of bones is structure. The collection of bones in the animal forms the skeleton. This provides the framework that defines an animal's shape and size. Differences in both size and shape are very obvious in veterinary medicine. The skull provides a clear example of this variation. When seeing only the bones of the skull, it is easy to distinguish the skull of a

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cat from that of a horse. Having muscles closely associated with the skeleton provides movement of the bones at a joint. The movement of bones allows locomotion and function of the animal.

The strength of bones also protects more fragile tissues. The rib cage gives protection to the heart and lungs, whereas the skull protects the delicate brain. Bone acts as a reservoir for calcium and phosphorus. In times of need, the minerals are moved from the bone and sent into the bloodstream. Excess minerals can be stored in the bone. Calcium plays an essential role in muscle contraction and enzyme activity. Phosphorus is necessary for energy metabolism within the cell. Bone, in response to several hormones, maintains a tight regulation on the blood level of these minerals. These hormones, calcitonin and parathyroid hormone, will be discussed in much greater detail in Chapter 10.

The long bones are present in the legs (and arms in humans). The femur and humerus are classified as long bones. They have a dense outer shell and a hollow shaft. Bone marrow is made in this hollow center, the medullary cavity. Bone marrow in turn produces blood cells.

BONE STRUCTURE

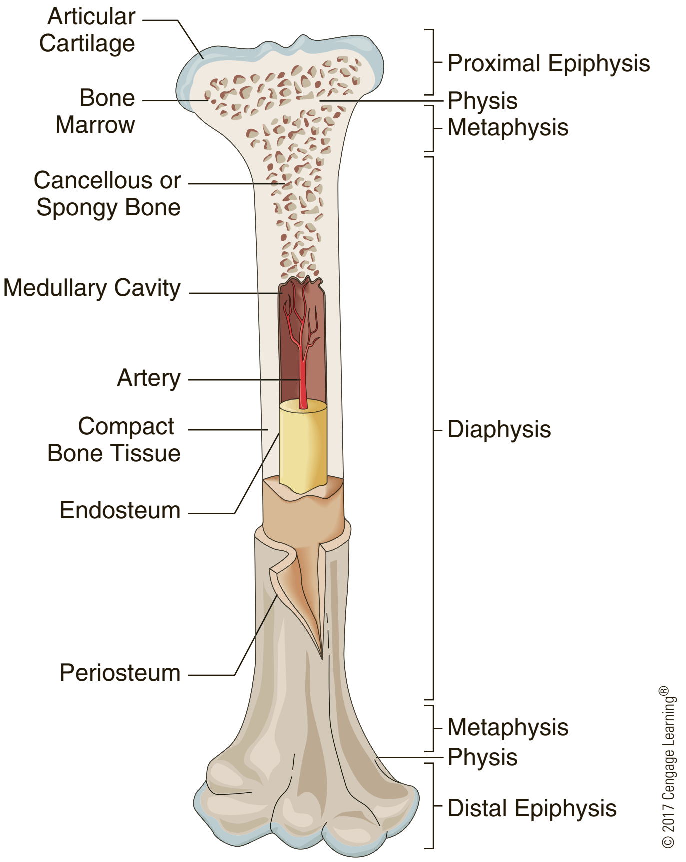
Objective

- Detail the Structure of Bone

Splitting a long bone along its length shows the typical structure of bone (Figure 3–3). The outer shell is composed of dense or compact bone. The term *cortical bone* is also used for this region. The greater the forces placed on a bone, the thicker this layer will be. In the femur, this compact bone is thickest in the middle of the shaft, where greatest strain occurs.

Within compact bone lies a more loosely arranged bone, called spongy or cancellous bone. Spongy bone is found within the long bones but not inside the flat bones of the skull or pelvis. It only fills the ends of these long bones. Spongy bone is made up of tiny spicules and plates of bone. The spicules look random but are actually arranged to maximize strength. The spongy arrangement keeps the weight of the bones much lighter than that of a solid bone of the same dimension. The medullary cavity is located in the hollow center of the shaft. The bone marrow lies within the medullary cavity and the spaces of the spongy bone. As mentioned earlier, bone marrow produces blood cells.

A



B

FIGURE 3–3 A. Illustration of bone structure. B. Photograph of the internal structure of bone.

Bones are covered with a thin connective tissue called the periosteum. The periosteum blends into tendons and ligaments, binding them to the bone. The periosteum has an extensive blood and nerve supply. Hence trauma to the periosteum is quite painful. The portion of bone within the joint is covered with cartilage and not by periosteum. This articular cartilage provides protection as the bones move against one another within a joint. The open spaces within bone are covered with a similar connective tissue, the endosteum. Both the periosteum and endosteum provide cells necessary for the repair of damage.

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A dried bone is composed of about 70% inorganic minerals and 30% organic components. The inorganic minerals have a high level of calcium and phosphorus. This is found as crystals of hydroxyapatite ($3Ca_3(PO_4)_2 \cdot Ca(OH)_2$). The organic portion contains collagen fibers, polysaccharides, and cells. The fibers provide a framework on which the hydroxyapatite crystals can be deposited. Whereas organic fibers give the bone a small amount of elasticity and resiliency, minerals give bone its typical hardness and strength. Without the organic material bones would be quite brittle. The collagen fibers and the hydroxyapatite crystals make up the matrix that surrounds the cells.

There are three types of bone cells. Osteoblasts, found in close association with the periosteum, lay down the collagen matrix. Osteoblasts are important in increasing the diameter of bone and in the healing of fractures. During the formation of bone these osteoblasts become encased in matrix, developing into osteocytes. The osteocytes are found in microscopic cavities of mature bone, the lacunae. The osteocytes are responsible for maintaining the bone matrix. Osteoclasts are large multinucleated cells that release the minerals from bone. Bone is a living tissue that is always being remodeled in response to physical forces on the body and the body's need for calcium.

Osteoporosis is a condition in which the bones lose their normal density. Several disease conditions can result in this decrease of bone mass. The problem can also occur in animals when a limb is not used for long periods (e.g., following extended time in a cast). Because the bone is not subjected to physical forces, new mineral is not deposited. Osteoclasts continue to release the minerals into the bloodstream. The bones can become so thin that they can break under normal usage. Osteoporosis that occurs from disuse is reversible once the animal begins to use the leg.

Bone is composed of a collection of microscopic units called osteons or haversian systems. There is a haversian canal in the center of the osteon (Figure 3–4).

Photomicrograph courtesy William J. Bacha, PhD, and Linda M. Bacha, MS, VMD.

FIGURE 3–4 Microscopic structure of bone, showing osteons with a central canal. The bone matrix is deposited in a circular arrangement. Darkly stained osteocytes are visible within the matrix.

Blood vessels, nerves, and lymphatics run through this canal. Bone is laid in concentric circles around this channel, forming cylinders. Within these layers lie the osteocytes that maintain the bone matrix. Communication occurs between osteocytes through microscopic canals called canaliculi. Many osteons are joined to form the layers of bone. A fine connective tissue layer, the periosteum, covers the external surface of bone. The periosteum is the source of blood vessels that supply nutrients to the bone tissue. The small vessels enter the bone through Volkmann's canals, which cross osteons. Larger vessels may enter the shaft of a bone through a nutrient foramen. Typically these vessels supply the bone marrow. It is important to recognize that a nutrient foramen could be mistaken for a crack in one cortex of a bone when seen on a radiograph.

JOINT TYPES AND MOVEMENTS

Objective

- Name Joint Types and Their Accompanying Roles in Movement

Joints form where other tissues join two bones. Generally joints are classified by the amounts or types of movement allowed (Figure 3–5).

Fibrous Joints: The bones in a fibrous joint are brought together with a dense connective tissue. These are also called fixed joints because little movement is possible. This type of joint can be found in the skull, where it is called a suture.

Cartilage Joints: As the name suggests, the bones in this joint type are connected with cartilage. The growth plate of young animals serves as an example. The growth plate exists within a bone and allows for rapid growth. The cartilage layer within the growth plate is eventually replaced by bone as the animal reaches adulthood. A symphysis is another type of cartilage joint. Symphysis is found, for example, between the halves of the pelvis as well as between those of the lower jaw. A cartilage joint also occurs between two vertebrae and includes the intervertebral disk.

Synovial Joints: These joints are the true moveable joints. A dense layer of bone at the joint is covered with a layer of cartilage. This articular cartilage covers the contact surfaces of the two bones (Figure 3–6). The joint is enclosed with a joint capsule. The outer layer of the joint capsule contains strong connective tissue. This is lined with a synovial membrane, which produces synovial fluid. Synovial fluid provides lubrication to the joint and carries nutrients to the cartilage. Ligaments are also present to provide strength to the joint. Ligaments are a dense fibrous connective tissue band that connects bone to bone. Tendons, connecting muscle to bone, also can increase the stability of a

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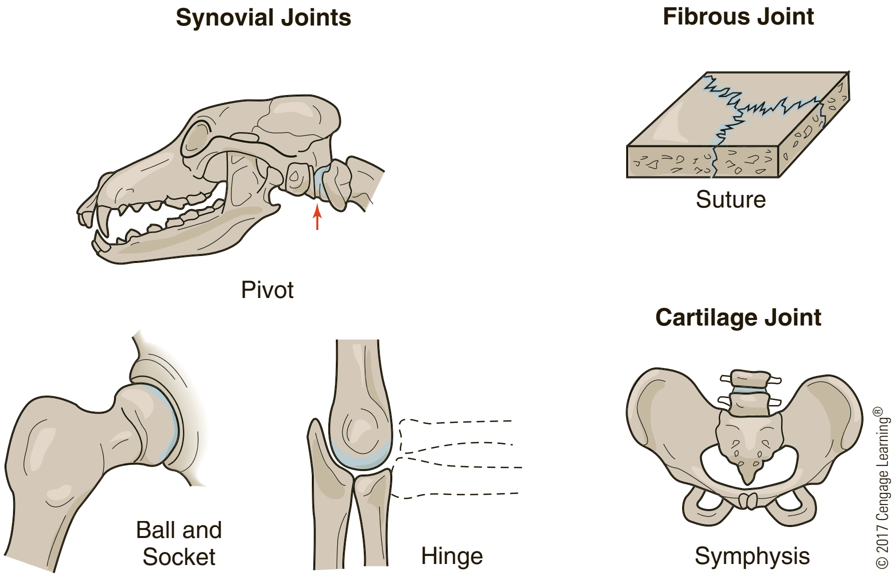

FIGURE 3–5 Joint types.

joint. Certain joints have a meniscus, which is a hard cartilage pad. The meniscus acts as a cushion between the bone ends. The knee joint has ligaments both inside and outside the joint capsule. Menisci are also present as cushions for the wide range of motion in this joint.

Several terms are used to describe the motion within a joint. The same description can be used for the muscle group that causes that motion. *Flexion* occurs when the angle between the two bones gets smaller. The opposite motion, *extension*, occurs as the angle between the bones increases. *Abduction* occurs when a part is moved away from the body, and *adduction* as the part is moved closer. When a part spins on its long axis, the movement is termed *rotation*. *Circumduction* describes a movement in which the end of the limb is moved in a circular motion.

The type of motion allowed also describes specific types of joints. The simplest, the hinge joint, allows movement in one axis. The classic example of a hinge joint is the elbow. The arm can be flexed and extended at the elbow in only one plane. A pivot joint allows rotation around a point. The pivot joint between the first and second vertebrae allows the head to rotate. The wrist is an example of an ellipsoid joint, which allows motion not only in hinge fashion but also in rotation. The ball-and-socket joint, such as the hip or shoulder, allows motion in any direction. This type of joint provides the greatest variety of motion.

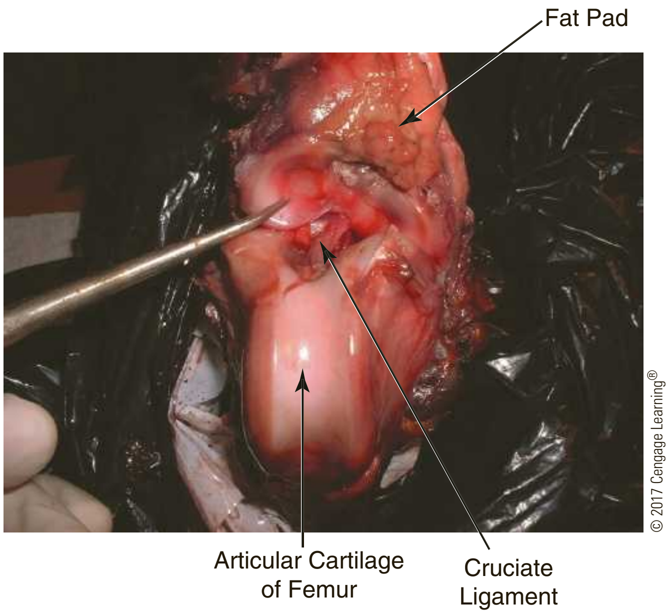

FIGURE 3–6 Internal structure of the knee joint. Probe identifies a meniscus.

AXIAL AND APPENDICULAR SKELETONS

Objective

- List the Two Major Sections of the Skeleton, Name the Corresponding Bones, and Compare Species Differentiation

Tremendous similarities exist in the skeletal structure of the domestic species (Figure 3–7). The skeleton can be divided into two major sections. The **axial skeleton** contains the skull, vertebrae, ribs, and sternum. The **appendicular skeleton** consists of the bones of the limbs. The total number of bones varies between species and even within a species. For example, dogs may or may not be born without the first digit (dewclaw) on their legs. Moreover, some dogs have very short tails with a small number of vertebrae, whereas others have long tails and more vertebrae. A typical dog has about 320 bones (134 in the axial skeleton and 186 in the appendicular skeleton). On the other hand, horses have fewer bones in the distal limbs than dogs, with a total of only 205 bones.

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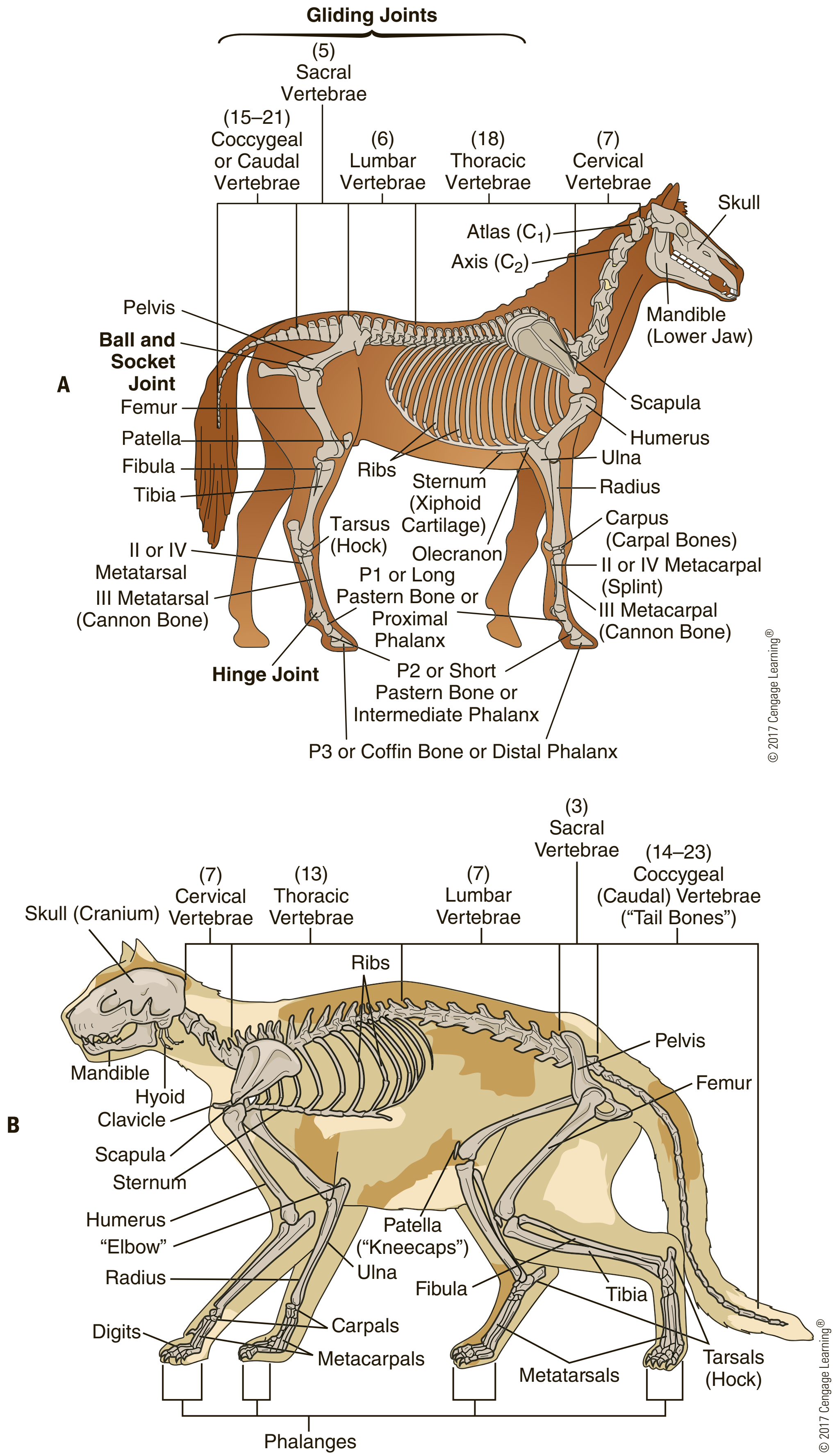

FIGURE 3–7 Comparison of the skeletons of a horse and a cat.

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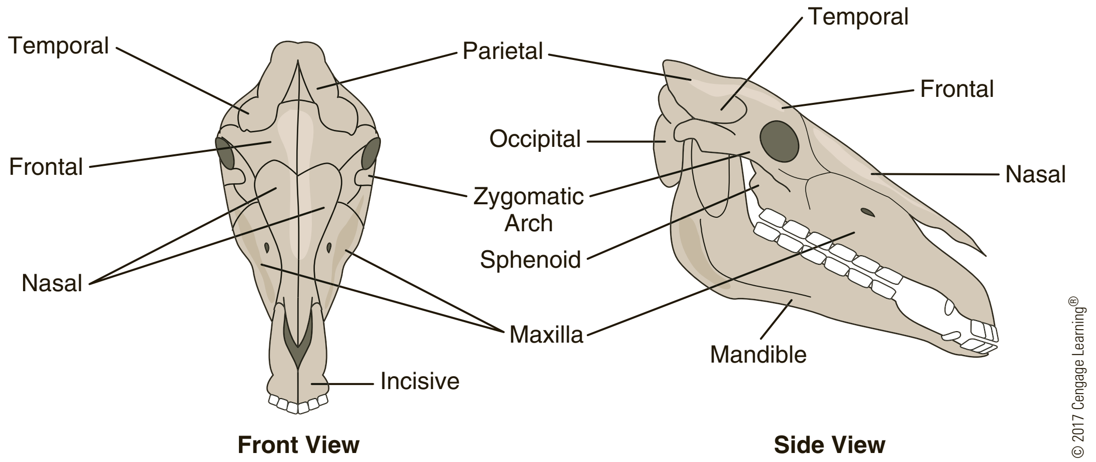

FIGURE 3–8 Skull structure of a horse.

Each bone is given a distinct name. In addition, the parts of the bone are also named. These sites often serve as points of muscle attachments or form portions of joints. Identifying regions of the bone gives more detailed information about the particular bone. For example, before operating on Missy's leg, a review of the surgical procedure was necessary. This protocol mentioned several points of the tibia that would act as landmarks during the surgery.

Found in the axial skeleton, the skull (cranium) combines numerous flat bones (approximately 50 in the dog) (Figure 3–8). The skull performs many functions, most notably protection for the brain and other organs of the special senses (sight, hearing, taste, and smell). A moveable mandible (lower jaw) allows animals to secure and chew food. The jaw joint is a synovial joint, whereas other bones of the skull are connected with the tight fibrous joint called a suture. The bones of the jaws hold the teeth, which vary tremendously among species due to diet adaptations (Figure 3–9). The shape of the skull also differs among and within species. For instance, consider the long narrow nose of the collie and the short broad nose of the pug. Regardless of appearance, the basic skull anatomy remains quite similar. The size of the bones in the skull accounts for differentiation.

The vertebral column extends through the length of the body from the skull. The vertebral column protects the spinal cord and allows movement. Force from the hind limbs transfers through the spinal column to propel an animal.

The body of the vertebra is covered with a bony arch, creating the vertebral foramen (Figure 3–10). The entire series of vertebrae with all of the bony arches creates the vertebral canal, housing the spinal cord. The spinous process and transverse processes are sites of attachment for tendons and ligaments. The length of the spinous process varies between species and between the different regions of the vertebrae. The vertebrae in the thorax of the horse have very long spinous processes creating the region called the withers. Between the bodies of the vertebrae (except between C1 and C2 and within the sacrum) lie intervertebral disks.

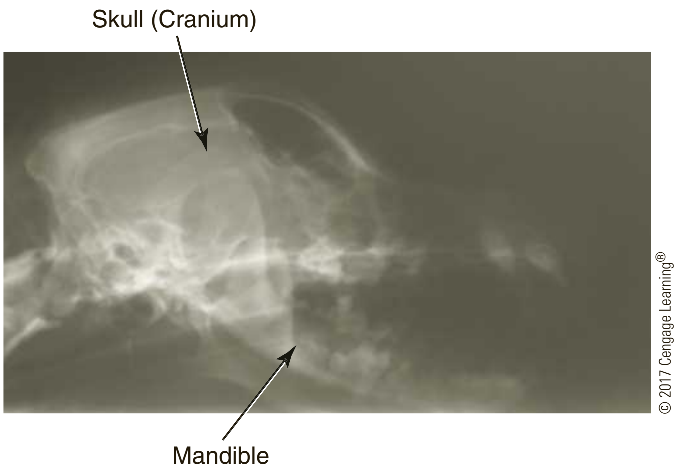

FIGURE 3–9 Radiograph of the skull of a dog.

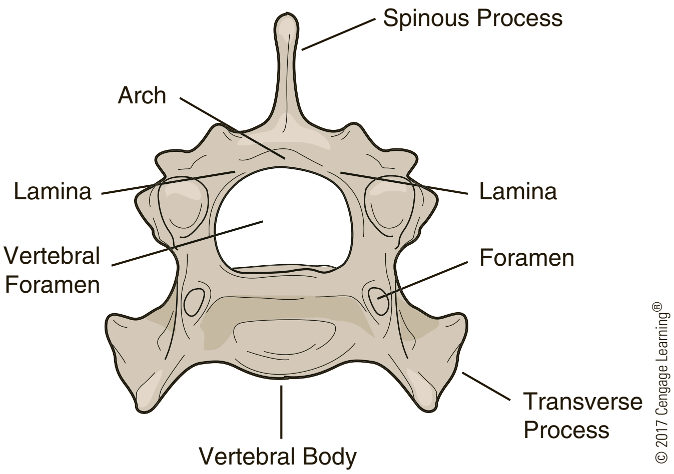

FIGURE 3–10 The structure of a vertebra.

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The disks have strong, fibrous outer rings and soft, spongy centers. Disks provide cushioning between the vertebrae bones. The arrangement of vertebrae allows for movement and bending in any direction and also allows for a certain amount of twisting along the long axis of the body.

The intervertebral disk has a clinical significance in many dogs. Although **intervertebral disk disease** can occur in any breed, certain breeds, such as the dachshund, Pekingese, and cocker spaniel, have higher incidences of the disease. In this condition, the center of the disk becomes less spongy. Pressure between the vertebrae causes the center to rupture through the fibrous outer layer. The bulging disk can press on nerves or the spinal cord. Dogs with this condition may experience severe pain and can be paralyzed. Depending on the severity, the afflicted dogs may be treated medically or surgically.

The vertebral column is broken down into anatomic divisions. At the head end, the cervical vertebrae make up the neck (Figure 3–11). Mammals, from cats to horses to giraffes, have seven cervical vertebrae. The first cervical vertebra is also called the atlas. This vertebra possesses a unique shape and allows up-and-down motion of the head, as in nodding to signify yes. The axis, the second vertebra, permits the head to rotate back and forth, as seen in shaking the head to indicate no. The remaining five cervical vertebrae are all similar in size and shape.

The thoracic vertebrae are found in the next division of the spinal column. There is one set of ribs for each thoracic vertebra (Figure 3–12). The ribs are flat bones (like the bones of the skull) and are essential to protect the heart and lungs. This framework also allows expansion of the lungs that occurs during breathing. Dogs, cats, cattle, goats, and sheep all have 13 pairs of ribs. Horses have 18 thoracic vertebrae. The sternum, a group of bones, forms the floor of the thorax. In older animals, the cartilage joining the ribs to the sternum can be replaced with bone. The dog has nine sternal ribs that join to the sternum with costal cartilage.

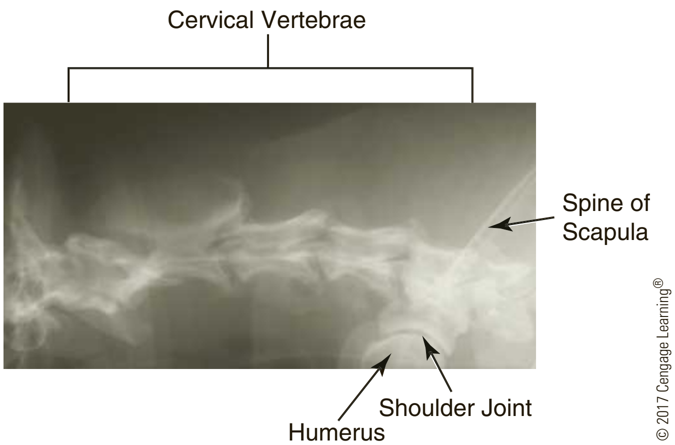

FIGURE 3–11 Radiograph of the cervical spine of a dog.

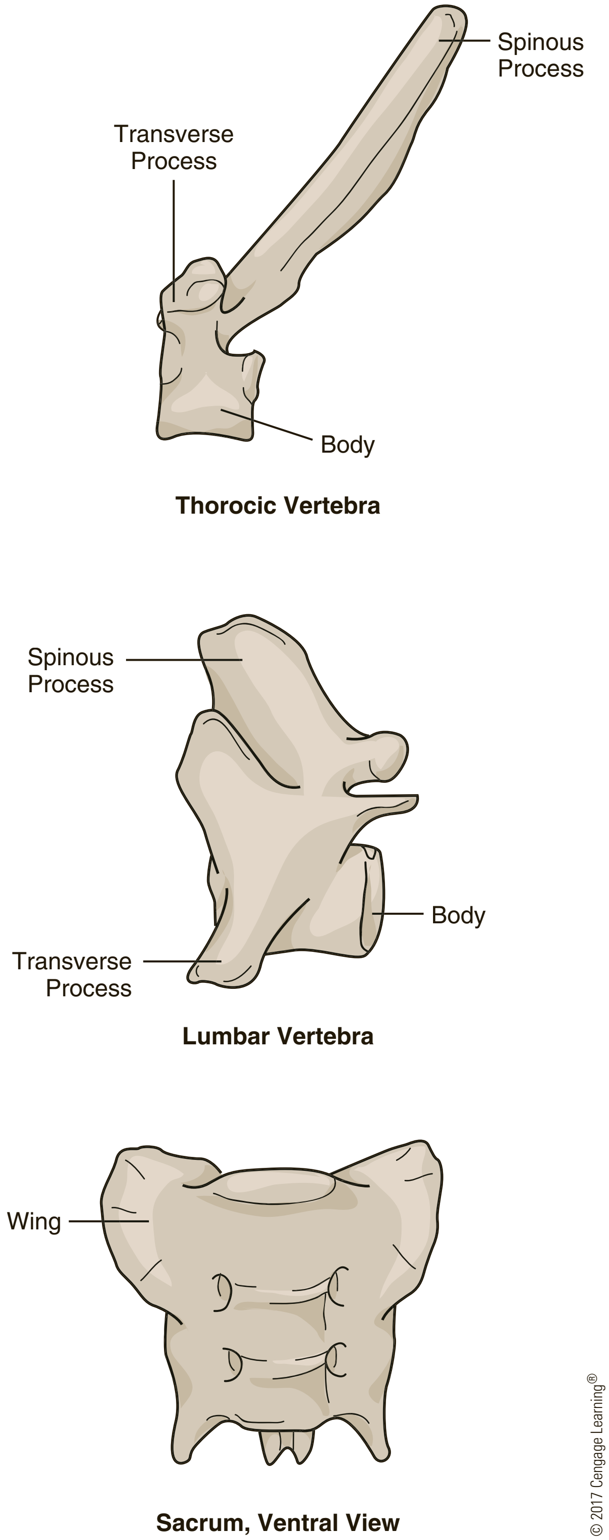

FIGURE 3-12 Comparison of the structure of thoracic, lumbar, and sacral vertebrae.

The lumbar vertebrae, located in the lower back, lie between the thoracic vertebrae and the pelvis (Figure 3–13). This area flexes and extends as animals walk and run. In addition, these vertebrae support the organs in the abdomen. The muscles of the abdomen

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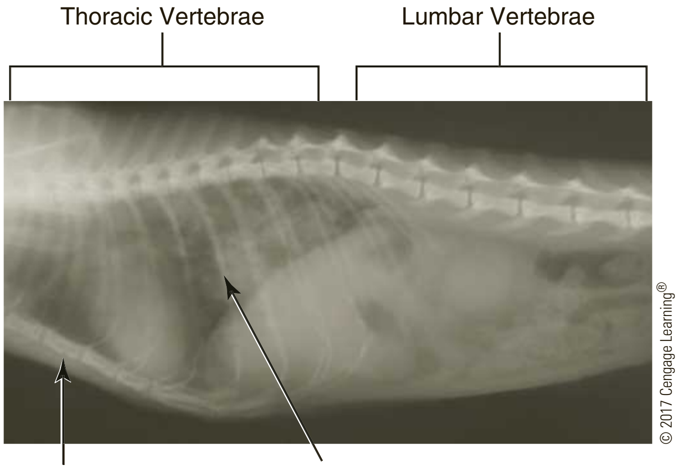

FIGURE 3–13 Radiograph of a cat, showing the thoracic and lumbar spine. Ribs and sternum are also visible.

attach to these vertebrae, forming a sling that supports internal organs.

The sacrum, a group of three sacral vertebrae, fuses to support the pelvis (Figure 3–14). In addition, the sacrum articulates with the last lumbar vertebra and the first caudal vertebra. The sacrum then joins with the pelvis, allowing the hind limbs to support the weight of the body. This connection can be damaged. The pelvis may split away from the sacrum when dogs and cats are hit by cars (HBC). During this type of accident, fracture of the pelvis itself is also common. Very painful lameness often results from a split pelvis or pelvic fracture. Many of these fractures heal if the animal's activities are restricted. In severe cases, surgeries may be required.

The final group of vertebrae is called caudal. These small vertebrae comprise the tail. As mentioned, the numbers of vertebrae vary among species and within a species. The typical dog has 20 caudal vertebrae, but this can range from 6 to 23.

The appendicular skeleton includes the bones of the forelimbs and hind limbs. A study of this part of the skeleton provides a clear examination of comparative anatomy. Although the same anatomic terms are used for all mammals, great differences exist in the numbers and sizes of bones in the mammalian appendicular skeleton. For instance, a dog has four or five toes, whereas a horse has only one.

The forelimb, or thoracic limb, does not have a bony connection to the axial skeleton. The scapula, or shoulder blade, lies flat against the rib cage (Figure 3–15). The scapula connects to the axial skeleton with a group of muscles. This attachment allows the scapula to move over the rib cage. This rotation ranges as high as 25 degrees in animals such as cats while running. This flexibility is also useful in cats as they land after a jump. As the cat falls, it extends its front legs fully at both the scapula and the elbow. As the front feet hit the ground, the elbow flexes and the scapula rotates. The cat makes this very coordinated act look quite graceful. Clinically, this is of significance when cats fall from extreme heights. In large cities, this happens often as cats tumble from balconies or windows of tall buildings. In **high-rise syndrome**, the falling cat rarely breaks a leg; however, it will often break its lower jaw. The high speed of the falling cat forces the jaw to contact the ground.

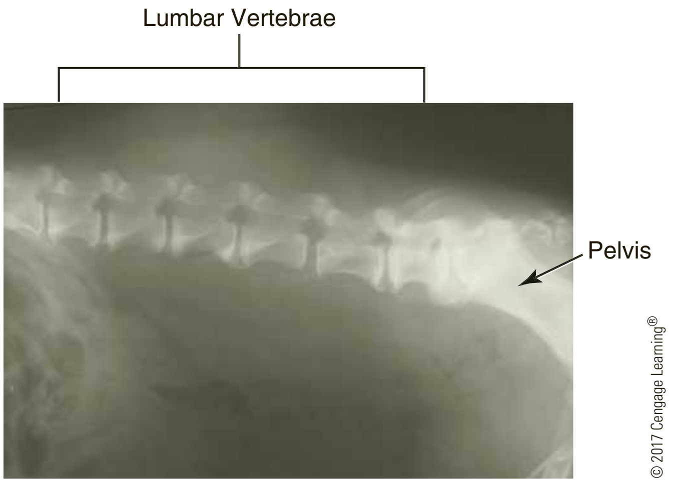

FIGURE 3–14 Radiograph of the lumbar spine of a dog. A portion of the pelvis is also visible. This dog is showing an age-related change called spondylosis. In spondylosis, bone spurs are formed that can eventually bridge between vertebrae.

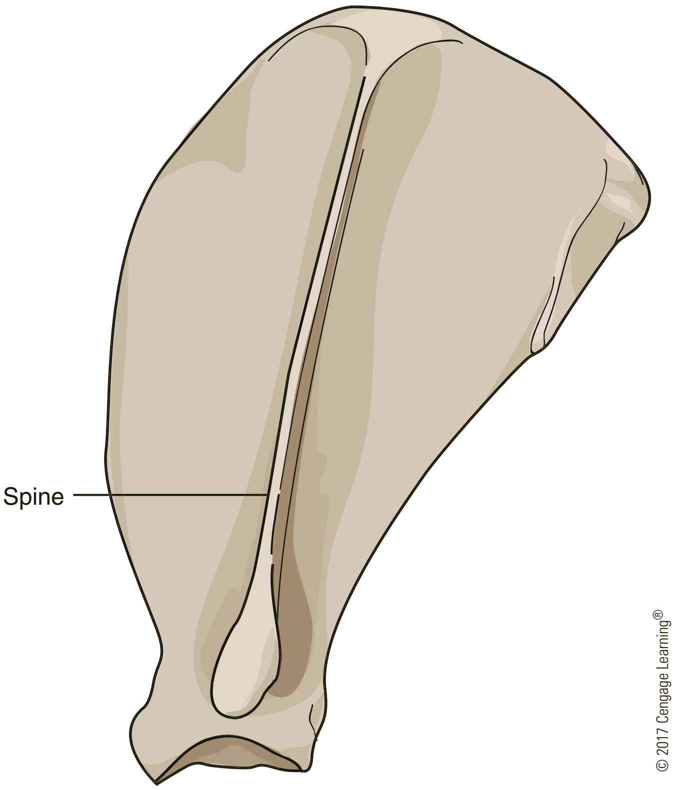

FIGURE 3–15 The scapula.

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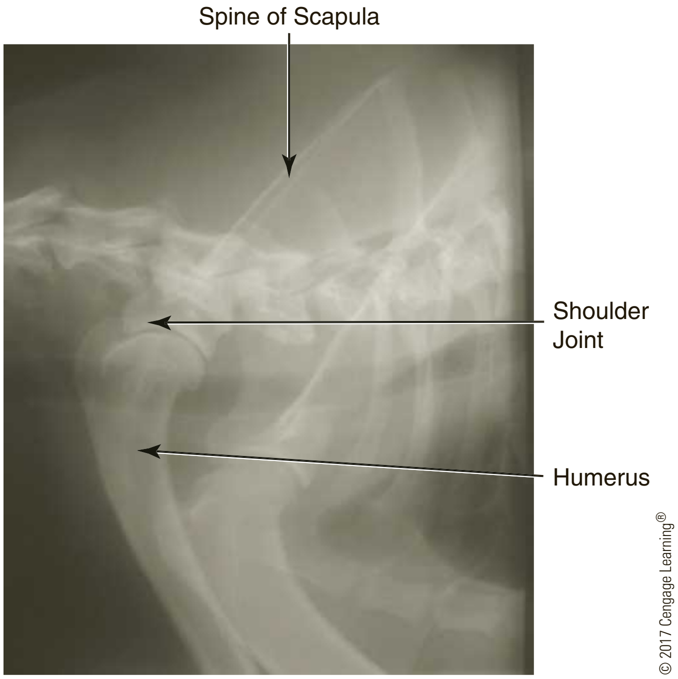

FIGURE 3–16 Radiograph of the scapula and shoulder joint of a dog.

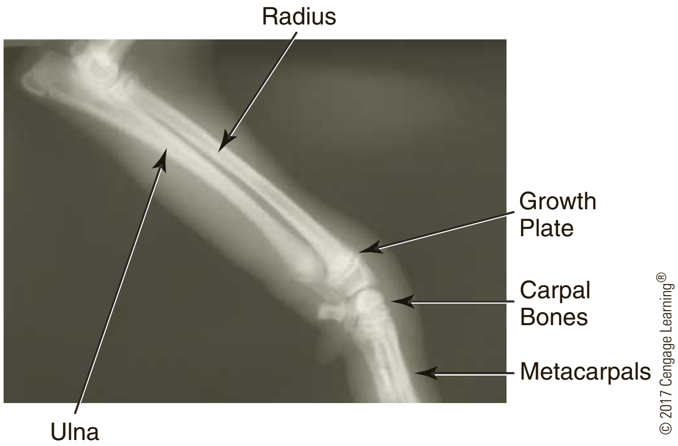

FIGURE 3–17 Radiograph of the radius and ulna of a young dog. Note the growth plates visible in the radius and ulna.

Table 3–1 Number of Carpal Bones

Dog	7
Ruminants	6
Horse	7 or 8

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The humerus is the upper bone of the forelimb. The scapula joins the humerus through a shallow ball-and-socket joint that allows for a wide range of motion (Figure 3–16). The humerus then joins at the elbow with the radius and ulna. The ulna runs to the point of the elbow, where a groove accepts the end of the humerus. The olecranon is the portion of the ulna that makes up the point of the elbow. This is a consistent region in all species. In dogs and cats, the ulna extends distally as far as the radius. In horses, however, the ulna fuses to the middle of the radius and the distal portion is absent. The radius closely attaches to the ulna and forms the remainder of the elbow joint (a hinge joint that permits motion in only one plane). The forearm can be rotated, but this occurs between the radius and ulna, not at the elbow joint.

The radius and ulna run to the level of the carpus (Figure 3–17). The carpus in animals corresponds to the wrist in humans. The carpus, a group of bones, is arranged in two rows. Table 3–1 lists the number of carpal bones found in several species. The carpal bones join to the long metacarpal bones. In this region, differences among species become very dramatic. Dogs and cats have four long metacarpal bones and one much smaller. The smaller bone associates with the first digit, called the dewclaw (Figure 3–18). As previously stated, horses have only one major metacarpal bone, which corresponds to the third one in other species. This large weight-bearing metacarpal bone is often referred to as the cannon bone. The horse has two smaller metacarpal bones, also called the splint bones. These splint bones are tightly attached to the cannon bone with a ligament. In young horses during training, the periosteum in this region can become inflamed and produce lameness. Ruminants such as cattle and sheep also have one very large metacarpal

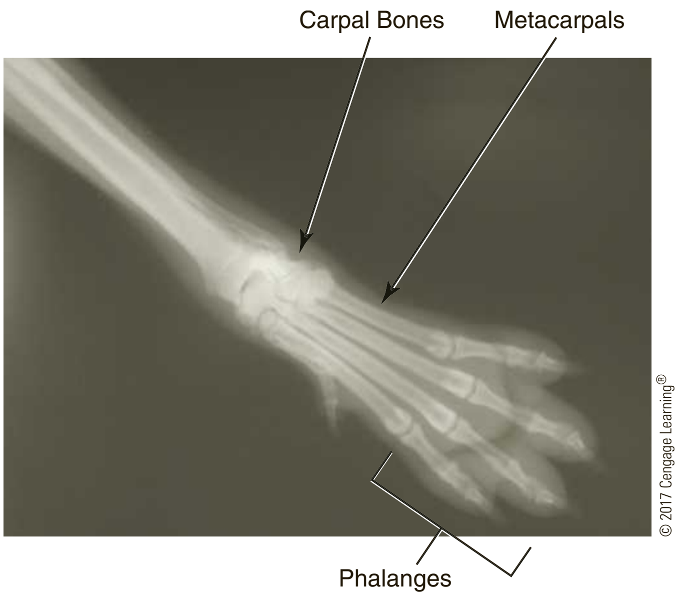

FIGURE 3-18 Radiograph of the carpus, metacarpals, and phalanges of a dog.

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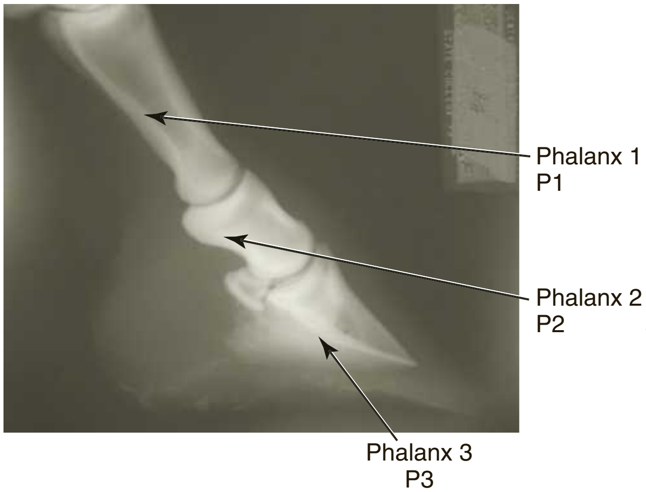

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FIGURE 3–19 Radiograph of the foot of a horse.

bone. As the ruminant embryo develops, the third and fourth metacarpal bones fuse into one structure.

The toes or digits contain three bones, the phalanges. The number of toes corresponds to the number of metacarpal bones. The singular form of the word phalanges is phalanx. The last *phalanx* is *covered* by the nail or hoof (Figure 3–19). The sesamoid bones are quite small and are found in tendons where a change in direction occurs. Sesamoid bones help minimize wear on the tendon. In horses, there are two sesamoid bones at the joint between the metacarpal bone and the first phalanx. In horses, this joint is often called the fetlock joint, and the region between the fetlock and hoof is the pastern. Another sesamoid, the navicular bone, occurs at the joint between the last two phalanges.

In contrast to the thoracic limb, the pelvic limb forms a bony connection with the spine. As discussed earlier, the fused vertebrae of the sacrum join with the pelvis (Figure 3–20). The pelvis is made of two halves. Each half divides into regions named the ilium, ischium, and pubis. The ilium, the most forward portion of the pelvis, joins with the sacrum at the iliosacral joint. The ilium provides a large flat surface for the attachment of muscles. The craniodorsal portion of the ilium is often visible in lean cattle and is known as the point of the hip or the hook bone (Figure 3–21). The ischium makes up the caudal portion of the floor of the pelvis, whereas the pubis forms the cranial floor. The caudal portion of the ischium is visible in lean cattle on either side of the tail. In lay terms these are called the pin bones. The halves of the pelvis join in the middle, forming the pubic symphysis, a basically immovable cartilage joint. During parturition or birth the cartilage softens in response to hormonal changes, thus permitting the newborn to move through the pelvic canal.

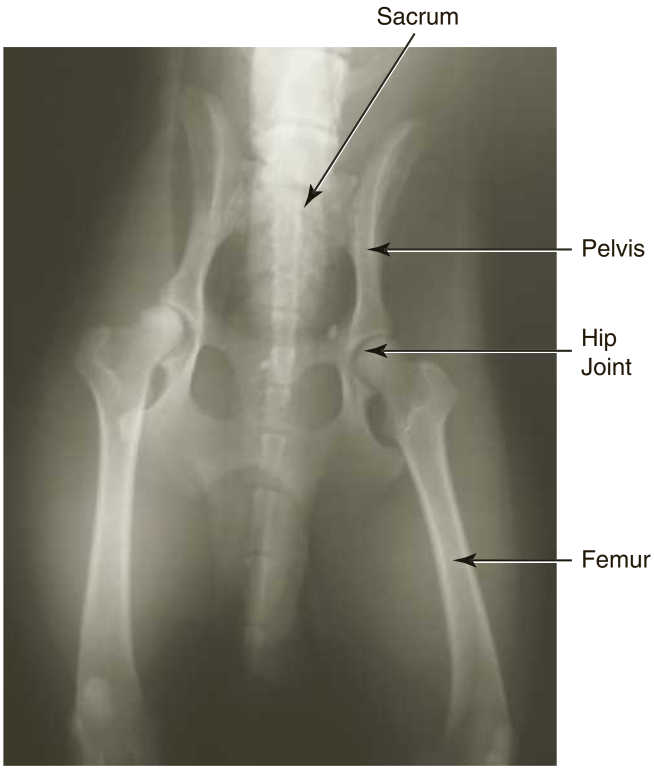

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FIGURE 3–20 Radiograph of the pelvis.

The ilium, ischium, and pubis meet to form the acetabulum. The acetabulum, or socket portion of the hip joint, lies on either side of the pelvis. This socket accepts the ball portion of the femur. The femoral head is held in place by a strong ligament within the acetabulum and by the surrounding muscles. The hip joint serves as a classic example of a ball-and-socket joint.

The femur extends down the leg to the level of the knee or stifle. At this point, the femur joins with the tibia (Figure 3–22). Also present in the lower leg is a fibula. This bone is much smaller than the tibia and plays a less significant role in our domestic species. The complicated knee joint is supported by two external ligaments, the medial and the lateral collateral ligament, and also by the tendon of the patella, or kneecap. The patella is the largest example of a sesamoid bone.

Internally, two ligaments located within the knee cross in an **X** (Figure 3–23). These cruciate ligaments provide great stability to the joint but can be damaged and torn. A common cause of lameness in dogs is a torn cranial cruciate ligament. Whereas this tear typically occurs in humans secondary to trauma, it is a degenerative condition in dogs. The ligament deteriorates with age and finally tears. This is important because dogs often develop the problem in both knees. Veterinarians diagnose this problem by pressing back on the end of

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A

B

FIGURE 3–21 A. Photograph of the rump of a cow. Notice the wings of the ilium (the hooks) and the ischium on each side of the tail (pins). B. Photograph of the pelvic bones of a cow. Notice the wings of the ilium and the ischium. Compare to the position on the cow.

the femur and forward on the tibia. If the ligament is torn, the tibia will slide forward, much more than in a normal leg. This **cranial drawer sign** indicates a diagnosis of torn cruciate ligament. In small-breed dogs, this condition often shows significant improvement with restricted activity. In larger dogs, surgery is often required to correct the condition.

The tibia, the heavy bone of the lower leg, closely attaches to the much smaller fibula. The tibia is the main weight-bearing bone of this region. The fibula supports little weight but does provide for muscle attachments in that region. The tibia extends down the leg to the hock joint (which corresponds to the ankle in humans). There, a hinge joint between the tibia and tarsal bones exists. The many tarsal bones are arranged in much the same fashion as the carpal bones of the front leg. (It is a common mistake for students to confuse the legs associated with carpal or tarsal bones. It is helpful to remember t, as in toes and tarsal, which are both associated with the hind limb.)

In the hind foot, the metatarsal bones and phalanges are arranged identically to the front foot. The number of bones in the hind foot generally matches that of the thoracic limb.

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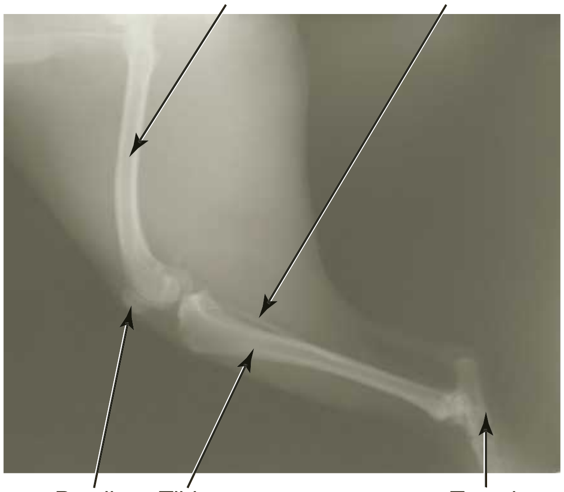

FIGURE 3–22 Radiograph of the hind limb, showing the femur and tibia.

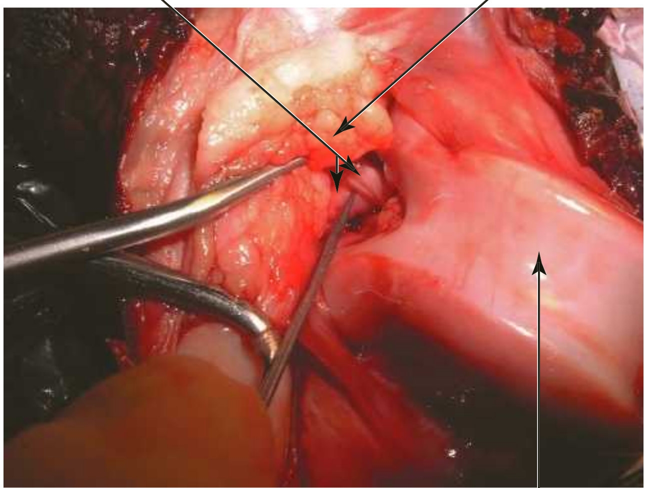

FIGURE 3–23 Photograph of the internal structure of the knee. Note the cross pattern of the two cruciate ligaments identified by the probe.

BONE GROWTH AND REMODELING

Objective

- Explain How Bone Grows and Remodels

Obviously there must be a mechanism for an immature animal's bones to grow longer. A long bone, such as the femur, divides into the shaft, or diaphysis, and the ends, or epiphyses. In a young animal, a cartilage plate separates the diaphysis from the epiphysis. These growth plates, or epiphyseal plates, are the sites of elongation. Bones also increase in diameter, with new cells deposited under the periosteum.

In young animals, the cartilage growth plate continues to grow. At the same time, at the edge, osteoblasts move into the cartilage. The bones increase in length as the osteoblasts lay down more osteoid matrix. The growth is under the control of growth hormone and the sex hormones. In this process, called ossification, the cartilage is replaced by bone tissue. **Ossification** involves more than just minerals being deposited. The cartilage is replaced by true bone, with all the appropriate cells, structure, and blood supply. As maturity approaches, the cartilage grows more slowly, and the growth plate narrows. Eventually, bone completely replaces the growth plate. After the growth plates close, bones do not increase in length.

For proper development to occur, the rate of limb growth must match. Injury to a young animal may result in premature closure of a growth plate (the weakest site in the bone). With sufficient trauma, the bone fractures at the growth plate. As this injury heals, the growth plate may be replaced with bone, causing the wounded site to cease growth in length. As a result, the limb on the injured side is shorter. However, animals with mismatched limbs compensate very well by adjusting the positioning of the shorter leg. For example, if one pelvic limb is shorter, the hock and stifle are kept in greater extension.

A significant problem can result when damage occurs to either the radius or ulna. If only one bone in the forelimb stops growing, the increasing length of the other forces the leg to curve. This problem can be a result of trauma but can naturally occur in certain breeds of dogs. Basset hounds typically have premature closure of the distal growth plate of the ulna. The radius is bound between the humerus and the carpus. Because it grows faster than the ulna, it develops a curve to fit between the other bones (Figure 3–24). In most of these dogs, the only effect is the typical short-curved leg. In certain

FIGURE 3–24 Radiograph of the radius and ulna of a basset hound. The growth plate of the ulna closed prematurely, forcing the radius to curve as it continued to grow.

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animals, the pressure of the radius partially dislocates (**subluxates**) the humerus from the elbow joint. This can cause such severe lameness that surgical intervention may be necessary.

Radiographs are produced when a stream of **x-rays** is passed through a body part, causing exposure of a piece of photographic film. X-rays are a form of electromagnetic radiation that can pass through living tissue. (The term x-ray is commonly used to describe the resulting picture. However, it is technically correct to refer to the photograph as the radiograph. Invisible x-rays expose the film.)

Dense structures allow only an extremely small amount of x-rays to pass, and are termed radiopaque. Tissues, such as teeth and bone, fit into this category and appear light on the radiograph. (Refer to Missy's radiograph, Figure 3–2, at the beginning of the chapter to see how white the bone appears.) Radiolucent tissues allow much more of the x-ray energy to pass through and show up dark on the radiograph. Variation among tissues permits the radiograph to be interpreted. The fracture in Missy's tibia shows up as a dark line through the center of the white bone.

Many radiographs are shown in this text. In these radiographs, there are basically five stages of density. Ranging from the most radiolucent to the most radiopaque are: (1) air (such as in the lung), (2) fat, (3) soft tissue or muscle, (4) bone, and (5) mineral (such as in teeth). Remember, air is the darkest and mineral the whitest on a radiograph.

X-rays are capable of damaging living tissues when used at high dosages and if repeated time and again. **Radiology**, the study of radiographs, is an essential part of veterinary and human medicine. However, the application of radiology must be done with judgment to minimize exposure of the animal, and the human doing the procedure (Figure 3–25). Film and the cassettes that carry films are designed for minimum x-ray use. Also, specially designed lead aprons and gloves are used to minimize exposure to humans. Lead effectively prevents x-ray penetration. To ensure safe working conditions, technicians and veterinarians are monitored for their x-ray exposure level.

In photography, there has been a dramatic shift away from cameras containing film to digital cameras. Radiology equipment is going through the same transition. Digital radiology equipment converts the x-rays into an electrical signal that in turn is converted into an image on a computer screen. This type of technology is expensive but offers many advantages over the old film method. The radiographic image is available much more quickly, and the need for radiographic film, developing equipment, and chemicals is eliminated. Having the image on the computer also allows for alterations in brightness, contrast, and size. Having the radiographic image as a computer file also allows easy transfer of the image to a specialty clinic or to a radiologist for consultation.

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FIGURE 3–25 Radiograph machine.

Radiographs throughout this text show anatomy in both healthy and diseased animals. Keep in mind that radiographs show a two-dimensional picture of a three-dimensional object. Although not always shown in the text, standard procedure mandates that two views (at 90 degrees to each other) of a single body part should be radiographed. Two views give the veterinarian a better understanding of the structure in question.

RELATION OF BONES, MUSCLES, AND MOVEMENT

Objective

- Relate Bone and Muscle Groups to Movement

Muscles are included in this chapter because of their close association with bone. Together, bones and muscles provide the ability to move. Skeletal muscles attach to bone or cartilage by connective tissue. Each level of muscle is covered in connective tissue, which combines to form a tendon. In most locations, this tendon appears as a narrow cord. Some muscles end so close to the bone that no obvious tendon can be seen, or they

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attach with a broad sheet of connective tissue called an aponeurosis. Muscles are described by the location of their attachments. The more fixed point is called the origin. The more moveable point is called the insertion. Muscles of the limbs always have the most distal point as the insertion. For example, the biceps (the muscle on the front of the upper arm) originates on the scapula and inserts on the radius and ulna.

Muscles that cross a joint are also described on the basis of the type of motion that they cause. Extensors cause the bones to move into straighter alignment or open the joint. Flexors on the opposing side bend the joint or decrease the angle between the bones. The names may also describe the muscle's shape, its location, or the number of heads.

Although skeletal muscle is described as voluntary, much of its activity is controlled without conscious thought. Muscles that control balance, posture, breathing, and swallowing often function spontaneously. Fortunately, animals (including humans) do not have to think about the individual functions of all these muscles. These muscles can be controlled voluntarily as well.

Muscles are often arranged in groups to achieve a single function. For example, three muscles make up the hamstrings (biceps femoris, semimembranosus, and semitendinosus). These muscles work together to extend the hip and flex the knee (Figure 3–26). The muscle or group working together to achieve the desired movement is called the agonist. In each situation, there is an antagonist muscle or group that performs the opposite movement. For example, when the hamstrings are the agonist, the quadriceps muscles on the front of the leg act as the antagonist. The antagonist naturally returns the body part to its prior position. A less obvious function is that the antagonist acts to make the agonists function much more smoothly by providing resistance to the agonist. Finally, the agonist and antagonist can contract with equal force to stabilize a joint without movement.

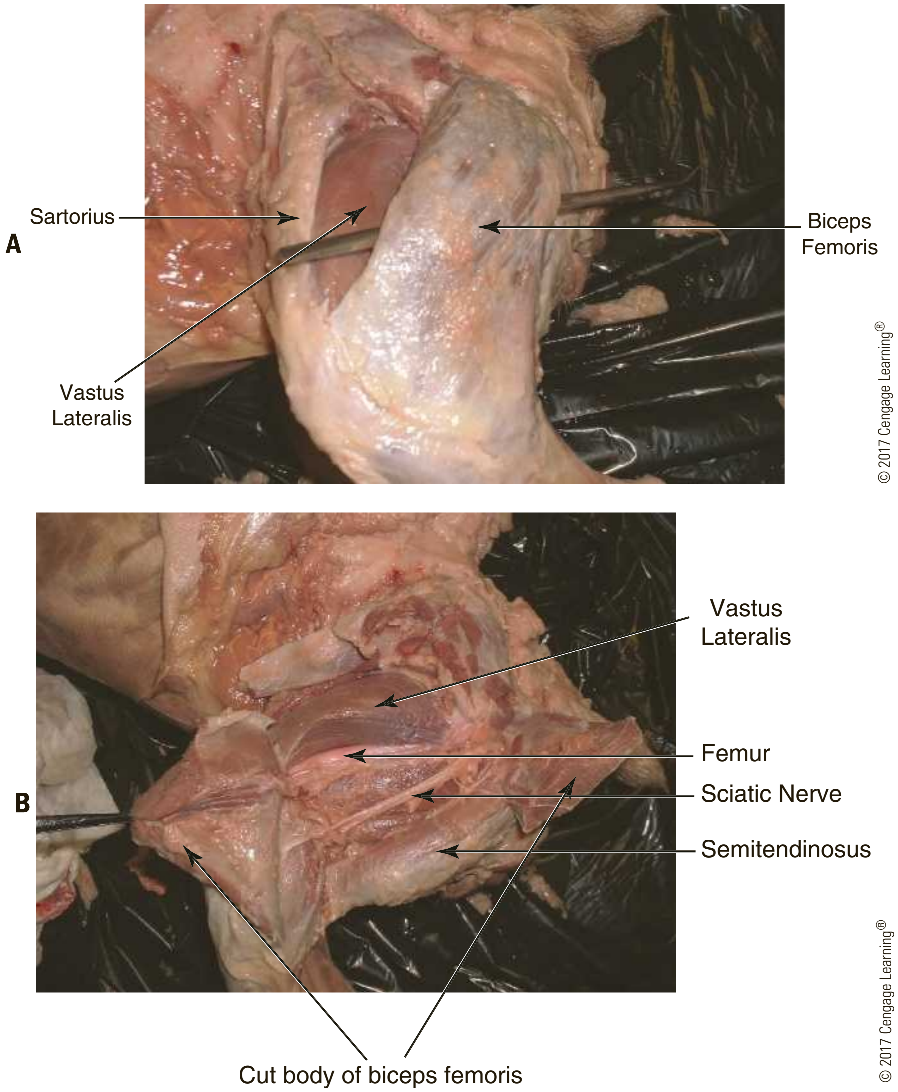

FIGURE 3–26 A. Superficial muscles of the thigh. B. Deep muscles of the thigh.

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CLINICAL PRACTICE

Objective

- Connect the Academic Materials Pertaining to the Musculoskeletal System to Clinical Practice

As in Missy, the Saint Bernard, fractured bones are a common abnormality. If the bone is broken into two pieces, a clean break, it is called a **simple fracture**. A **comminuted fracture** results in several fragments of bone. Missy's radiograph showed that she had a comminuted fracture. A **compound (open) fracture** results when one of the bone ends punctures through the skin. The risk of bone infection is higher in compound fractures.

For a fracture to heal, the bone ends must be put back in alignment and held without movement. Just as in humans, many fractures can be repaired with a cast or splint. In veterinary medicine, the support must be made to hold the weight of the animal. After correction, the animal must be able to use the leg. Very active pets have a hard time keeping casts in place, let alone clean and dry.

Surgical correction is often used to repair fractures. With surgery, some form of surgical stainless steel, such as a bone plate, is used to support the bone. A bone plate is applied to the outside edge of the bone and attached with screws (Figure 3–27). We offered to refer Missy for this type of surgery. Bone plates offer a very stable form of correction. Proper size plates must be correctly shaped to fit the bone.

Another method of repair is termed an **intramedullary pin**. I used this type of correction on Missy. During the surgery, I drove a stainless steel pin into the center of Missy's broken tibia (Figure 3–28). The pin entered the bone on the top of the tibia and then entered the medullary cavity. The pin was driven to extend in the distal piece of tibia, very close to the hock joint. Because the bone was shattered into many pieces, the pin alone would not have been sufficient to support the bone. To stabilize the pieces, I also added several wires wrapped around the bone fragments. These are called cerclage wires. Radiographs are taken to ensure proper placement of the pin before completing the surgery. One possible mistake would have been to drive the pin too far, causing irritation of the hock joint. Satisfied with the placement and security of the repair, I finished the surgery. For the first two weeks, I also kept a padded splint on Missy's leg. This gave a little more support and helped to minimize swelling.

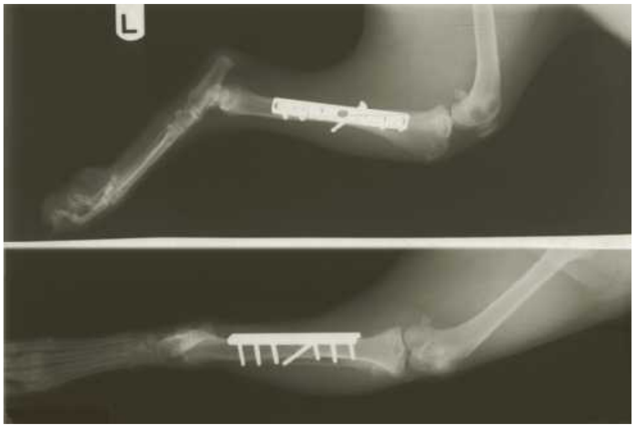

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FIGURE 3–27 Radiograph showing repair of a tibial fracture, using a bone plate and screws.

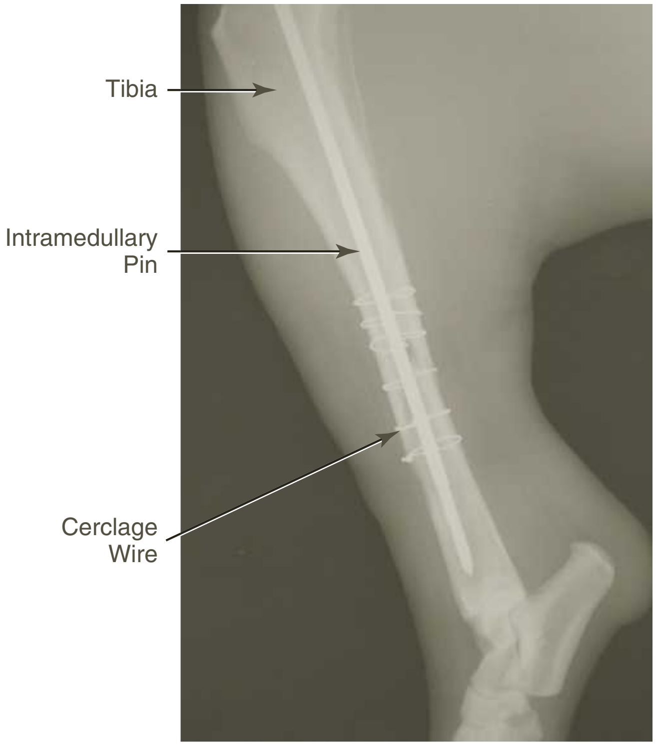

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FIGURE 3–28 Radiograph showing the repair of Missy's tibia. The bone was repaired with an intramedullary pin and six cerclage wires.

After surgery, Missy's bone began to repair itself. The process of bone healing is very similar to that of bone growth in an immature animal. Because of the trauma to the bone, blood fills the gaps between the fracture ends. Cells move into this clot, laying down cartilage. This initial structure, which helps to stabilize the fracture site, is the beginning of a firm structure called a callus.

After approximately two weeks, the cells develop into osteoblasts. This cartilage callus gradually is replaced by bone. This bony callus not only fills in between the fragments but also extends into the marrow cavity and outside the edge of the bone. Two months after the surgery, the bony callus in Missy's leg filled the gaps between the fracture ends (Figure 3–29). It also extends outside the original bone margin and has actually covered the cerclage wires. Over the following months and years the callus will continue to be remodeled.

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FIGURE 3–29 Radiograph of healing bone two months following surgery. Note the callus formation surrounding the site of the fracture.

FIGURE 3–30 Radiograph of a dog with hip dysplasia. Note the shallow acetabulum and the subluxation (partial dislocation) of the femur.

Missy's case was quite successful. Not all bone repairs end as favorably. Had my repair allowed for even a small amount of movement after the surgery, the fracture would not have properly healed. Having the edges in alignment and completely immobilized is essential for healing. Bone infection, especially in an open fracture, is another reason that fractures do not heal.

Hip dysplasia commonly occurs in dogs. In this condition, the ball-and-socket joint of the hip becomes diseased. A normal animal should have a deep socket that holds the head of the femur. In hip dysplasia, the socket is very shallow (Figure 3–30). Due to the poor structure, the joint subluxates as the dog moves. Over time the cartilage lining the acetabulum and the head of the femur become worn. This is called **degenerative joint disease**. Dogs with this condition develop pain and lameness and often have trouble rising.

Hip dysplasia is generally associated with large- and giant-breed dogs, but any dog can have it. Genetics plays a role in this disease. If two dogs with hip dysplasia are bred, the resulting puppies are likely to have it as well. Nutrition has also been shown to influence the severity of the disease. Larger-breed dogs fed to maximize growth seem to have an increased risk for the disease.

The clinical signs of hip dysplasia can vary from a very mild lameness to such severe pain that the dog will not stand. The most common treatment for mild cases is anti-inflammatory medications. An over-the-counter medicine, aspirin, can be used in mild cases. More potent drugs are available for severe pain. In the worst cases, total hip replacements are performed.

Foals, calves, pigs, and lambs all can develop a type of lameness called **joint ill**. After birth, the umbilical cord or navel has an open end, because these umbilical vessels are torn to separate the newborn from its mother. Farm animals are often born into conditions that allow bacteria to enter these vessels. An infection can result. Occasionally, the bacteria enter the bloodstream and spread throughout the body. The bacteria can land in the joints. The joint then becomes the new site of infection. On examination, these animals have an elevated body temperature and swollen, painful joints. They are often reluctant to rise or walk. Although only one joint may be affected, the condition often involves multiple joints. If the infection is caught early, antibiotics will correct the problem. Permanent damage to the joint cartilage is possible.

Considering how horses are used, you would not be surprised that lameness is a common complaint. One of the most common causes of forelimb lameness is a condition termed navicular syndrome. Damage or degeneration of the navicular bone is the reason for this type of lameness. Navicular syndrome also involves damage to other structures in the region, including tendons, ligaments, and joints.

Often when the signs begin, the horse has a mild lameness that actually improves with exercise. Typically the signs develop slowly over time until the

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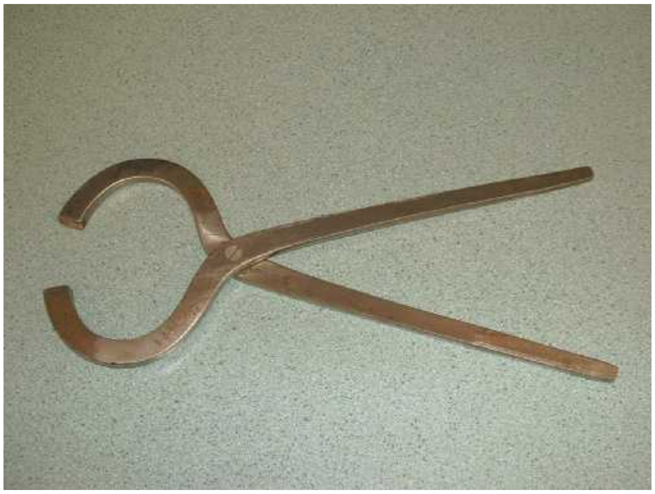

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FIGURE 3–31 Hoof testers can be used to apply pressure to specific points on a horse's hoof. This is a useful tool in localizing a cause of lameness.

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FIGURE 3–32 A veterinarian tests for cranial drawer sign in a dog's knee joint. The arrows show the direction of force being applied.

lameness becomes more serious and worsens with exercise. Although it commonly occurs in both feet, one side is usually more severely affected. The horse often shortens its stride in an attempt to minimize the pain. A hoof tester can be used to squeeze over the region of the navicular bone to narrow down the possible location of the pain (Figure 3–31). Veterinarians can also use a local anesthetic to block pain to certain regions. This can localize the source of problems. Radiographs are also very helpful when the navicular bone is specifically involved.

With mild cases, conservative treatment is usually tried. This involves proper hoof trimming and corrective shoeing in an attempt to improve the gait of the horse. In addition, rest and anti-inflammatory drugs are used. In severe cases, surgery may be attempted to improve the animal's comfort level.

Cranial cruciate rupture was discussed earlier in the chapter. If cranial drawer sign is present, surgical correction may be necessary to stabilize the knee joint (Figure 3–32). Many different techniques exist to right the problem. It is beyond the scope of this text to discuss the techniques, benefits, and drawbacks of each procedure. One technique is called an extracapsular stabilization suture.

In this method, an incision is made lateral to the patella (Figure 3–33). The joint capsule is incised and the patella is luxated medially. This opens the joint for the surgeon to examine the internal structures of the knee. The remnants of the torn cruciate ligament are removed because they increase the inflammation within the joint. The medial meniscus is also examined to see if it is intact. This meniscus is often torn in animals with a cranial cruciate rupture, and again any damaged portions are removed. The patella is replaced and the joint capsule is sutured.

To stabilize the joint a heavy nylon suture is connected between the fabella (a sesamoid bone behind

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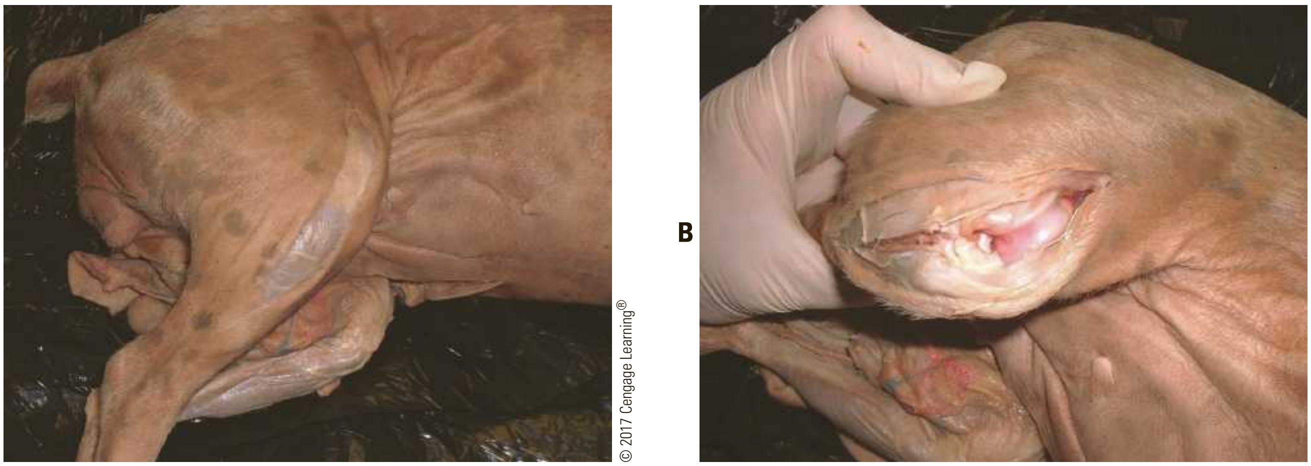

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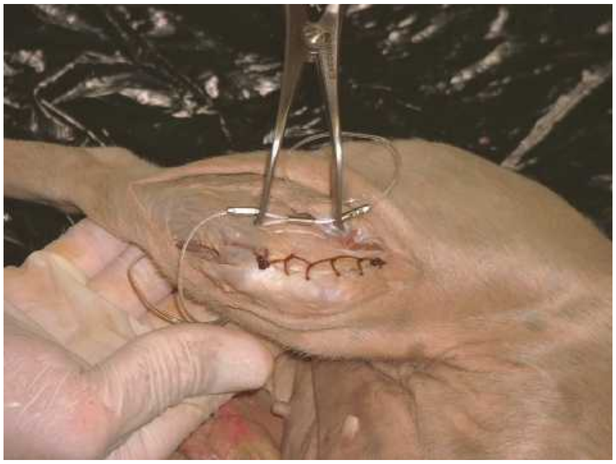

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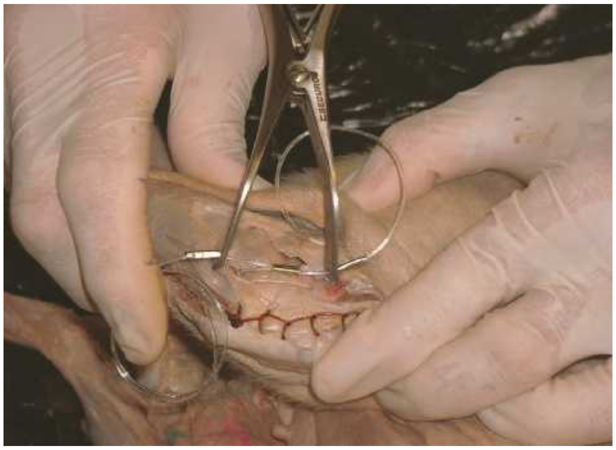

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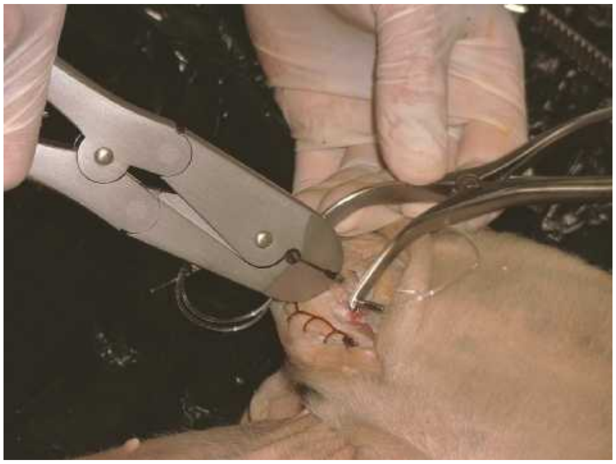

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FIGURE 3–33 This series of photographs demonstrates one method of lateral stabilization suture technique for repairing a cranial cruciate rupture. A. A skin incision is made on the lateral edge of the knee. B. The joint capsule is incised and the patella is luxated medially. Note that the articular cartilage of the femur is visible. C. The remnants of the torn cruciate ligament are removed. D. A retractor is used to open the joint, and the meniscus is evaluated for damage. E. The patella is returned to its natural location, and the joint capsule is sutured. F. Two holes are drilled in the cranial aspect of the tibia. G. A heavy nylon suture is placed behind the small fabella, located at the caudal edge of the femur. H. The suture is passed through one hole in the tibia and then returned through the second hole. I. The two ends of the suture are passed in opposite directions through a crimp clamp. J. A crimp clamp is placed on each end and crimped in position. Once crimped, the nylon is unable to slip through the clamp. K. A tensioner is used to stretch the nylon suture. L. The knee is tested to ensure that the cranial drawer has been corrected. M. The center clamp is then crimped, and the ends are cut close, the outer two clamps being removed. The subcutaneous tissue and the skin are then sutured.

the distal femur) and then, through holes drilled in the proximal tibia, the loop of this suture is secured to tighten the joint. The tension supplied by the suture mimics the control provided by an intact cranial cruciate ligament. Once the suture is in place, the subcutaneous connective tissue and skin are closed with sutures. Following surgery, restricted activity allows the site to heal. The dog is brought back into activity gradually.

SUMMARY

Bones provide form for animals. Moreover, bones are composed of a compact dense outer layer and a more loosely arranged center. Three basic types of joints (fibrous, cartilage, and synovial) serve to join bones together. The movement they allow further classifies synovial joints. The bones of the skeleton divide into two main sections, the axial (centerline) bones and the appendicular (limb) bones. A thorough understanding of bones allows practitioners to treat disease conditions and injuries of the musculoskeletal system.

REVIEW QUESTIONS

1. Define any 10 of the following terms:

   herd check
   radiograph
   orthopedic surgeon
   axial skeleton
   appendicular skeleton
   intervertebral disk disease
   high-rise syndrome
   cranial drawer sign

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ossification
subluxate
x-rays
radiology
simple fracture
comminuted fracture
compound (open) fracture
intramedullary pin
hip dysplasia
degenerative joint disease
joint ill

2. True or False: Aspirin can be used to treat hip dysplasia.
3. True or False: The hinge joint allows rotation.
4. Dried bone consists of ________% inorganic and ________% organic material.
5. The appendicular skeleton contains the bones of the ________.
6. The smallest metacarpal bone in a dog is called the ________.
7. The cranial drawer sign diagnosis indicates a torn ________ ligament.
8. In immature animals the growth plate consists of ________.
9. Canine hip dysplasia is a degenerative ________ disease.
10. Joint ill occurs when bacteria enter the ________ of newborns.

FIGURE 3-34

11. What type of joint is the pelvis?
12. Where are the cervical vertebrae located?
13. Does abduction occur when a body part is moved closer to or further away from the body?
14. Do teeth and bones appear light or dark on a radiograph?
15. What is the scapula?
16. Name the fractured bone(s) in Figure 3–34.
17. What five basic functions are furnished by bones?

ACTIVITIES

Materials needed for completion of activities:

long bone from butcher shop
two same-type chicken bones
vinegar
beaker
clay
pipe cleaners
Popsicle sticks
toothpicks

1. Clean two similar-type chicken bones. Allow one to dry on a windowsill and submerge the other in vinegar for four days. At the end of the four days, check the hardness of each. The bone that sat in vinegar should be pliable. The acidic vinegar should have dissolved the calcium in the bone.
2. Obtain a long bone from a butcher shop. Ask the butcher to section it lengthwise. Examine the bone for the various structures (compact bone, spongy bone, medullary cavity, bone marrow).
3. Using clay and Popsicle sticks, model the various types of joints.
4. Using clay, pipe cleaners, Popsicle sticks, and toothpicks, fashion a portion of the skeleton.
5. Health fairs often offer osteoporosis screening using a very quickly completed heel scan technique. Students accompanied by parents or guardians may want to learn of their bone density using this method.
6. Research images of surgical repairs of bone breaks.
7. Adequate calcium, vitamin D, and weight-bearing exercise prevent osteoporosis. Research which levels are appropriate and determine if you are getting enough of each. If not, devise a plan to meet the requirements.

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CHAPTER 4

The Circulatory System

Objectives

Upon completion of this chapter, you should be able to:

- List blood components and explain the functions of blood.
- Identify the basic structures of the mammalian heart.
- Trace the flow of blood through the heart and body while detailing the parts of blood vessels and their structural significance.
- Use knowledge of heart function and control to explain the clinical significance of the electrocardiogram; heart sounds, including heart murmurs; and blood pressure.
- Discuss the clinical significance of the academic material learned in this chapter.

Key Terms

hardware disease
centrifuge
serum
erythropoiesis
cranial
caudal
arteries
veins
pacemaker system
cardiac cycle
systole
diastole
electrocardiograph
electrocardiogram
arrhythmia
tachycardia
cardiopulmonary resuscitation (CPR)
heart murmur
heart failure
hypo-
hyper-
-emia
autoimmune disease
shock

Introduction

The circulatory system is essential to support the life of each of the millions of cells that make up an animal. Blood itself has a wide range of functions that help to maintain the animal. The circulatory system is essential for delivering nutrients and removing metabolic waste from the body's cells. Blood also carries hormones, which act as chemical messengers to control the activities of the body. The heart and blood vessels provide the means to deliver blood throughout the body.

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A Day in the Life
ADR—Ain't Doin' Right...

I remember the day in veterinary school when our stethoscopes arrived. The air filled with excitement as we listened to our own heartbeats. This instrument became a necessary tool in everyday life as I began to examine animals. I must admit I felt cool walking around the hospital in a white lab coat with a stethoscope draped around my neck! It seems like yesterday, even though more than a few years have passed.

Several months ago I examined a cow that was ADR—ain't doin' right. As I walked into the pen, I could see she obviously wasn't feeling well at all. She appeared quite droopy, had lost a lot of weight, and had developed a swelling under her jaw. During the physical, I listened to her heart. It sounded like the noise from a washing machine in midcycle. The heart made a sloshing sound with every beat. Using the stethoscope, I diagnosed **hardware disease**. The cow had eaten a piece of metal that migrated from the stomach and lodged close to the heart. The location and structure of the heart provided me with the information necessary to interpret the symptoms of this disease. Hardware disease is often found during my appointed rounds. The next diagnosis is not.

This week, Dr. Deppen and I were both doing evening small animal appointments at the office. It was snowing heavily and we were hoping to finish at a reasonable hour. Dr. Deppen was seeing Lucky, a 12-year-old Schnauzer mix that had a history of having what the owners thought was a seizure. She detected that the dog's heart rate was too slow and the rhythm was very irregular. I had a chance to listen to the dog's heart as well and agreed that we should do more tests to detect the underlying problem.

The author James Herriot portrayed veterinary work in his best-selling collection of stories, *All Creatures Great and Small*. Times have changed considerably since Herriot practiced. Much more information and sophisticated medicines and techniques are now readily available. Still, I cannot possibly be an expert on all animals. Last year our office received a call from a local school. The sixth grade class mascot, Sonic the hedgehog, had a sore foot. In this case, my experience with hedgehogs was limited to reading just one obscure journal article. I had never even met one in real life. Therefore, I advised the teacher of my lack of experience but agreed to examine Sonic.

Photograph courtesy Richard Musselman.

FIGURE 4–1 A hedgehog.

Sonic arrived at the office in a cage (Figure 4–1). He looked just like a miniature porcupine. Because hedgehogs are nocturnal animals, Sonic was apparently taking his afternoon nap when he arrived at the office. I disturbed him as I tried to examine his leg. Sonic jumped and snorted in an attempt to scare me. To be honest, it worked! His prickly quills were quite sharp. My assistant and I then put on thick leather gloves and proceeded with the examination. Sonic countered with another protective measure. He rolled himself into a tight ball, so tight his legs were completely hidden. I referred to the journal article for help.

Following the recommendations, I anesthetized Sonic with an inhalant anesthetic. We placed him in the large clear mask. The anesthetic was slowly delivered with every breath. Finally Sonic relaxed enough so I was able to have a more thorough look. Once Sonic's leg was exposed, the problem was quite obvious. The rags that Sonic used as a nest had tattered edges with loose strings. One of these strings had wrapped tightly around his foot and stopped the circulation. The foot had turned dark and was oozing. All mammals rely on circulation to maintain their bodies. What happened to Sonic's foot when the blood supply was stopped?

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BLOOD COMPONENTS AND FUNCTIONS

Objective

- List Blood Components and Explain the Functions of Blood

Blood separates into a fluid portion and a formed-element portion. If blood is placed in a tube and spun in a **centrifuge**, the formed elements settle to the bottom of the tube (Figure 4–2). The cellular portion of the blood makes up about 30% to 45% of the total contents. This percentage varies dramatically among species and animal ages. The remaining fluid portion is called plasma. Normal plasma, without the red blood cells, is a transparent fluid that varies in color from clear to a very light yellow.

Plasma consists mainly of water. For most animals, plasma contains 91% to 94% water. Protein makes up 5% to 8% of the plasma. The protein in the plasma creates the pale yellow color. The remainder of the plasma is a combination of electrolytes, gases, nutrients, metabolic wastes, and hormones. The electrolytes include sodium, potassium, calcium, magnesium, chloride, phosphorus, and bicarbonate. Oxygen, carbon dioxide, and nitrogen are all gases transported in the blood. Many nutrients, including amino acids, lipids, and glucose are absorbed from the intestinal tract and delivered to other sites in the body for utilization.

The protein portion of the blood can be divided into three types: albumin, globulins, and fibrinogen.

Albumin, the major protein in blood, maintains the water in the bloodstream. Albumin draws water into blood vessels through osmosis. The large albumin molecules do not diffuse from the blood vessels. The presence of protein within the blood vessels increases the osmotic pressure, helping to retain water within the bloodstream. The liver produces albumin and secretes it into the bloodstream.

Globulins, another type of protein in the plasma, are antibodies produced to fight disease. The immune system produces these antibodies to fight specific disease-causing organisms. The globulins can be used to make a diagnosis in infectious diseases. A high level of globulin for a particular organism is evidence that the animal has been exposed to it. Other globulins are used for transporting certain molecules, such as hormones.

Fibrinogen, the third type of protein found in the plasma, aids in clotting blood. When a blood vessel is

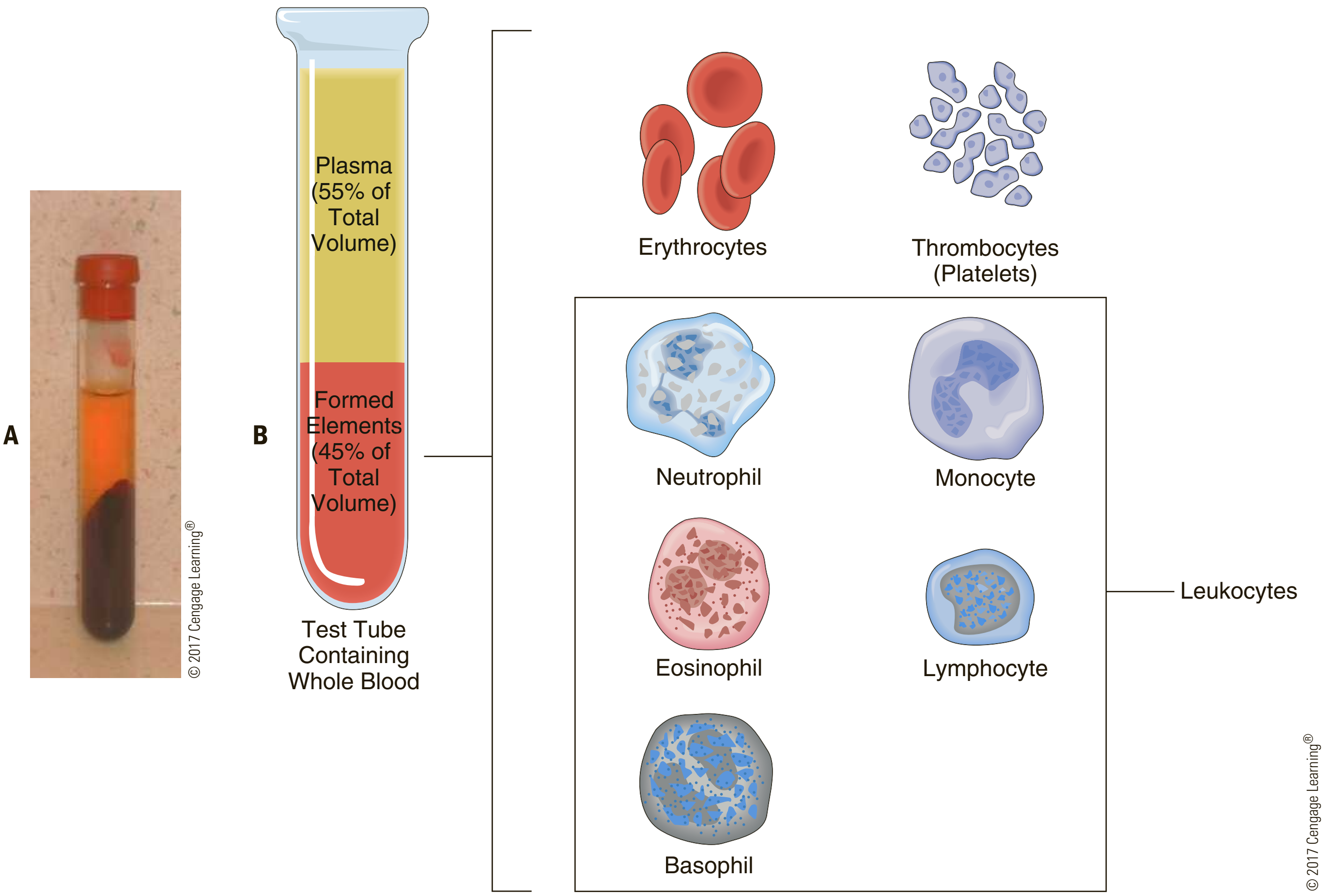

FIGURE 4–2 A. Centrifuged blood separating serum from the formed elements. B. Blood and its components.

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damaged, fibrinogen is converted to fibrin. The fibrin forms fibrous threads that attach to the damaged vessel. If the clotting proteins are removed from plasma, the resulting fluid is called **serum**.

The formed elements of the blood are divided into three fractions: red blood cells, white blood cells, and platelets. Red blood cells are also called erythrocytes. White blood cells are also called leukocytes.

Red blood cells (RBCs) carry oxygen. Mature RBCs do not have a nucleus (Figure 4–3). The biconcave disk shape of RBCs provides a large surface area, which allows the cell to efficiently exchange oxygen and carbon dioxide. In addition to increasing the surface area, the shape minimizes the distance to which oxygen must diffuse. Changes in the fluid status of the animal can also affect the amount of water within the RBC. Because of the biconcave disk shape, a small amount of additional fluid entering the cell will not cause rupture of the membrane. Excessive changes can actually cause a rupture of the RBC. An adult dog has approximately 6 to 8 million RBCs per microliter (μl).

RBCs are produced in the bone marrow. As the cells are produced, the immature RBCs contain a nucleus. These immature RBCs are occasionally found in the bloodstream. This usually occurs when the body is producing a large amount of RBCs, such as an animal that recently lost a large amount of blood.

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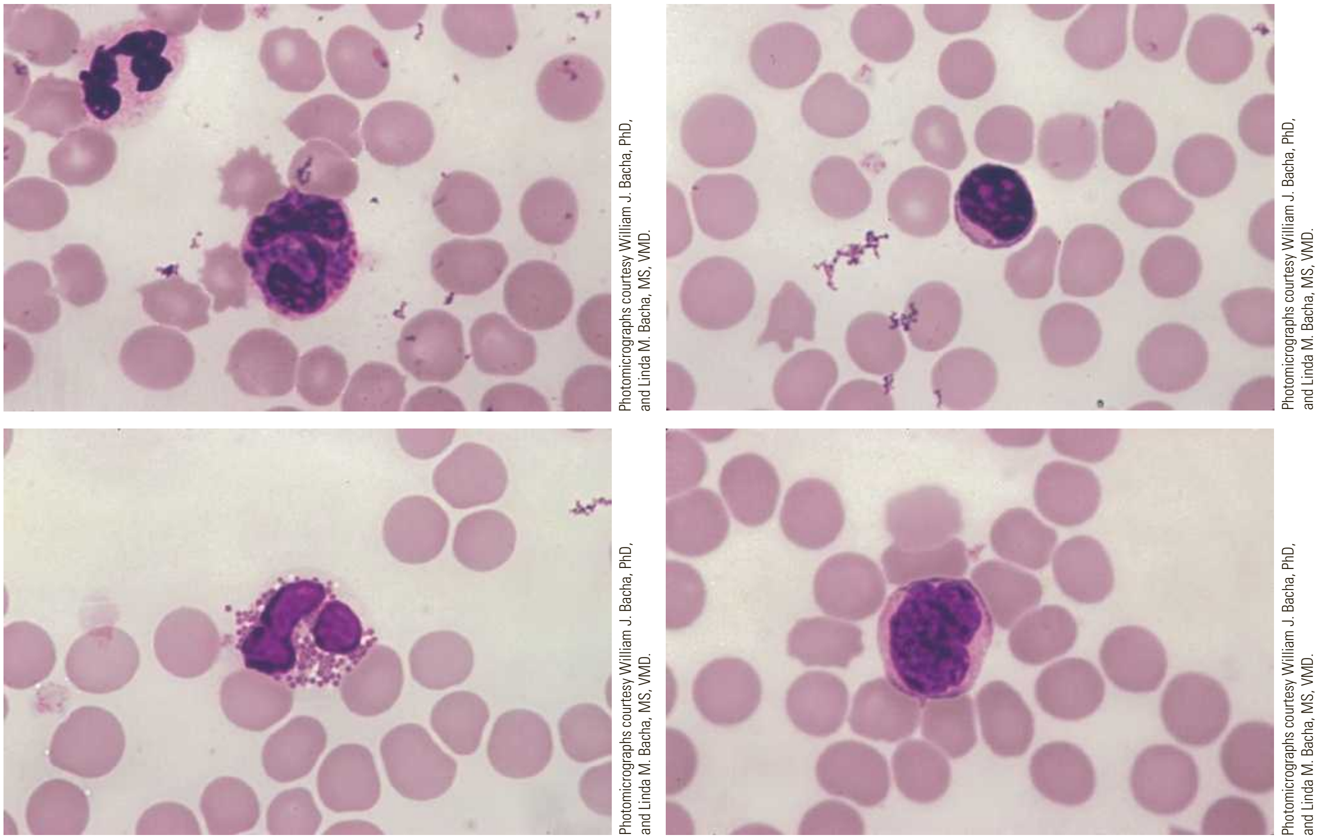

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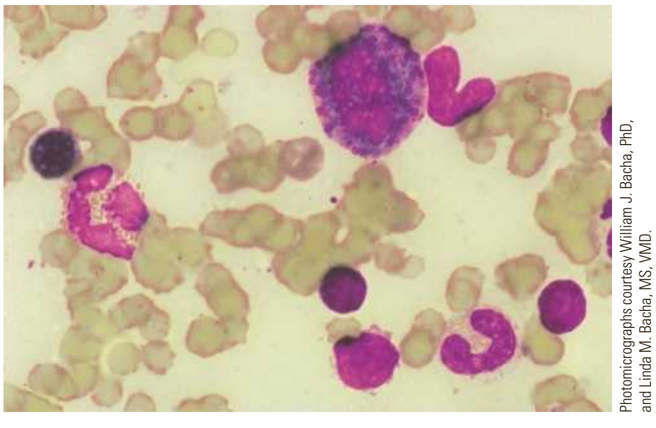

FIGURE 4–3 Photomicrographs of blood and bone marrow. A. A blood smear from a dog. Numerous red blood cells are visible. The large, darkly stained cell with granules is a basophil. The other white blood cell with lightly stained cytoplasm and segmented nucleus is a neutrophil. B. A blood smear from a dog showing a small lymphocyte. Two platelets are also visible. The dark spots visible are deposits of stain. C. A blood smear from a dog showing an eosinophil. The cell has granules and a nucleus similar in shape to that of a basophil. The granules, however, stain differently between cell types. D. A blood smear from a dog showing a monocyte. E. A bone marrow smear from a dog. Multiple white blood cells are visible, including an immature neutrophil or band cell.

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Table 4–1 Life Span of Red Blood Cells (in days)

Dogs	100–110
Cats	66–78
Horses	150
Sheep	150
Cattle	160
Humans	120

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The production of RBCs by the bone marrow is called **erythropoiesis**. RBCs have a limited life span and are constantly being replaced (Table 4–1). In addition to the normal turnover of RBCs, conditions such as blood loss increase the need for more cells. When the number of RBCs decreases, the amount of oxygen delivered to the tissues also declines. Special receptors in the kidney detect such a change and release a hormone called erythropoietin. Erythropoietin stimulates the bone marrow to produce more RBCs.

The RBCs contain hemoglobin, which is the protein responsible for transporting oxygen. Hemoglobin is an iron-containing molecule. It contains four subunits, each with a globin protein and the iron-containing heme molecule. Each subunit can bind a molecule of oxygen. Thus, a complete hemoglobin can transport four oxygen molecules. The globin molecule helps to keep the oxygen from binding securely (i.e., prevents complete oxidation) and allows it to be released readily in the tissues. The iron gives the red appearance to hemoglobin. Hemoglobin is efficient at binding oxygen, which is extremely important because oxygen is poorly soluble in plasma. Only about 3% of the oxygen in blood is dissolved in the plasma. The hemoglobin carries the remaining 97% of the oxygen.

The oxygen concentration of hemoglobin is highest in the capillaries of the lungs. As the blood is pumped to tissues in which the oxygen concentration is lower, the oxygen is released from the hemoglobin. The higher the level of carbon dioxide at the tissue level, the more oxygen is released. Some of the carbon dioxide is carried by hemoglobin, which helps to release the oxygen. A lower pH (more acidic) also increases the release of oxygen. Active muscles produce lactic acid, which lowers the pH. As a result, more oxygen is released at the site of these active muscles. The elevated temperature that occurs in active tissues also increases the release of oxygen.

Carbon monoxide is a gas released from poorly vented heaters and the exhaust from automobiles. The gas is colorless and odorless, so it is not detected by the animal breathing it. Carbon monoxide is extremely toxic because it binds to hemoglobin with a higher affinity than does oxygen. It also increases the affinity of hemoglobin to oxygen so it is released less freely. The toxic effect occurs because the blood is unable to carry enough oxygen to the tissues. With prompt diagnosis the supplementation of high levels of oxygen may be lifesaving. In the past small birds such as canaries were taken into mines as sentinels for elevated carbon monoxide levels. With their high metabolic rate the canaries were more susceptible to poisoning by the gas. If the miners saw the bird drop from its perch they knew to head for safer areas. Currently inexpensive carbon monoxide detectors in enclosed areas can prevent loss of life with early detection.

Hemoglobin carries only about 20% of the carbon dioxide. Most of the carbon dioxide is transported in the cytoplasm or the RBCs and plasma. Much of the carbon dioxide is converted to bicarbonate with the aid of an enzyme, carbonic anhydrase (Figure 4–4). The hemoglobin without bound oxygen helps to keep the pH normal by absorbing much of the free hydrogen ions. The blood then carries the bicarbonate to the lungs, where the carbon dioxide is released.

Leukocytes, or white blood cells (WBCs), are present to help fight infection. The five major types of white blood cells can be divided into two major classes, granulocytes and agranulocytes, based on the microscopic appearance of the cytoplasm. Neutrophils, eosinophils, and basophils—the granulocytes—all have granules within the cytoplasm. The granules pick up different stains, which aids in the identification of these types. The agranulocytes—lymphocytes and monocytes—have a smooth cytoplasm.

Like RBCs, the WBCs are also produced in the bone marrow. WBCs spend only a portion of their time in the bloodstream. The remainder of the time, the cells move into tissues to fight infection. The total count of

$$CO_2 + H_2O \xrightarrow{\text{Carbonic Anhydrase}} H_2CO_3 \longrightarrow H^+ + HCO_3^-$$

$$\left(\text{Carbon Dioxide} + \text{Water} \longrightarrow \text{Carbonic Acid} \longrightarrow \text{Hydrogen Ion} + \text{Bicarbonate Ion}\right)$$

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FIGURE 4–4 The chemical form of carbon dioxide in blood.

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WBCs in the blood of a normal dog ranges from 6,000 to 17,000 per microliter. The total count and types of WBCs present can be used to help diagnose infectious conditions in animals. Different WBCs have different functions, and changes in their number are useful in understanding the disease process.

The neutrophil is the predominant WBC in dogs, cats, and horses. The main function of neutrophils is to phagocytize (ingest in a form of endocytosis) and destroy microorganisms and cellular debris. The organism is taken into the cell in a membrane-bound sac that joins with granules within the cytoplasm. These granules contain enzymes that can destroy organisms. Neutrophils generally perform this function in the tissues, not in the blood. The neutrophil has a nucleus that appears segmented or divided (Figure 4–3A). This is the typical appearance of a mature neutrophil. If the body is attacked by an infection, the neutrophils move to the tissue infected (such as the lungs in pneumonia). The neutrophils respond to chemical factors in the diseased tissue and squeeze between the endothelial cells of the capillaries. (The term *diapedesis* describes this process of cells migrating out of the vessels.) Within hours the bone marrow releases a large number of neutrophils that have been held in reserve. The bone marrow then begins to increase production of the neutrophils. This higher production level takes three to four days to be fully transferred to the bloodstream. To speed up production, the bone marrow releases less-mature neutrophils into the blood. These immature neutrophils, also called band cells, have a nucleus that is shaped like a **U** (Figure 4–3E). A high percentage of band cells in blood tells the veterinarian that an animal is actively fighting an infectious agent.

Monocytes, another WBC, actively phagocytize microbes (Figure 4–3D). Monocytes are produced in the marrow and move into the bloodstream and then into the tissues. In the tissues, monocytes mature into macrophages. Some of these macrophages are established in places such as the spleen, lymph nodes, lung, or liver. They remove microorganisms, dead cells, and foreign particles (such as inhaled dust in the lungs).

Eosinophils look similar in appearance to neutrophils with the segmented nucleus. Staining characteristics help to distinguish each of the granulocytes. The eosinophils also have a large number of visible granules in the cytoplasm (Figure 4–3C). Eosinophils play roles in fighting parasites and also in allergic reactions. The eosinophils help to limit inflammation by releasing the contents of the granules at the tissue site of an allergic reaction.

Basophils are darkly staining cells with many granules and a segmented nucleus (Figure 4–3A). Basophils, like eosinophils, are involved in allergic reactions. Some of the granules in basophils contain histamine. Many students are familiar with antihistamines taken for hay fever. Antihistamines block the effects of histamine. Histamine causes inflammation in the linings of the nasal passages and respiratory tract. This inflammation produces the signs of sneezing and runny nose, common among hay fever sufferers. Histamine causes similar effects in animals.

Lymphocytes, which have a single nucleus, are essential in immune function (Figure 4–3B). Lymphocytes produce the antibodies that help fight disease. These antibodies make up a portion of the globulin that is found in plasma. Lymphocytes are found in all the tissues and organs used in fighting infection. Unlike many of the WBCs, lymphocytes are not involved in phagocytosis. They are present in the tonsils, lymph nodes, spleen, and thymus and are able to move back and forth between the bloodstream and tissues. A more detailed discussion of the immune system is found in Chapter 11.

Neutrophils and lymphocytes make up the largest number of WBCs found in circulating blood. Using the illustrations in this text, students can identify the individual types of cells. It will be more difficult to find the basophils, eosinophils, and monocytes than the common neutrophils and lymphocytes. Table 4–2 shows the normal ranges found in domestic species.

Platelets are the third type of formed element. Platelets, produced in the bone marrow, aid in the normal clotting of blood. Blood clotting is a very complicated process involving the platelets and numerous proteins and factors in the blood.

Immediately after a blood vessel is cut, there is a constriction of the vessel. Through this simple reflex the size of the leak is automatically decreased. Platelets then begin to attach to the edges of the damaged vessel, plugging the hole. In addition, a number of clotting factors help to convert the fibrinogen protein found in the plasma into fibrin, which completes the plug. There are 13 factors identified in the process of clotting blood. Over time the fibrin clot is replaced with repaired blood vessel.

The ability of an animal to clot vessels is quite impressive. Farm cats, with legs amputated by farm equipment, have been known to stop bleeding without intervention. The mammary vein on the lower abdomen of a cow can be over an inch in diameter. One cow with a hole in its mammary vein more than an inch in length stopped bleeding before the veterinarian arrived at the farm. However, the laceration was sutured for extra insurance against bleeding. The ability of animals to clot unaided is amazing.

Only the damaged blood vessel wall stimulates the formation of a clot. The normal smooth epithelial lining of the vessels does not stimulate clotting. Abnormal clots potentially cause damage to tissues by stopping blood flow.

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Table 4–2 Normal Ranges for Blood Cells

	Adult Dog	Adult Cat	Adult Cattle	Sheep	Goats	Swine	Horses
Red blood cells (millions/μl)	5.5–8.5	5.5–10.0	5–10	9–15	8–18	5–8	7–13
Packed cell volume (%)	37.0–55.0	24.0–45.0	24–46	27–45	22–38	32–50	32–53
White blood cells (cells/μl)	6,000–17,000	5,500–19,500	4,000–12,000	4,000–12,000	4,000–13,000	11,000–22,000	5,400–14,300
Neutrophils—mature	3,000–11,500	2,500–12,500	600–4,000	700–6,000	1,200–7,200	3,080–0,450	2,260–8,580
Neutrophils—bands	0–300	0–300	0–120	Rare	Rare	0–880	0–1,000
Lymphocytes	1,000–4,800	1,500–7,000	2,500–7,500	2,000–9,000	2,000–9,000	4,300–13,600	1,500–7,700
Monocytes	150–1,350	0–850	25–840	0–750	0–550	200–2,200	0–1,000
Eosinophils	100–1,250	0–1,500	0–2,400	0–1,000	50–650	55–2,420	0–1,000
Basophils	Rare	Rare	0–200	0–300	0–120	0–440	0–290

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The first major function of blood is to transport substances throughout the body. The list of transported components includes oxygen, carbon dioxide, nutrients, wastes, electrolytes, and hormones. Secondly, blood helps to protect the body from infectious diseases. The WBCs stand as the first line of defense against organisms attacking the body. The clotting ability of blood provides a tremendous protective measure for injured animals. Finally, the circulatory system is essential for maintaining homeostasis in the body. Keeping body temperature regulated and maintaining a consistent pH is essential for survival of the animal.

MAMMALIAN HEART STRUCTURES

Objective

- Identify the Basic Structures of the Mammalian Heart

Mammals have a four-chambered heart. This provides for two separate circulatory paths. The first is the pulmonary side, where blood pumps to the lungs to exchange oxygen and carbon dioxide. The second pathway delivers blood into the systemic circulation, where the blood moves to the entire body. The systemic circulation delivers blood rich in oxygen and nutrients to the organs of the body.

The heart is located low in the chest between the two lungs. The heart lies in the mediastinum, which separates the thorax into two halves. In addition to the heart, the trachea, esophagus, lymph nodes, and some major vessels are located within the mediastinum (Figure 4–5). The heart is contained within a fine membrane, called the pericardium. The pericardium is actually made up of two layers: a visceral layer, which is tightly attached to the heart, and an outer parietal layer. This type of two-layer system also occurs within the lining of the chest cavity and lungs, and in the abdomen. To visualize this setup, imagine taking a partially inflated balloon and firmly placing it over a heart. This would result in one layer of the balloon tightly wrapped around the heart, an air space, and the outer layer of balloon. This smooth-lined sac helps to protect the heart and allows it to beat with little resistance. The space between the parietal pericardium and the heart is called the pericardial sac. In a healthy animal, there is very little space in the pericardial sac; the two layers are in close apposition.

The heart, a hollow muscular organ, divides into four chambers (Figure 4–6). The wall of the heart is mainly composed of cardiac muscle, the myocardium. Smooth epithelium lines both the inside and outside of the myocardium.

Valves in the heart keep blood flowing in one direction. These valves separate the chambers on each side of the heart. They are also present in the major vessels leaving the heart. A muscular septum separates the right and left sides of the heart.

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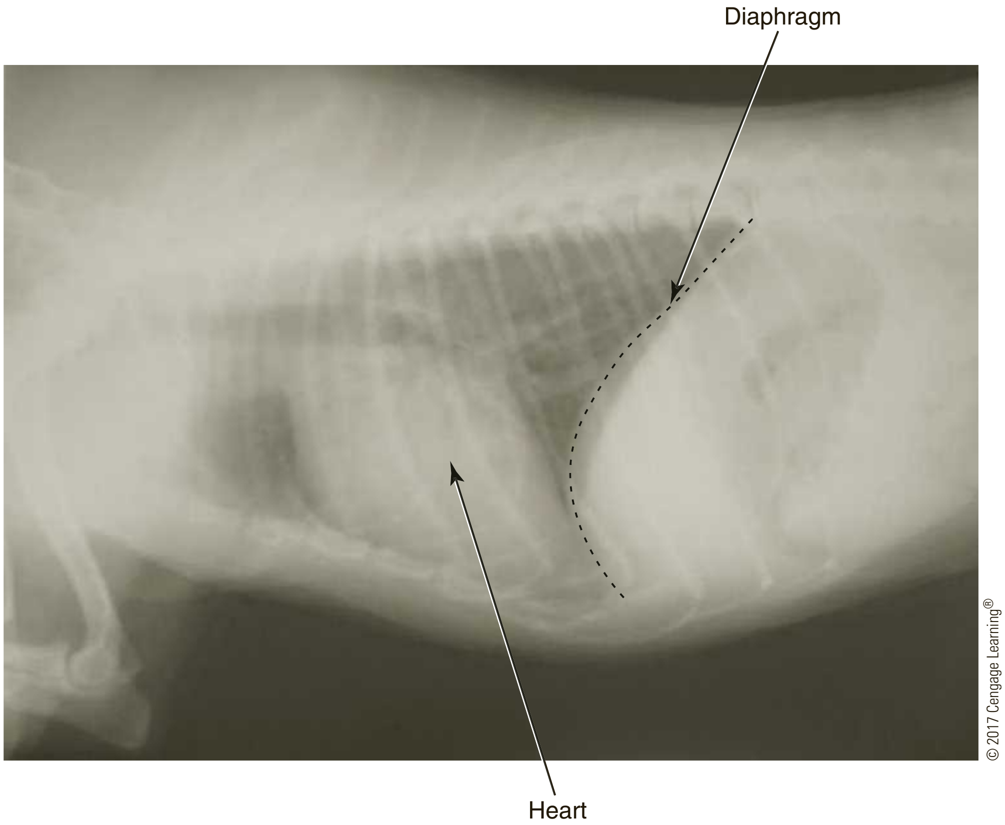

FIGURE 4–5 Radiograph of chest showing the position of the heart within the thoracic cavity.

BLOOD VESSELS AND BLOOD FLOW

Objective

- Trace the Flow of Blood through the Heart and Body While Detailing the Parts of Blood Vessels and Their Structural Significance

Understanding the pathway of blood flow helps students understand the structure of the heart and circulatory system. By learning how the blood flows, pupils gain knowledge of the two halves of the circulatory system and also the anatomy of the heart and vessels.

The blood returning from the systemic circulation to the heart has delivered oxygen and nutrients and picked up carbon dioxide and other waste products. Blood returns to the heart in the large vessels, either the cranial or caudal vena cava (Figure 4–7). The **cranial** (relating to the head) vena cava brings blood from structures in front of the heart. The **caudal** (relating to the tail) vena cava returns blood from structures behind the heart (Figure 4–8). Students familiar with human anatomy may recognize the terms *inferior* and *superior vena cava*. The inferior vena cava corresponds to the caudal vena cava, delivering blood from organs below the heart. The superior vena cava delivers blood from organs above the heart. The terms *inferior* and *superior* are used because of the human upright posture.

Blood from the venae cavae flow into the right atrium. The atrium is a relatively thin-walled chamber. The right auricle is the small blind pouch of the right atrium. The terms *atrium* and *auricle* are often wrongly used interchangeably. The auricle is a portion of the atrium. As blood fills the right atrium, much of it passively flows into the right ventricle. Once the atrium contracts, it forces the remainder of the blood into the right ventricle.

The right ventricle has a thicker muscle wall than the atrium. The right ventricle pumps the blood to the lungs. Separating the atrium from the ventricle is the right atrioventricular (AV) valve (Figure 4–9). The valve opens easily as the blood flows into the ventricle. Once the ventricle contracts, the pressure from the blood on the valve automatically forces it to close. These valves have flaps that are made of a thin layer of connective tissue, which are pushed by the blood. Tough fibrous cords, chordae tendineae, connect papillary muscles in the wall of the ventricle to the flaps of the valves. These cords keep the flaps of the valves from going too far, effectively sealing the opening between the two chambers. The AV valve, therefore, is necessary to keep blood from going back into the atrium. The blood is then efficiently pumped into the pulmonary circulation. In humans, the right AV valve has three flaps (also called cusps) and is often referred to as the

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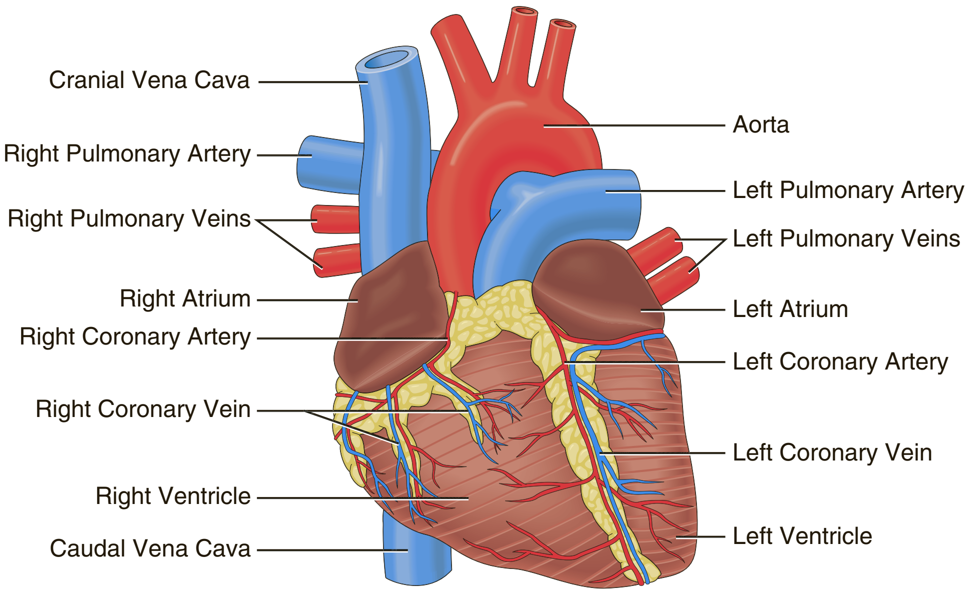
A



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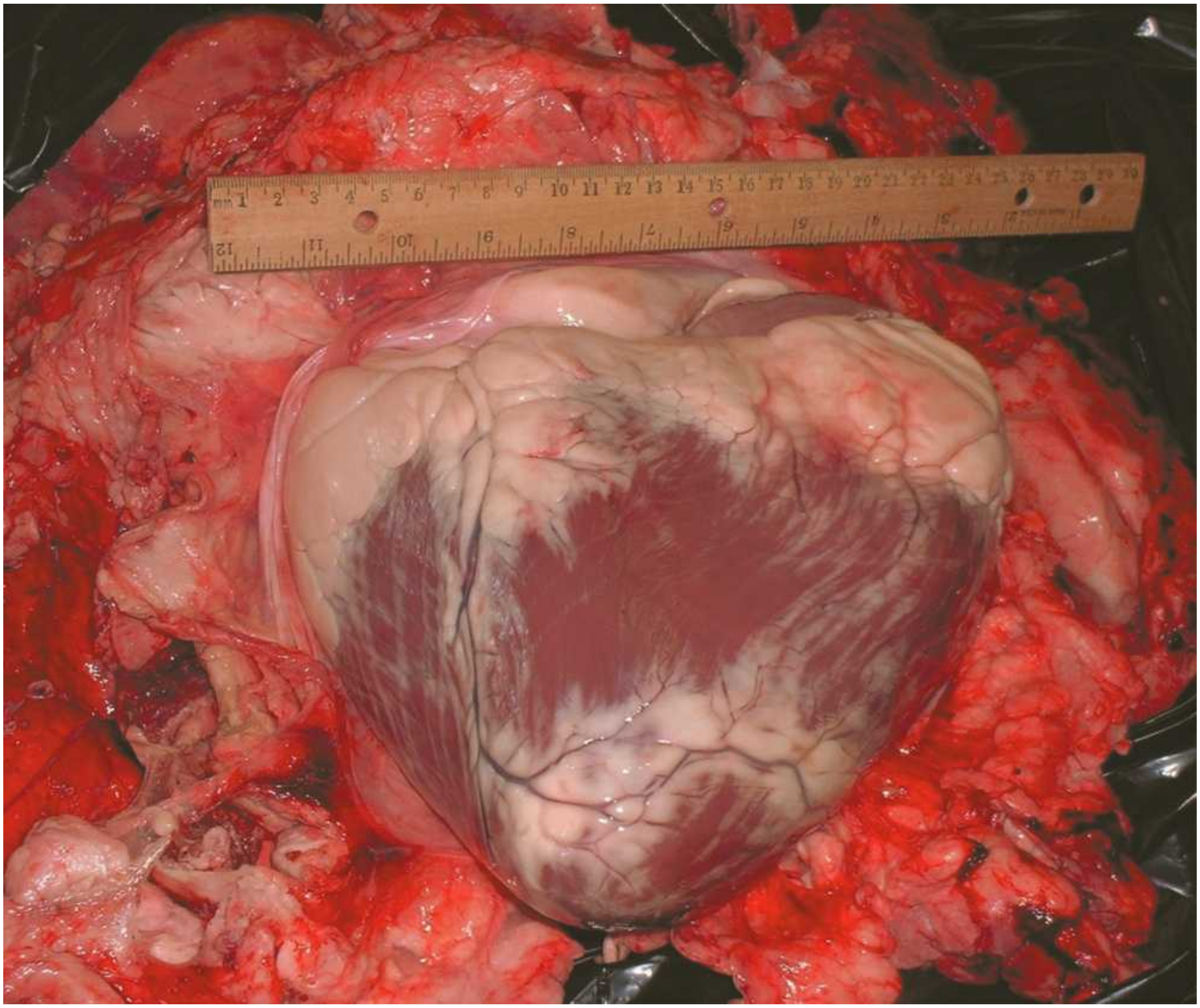

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FIGURE 4–6 A. The external structures of the heart. B. A gross specimen of the heart of a cow.

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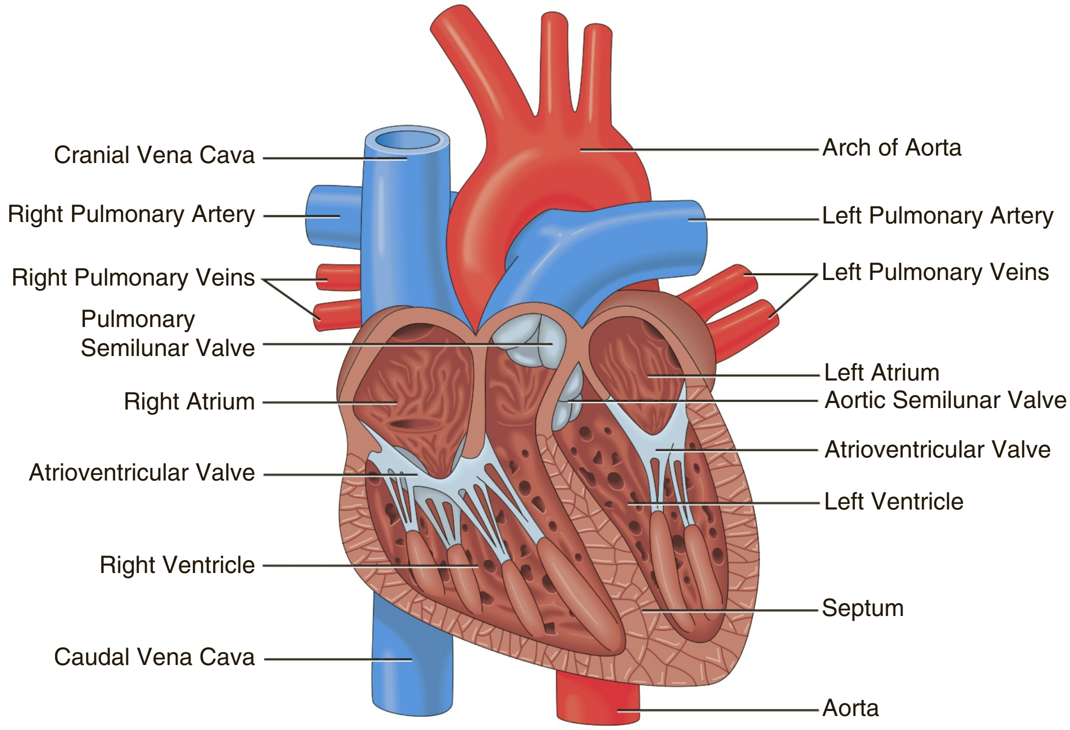

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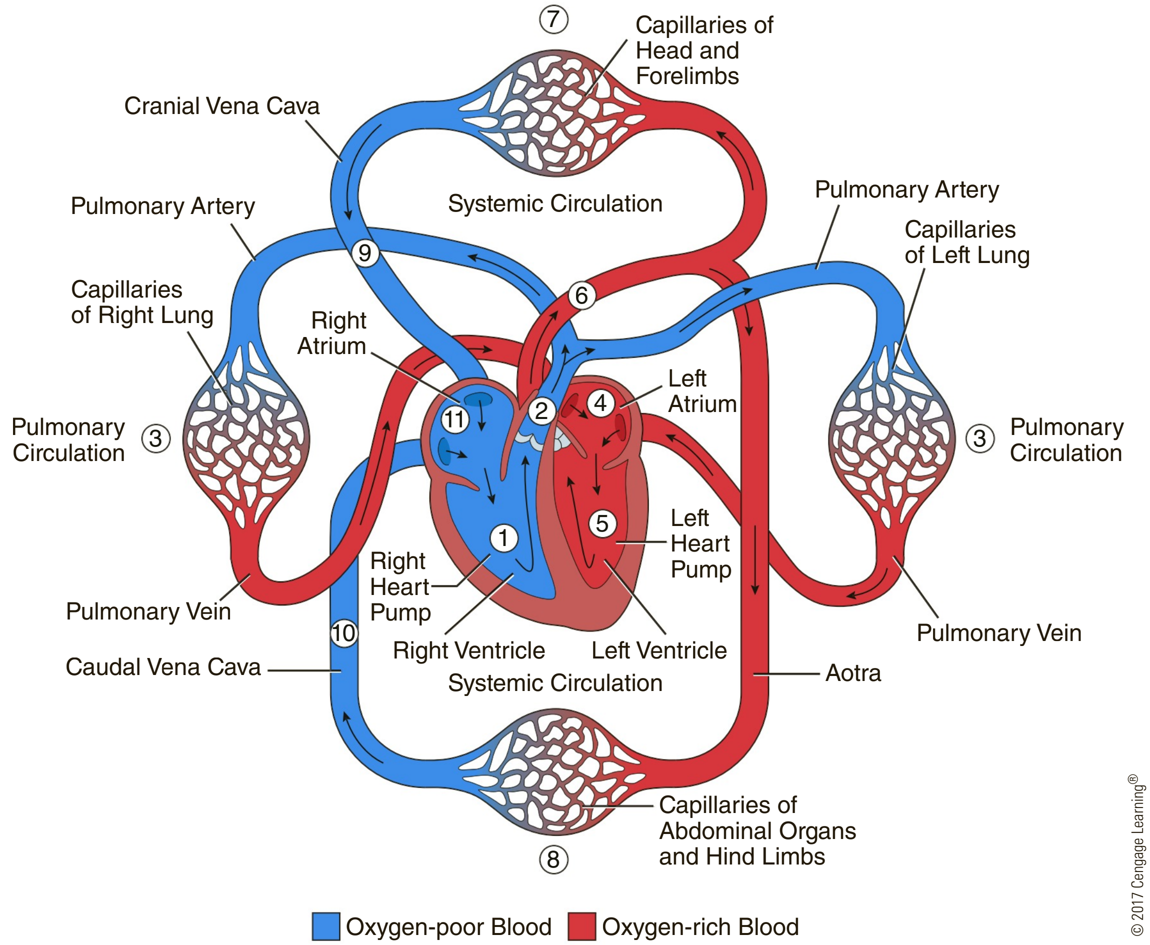

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FIGURE 4–7 A. The internal structure of the heart. B. The flow of blood through the body.

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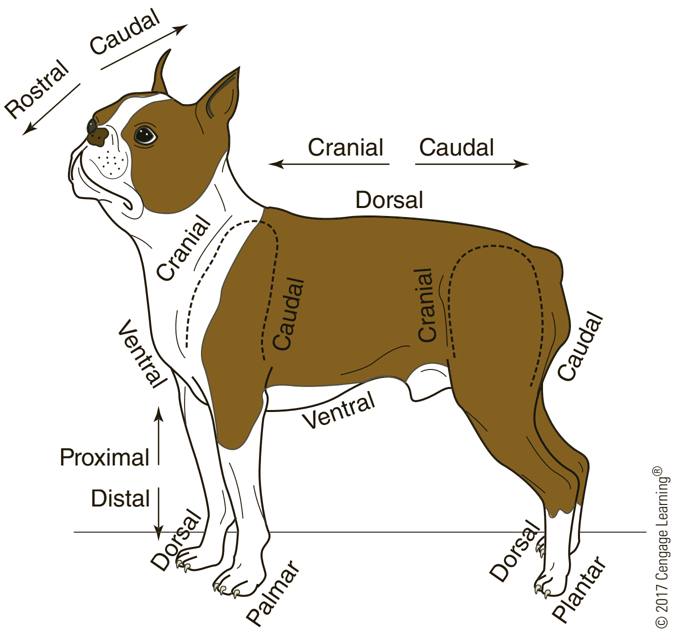

FIGURE 4–8 Directional terms used in describing relative position. Note the relationship of cranial and caudal with its association to the vena cava.

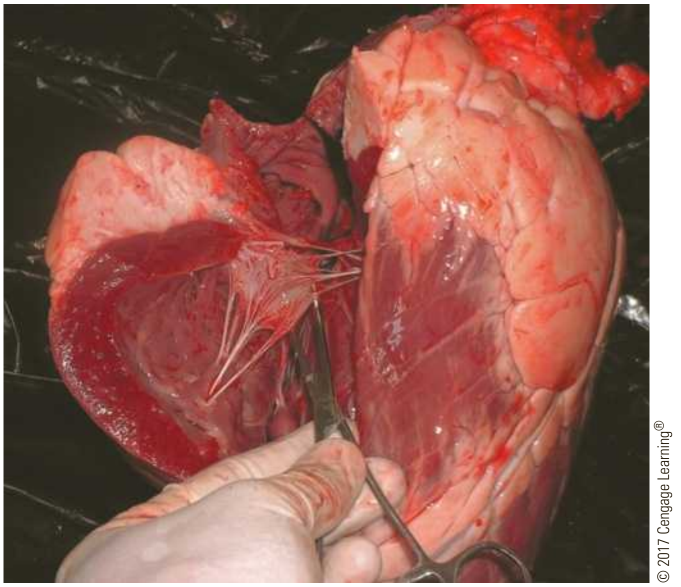

FIGURE 4–9 Atrioventricular valve. The hemostat is under the leaf of the valve. Note the chordae tendineae that secure the edge of the valve.

tricuspid valve. Dogs and cats have only two major leafs to the right AV valve.

As the right ventricle contracts, the blood flows into the pulmonary **arteries**. Arteries carry blood away from the heart. In an adult animal, the pulmonary arteries are the only ones that carry oxygen-poor blood. The right ventricle is separated from the pulmonary arteries by the pulmonary valve. The pulmonary valve keeps blood that has entered the pulmonary artery from flowing back into the heart.

Arteries have both smooth muscle and elastic connective tissue in their walls. When the smooth muscle contracts in vasoconstriction, the size of the opening decreases. When the muscle relaxes, vasodilation or an increase in the size of the vessel occurs. The smooth muscles influence the blood pressure by controlling the size of the vessels. The artery can also open to direct blood to certain areas. For example, a skeletal muscle that is being used actively requires a greater amount of blood.

As the heart pumps blood into the artery, the elastic tissue stretches. Once the heart relaxes, the elastic tissue begins to shrink to its original size (just as in releasing a rubber band). This elastic tissue helps to force the blood through the artery. The pulmonary valve is necessary to keep the blood flowing toward the lungs.

The arteries branch into smaller arterioles as they distribute through the lungs. The arterioles further branch into microscopic capillaries. The capillaries are the smallest vessels. The wall of the capillary has a simple squamous endothelium lining with a small amount of surrounding connective tissue. These thin-walled capillaries have an opening so small that only one red blood cell can pass through at a time. Transfer of nutrients and gases occurs only in the capillaries. For instance, in the lungs, carbon dioxide is exchanged for oxygen. Every cell in the body needs to be within 100 micrometers (μm) of a capillary to allow for the necessary exchanges to occur.

Fluid also leaks out of the capillaries and is an important part of the extracellular or interstitial fluid. The amount of this fluid needs to be finely maintained. Excess fluid returns to the bloodstream through lymphatic vessels. The amount of fluid that leaks from the capillaries is influenced by the pressure that occurs within the vessels relative to the pressure in the surrounding tissue. In addition, osmotic forces are balanced between the vessels and the extracellular fluid. If the extracellular environment stays the same, an increase in blood pressure will cause more fluid to leak. Osmotic pressure has the effect of drawing fluid toward the higher pressure. A decrease in the blood protein level lowers the osmotic pressure within the bloodstream, allowing more fluid to leak. Obstruction of flow in the lymph vessels will also create an increase in the extracellular fluid. *Edema* is the term that describes this excess fluid in the extracellular space.

The oxygen-rich blood then gathers into slightly larger venules. Many venules join into **veins**. Veins carry blood toward the heart. The veins then join into the main pulmonary veins that return the blood to the heart. The pulmonary vein, the only vein in adult animals that carries oxygen-rich blood, delivers blood into the left atrium. The veins possess a much thinner wall than similar-size arteries. The size of the opening is related to the amount of blood flowing within the vessel.

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The structure of the left atrium is very similar to that of the right atrium. An auricle is also present on the left atrium. As the atrium fills, much of the blood passively flows into the left ventricle. When the atrium contracts, the remainder of the blood is pumped into the left ventricle. An AV valve also separates the chambers on the left side of the heart.

The left ventricle has the thickest muscular wall of all the four chambers (Figure 4–10). The left ventricle must force the blood through the entire systemic circulation. The systemic circulation has to overcome the effects of gravity. Blood must be forced upward toward the brain and also must return from the feet. This requires pressure five times higher than the short pulmonary circulation. When observing an intact heart, the left ventricle makes up the point of the heart. As the ventricle contracts, the left AV valve prevents blood from flowing back into the left atrium. This valve (also called the bicuspid valve) is similar in structure to the right AV valve and has two flaps.

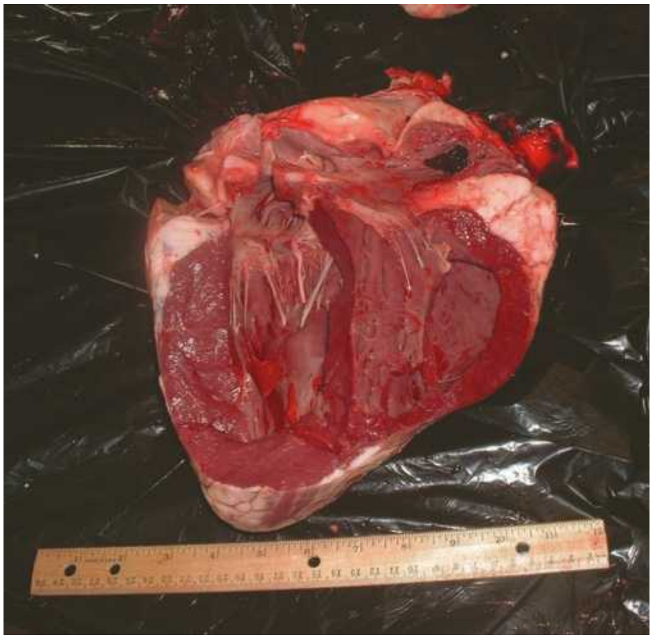

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FIGURE 4–10 A sectioned heart showing left and right ventricles. Compare the thickness of the walls of the two ventricles.

Blood is forced through the large elastic aorta by the left ventricle (Figure 4–11). The aortic valve separates the left ventricle from the aorta. Just as with the pulmonary valve, the aortic valve prevents blood from flowing backward into the heart. During contraction of the ventricles the sudden flow of blood causes the aorta to stretch, a function of the elastic tissues in the wall. During the relaxation phase of the cardiac cycle, the elastic tissue in the aorta wall begins to shrink (much like a stretched rubber band). The actual pressure in the aorta declines, but the elastic effect maintains a forward blood flow during this relaxation phase.

The main trunk of the aorta arches around the top of the heart and passes through the chest into the abdomen. The aorta divides into regions: ascending aorta, aortic arch, and descending aorta. Major branches of arteries separate from the aorta. Close to the heart, the coronary arteries branch to deliver blood to the cardiac muscle. These arteries are essential to heart function because the blood within the chambers of the heart does not supply nutrients to the heart muscle. Many other major branches derive from the aorta. These branches

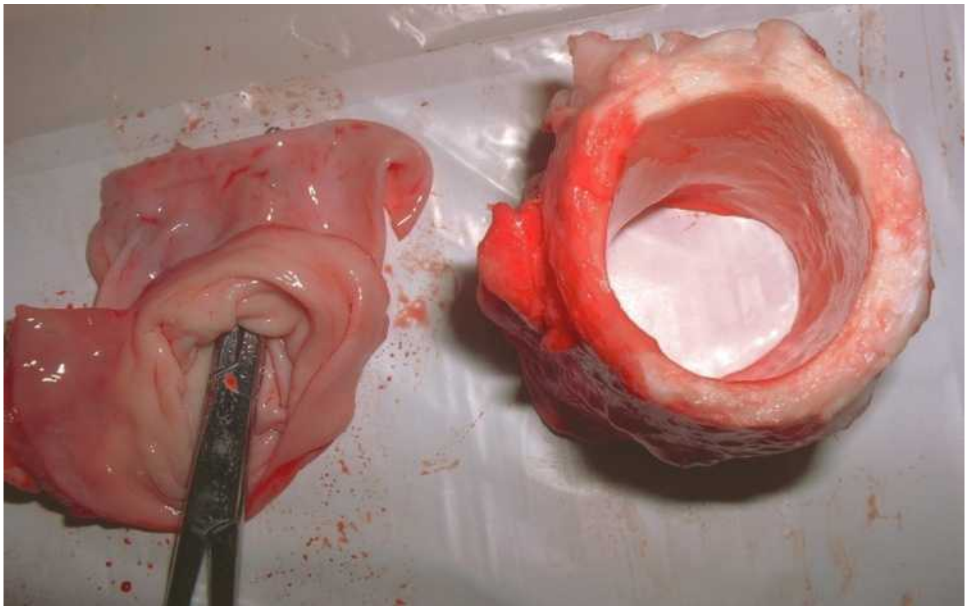

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FIGURE 4–11 Cross section of a large artery and vein. Compare the differences between the thin-walled vena cava on the left and the thick-walled aorta on the right.

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include the carotid arteries, supplying the head and brain; the mesenteric arteries, supplying the gastrointestinal tract; the renal arteries, supplying the kidneys; and the iliac arteries, supplying the hind legs.

Just as in the pulmonary circulation, the arteries branch into arterioles and then into capillaries. It is at this level that exchange with the tissues occurs. The capillaries organize into venules and then veins to eventually return blood to the heart. In many locations arteries, veins, and nerves all travel in the same bundle, a fact found very useful in many surgeries. Occasionally, a need arises to amputate a leg. When amputating the hind leg at the middle of the thigh (mid-femur), the veterinary surgeon knows that the major vessels run down the inside of the leg, close to the femur. The femoral artery and vein run close together in a division between muscles. During the amputation, it is necessary to identify these major vessels. The artery and vein are then tied, or ligated, to prevent major blood loss during the surgery.

Almost all of the vessels follow the pathway of artery, arteriole, capillary, venule, and vein. A few exceptions do occur in a specialized pattern called a portal circulation. The blood flow from the intestinal tract through the liver is one example of a portal circulation. Blood in the capillaries of the intestinal tract is rich in nutrients digested from recent meals. This nutrient-rich blood enters the portal vein; however, instead of returning to the heart, the veins branch into capillaries in the liver. The liver is extremely important in metabolizing the absorbed nutrients. The blood then leaves the liver through capillaries, funneled again into veins, and returns to the heart through the caudal vena cava. Two other portal systems, where blood flows through two capillary beds, occur in the kidney and in the brain (in the hypothalamus and pituitary gland).

ELECTROCARDIOGRAMS, HEART SOUNDS, AND BLOOD PRESSURE

Objective

- Use Knowledge of Heart Function and Control to Explain the Clinical Significance of the Electrocardiogram; Heart Sounds, Including Heart Murmurs; and Blood Pressure

The rate at which the heart beats is controlled in part by the nervous system. The actual beat, though, begins within the heart itself and will start without any nerve supply. The cells that begin the heartbeat are called pacemaker cells. The **pacemaker system** is important in maintaining the heart's regular rhythm. The system must also function to make the heart contract in a highly organized manner. The atria must contract first to fill the ventricles. When the ventricles contract, they need to do so in a way that pumps blood efficiently out of the heart.

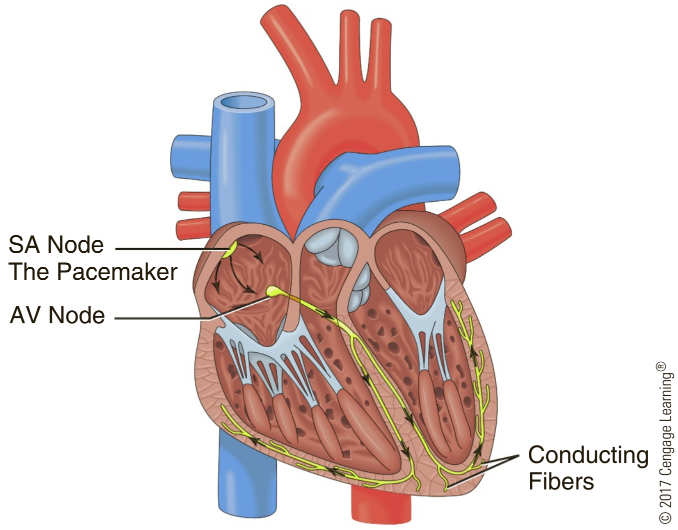

FIGURE 4–12 The heart conduction system. The signal is initiated in the sinoatrial (SA) node, or pacemaker. The impulse travels through the atria and is picked up by the atrioventricular (AV) node, which quickly distributes it through the ventricles via conducting fibers.

In mammals, the pacemaker is called the sinoatrial (SA) node (Figure 4–12). This specialized group of cardiac muscle cells is found in the right atrium, close to the cranial vena cava. An electrical signal begins in the SA node and spreads to the surrounding muscle cells. The SA node is influenced by the autonomic nervous system and by hormones, but the actual initiation of the signal would occur without nervous system input. On the other hand, skeletal muscle requires stimulation from a nerve to each muscle cell called into action. The specialized connection between cardiac muscle cells allows this signal to spread rapidly across the atria. The atria contract as a functional unit, forcing the blood into the two ventricles.

A slight delay occurs as the signal is picked up by the atrioventricular (AV) node. This delay allows the atria to contract and empty prior to the contraction of the ventricles. As the name suggests, this node is found close to the junction between the atrium and the ventricle. Connective tissue between the atria and ventricles prevents the signal from progressing to the ventricles, requiring that it transmits through the AV node. The AV node then sends an electrical signal through conducting fibers to the ventricles. These conducting fibers begin as a common bundle or bundle of His, then split into the left and right bundle branches. These branches further divide into Purkinje fibers, which rapidly distribute the stimulation to the ventricular cells. The contraction begins at the apex of the heart and then spreads across the ventricles. This provides an effective contraction for pumping the blood out through the major arteries.

Following a contraction there is a short refractory period during which the ventricular cells do not

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contract. This period allows for the ventricles to fill prior to the next contraction. The AV node has a pacemaker ability, as well. Typically the rate of the AV pacemaker is much slower than that of the SA node. This establishes the SA node as the primary pacemaker in setting the heart rate. If damage occurs to the SA node, the AV node can then create a rescue heart rate. This rate will be much slower and is a very serious condition.

A **cardiac cycle** includes one complete contraction and the relaxation that follows. During relaxation the atria fill with blood in preparation for the next contraction. The rate of this cycle varies between species. The rate for an individual animal can vary with breed and fitness level. The contraction phase of the cycle is called **systole**. **Diastole** is the relaxation phase.

Blood pressure measurements are taken during both phases of the cardiac cycle. The higher number occurs during systole as the heart contracts. The pressure then declines during diastole as the heart relaxes. Blood pressure is measured in millimeters (mm) of mercury (Hg). In human medicine a typical number, such as 120/80 mm Hg, represents the systolic over the diastolic pressure. In dogs normal blood pressure varies among breeds. Normal pressures range from 115/65 to as high as 150/90. Cats tend to have a tighter normal range, typically close to 125/88.

The events that occur in the contraction of cardiac muscle are very similar to those of skeletal muscle, discussed in Chapter 2. A major difference is that skeletal muscle cells act independently whereas cardiac cells have a special junction that allows the stimulation of one cell to flow to all the connected cells.

The flow of ions that allows the cardiac muscle to contract causes a small electrical current. The **electrocardiograph** is an electronic instrument that picks up this small electrical signal transmitted through the body's fluids. The **electrocardiogram** (ECG) is the tracing made by the instrument (Figure 4–13).

A letter identifies the different peaks. Each peak can be related to activity within the heart. The P wave is formed as the SA node fires and the atria contract. The QRS complex is formed as the ventricles contract. The T wave forms as the ventricles prepare for the next contraction. The PR interval is the time delay that occurs between the beginning of atrial depolarization and the beginning of ventricular depolarization. This interval shows the time necessary for the atria to contract and fill the ventricles and shows the delay that occurs in the AV node. Measuring this time delay on the ECG can be used to evaluate if there is abnormal function of the AV node or bundle branches.

The ECG identifies problems associated with the contraction of the heart. The size of the different peaks can be measured; abnormalities indicate changes in the size of the heart or damaged portions. The shape and frequency of the peaks can also be used to detect problems associated with the pacemaker and conduction system.

The normal consistent rate and rhythm is called sinus rhythm. It tells the veterinarian that the SA node begins each signal and the rate is very consistent. An **arrhythmia** describes any change in the rate, rhythm,

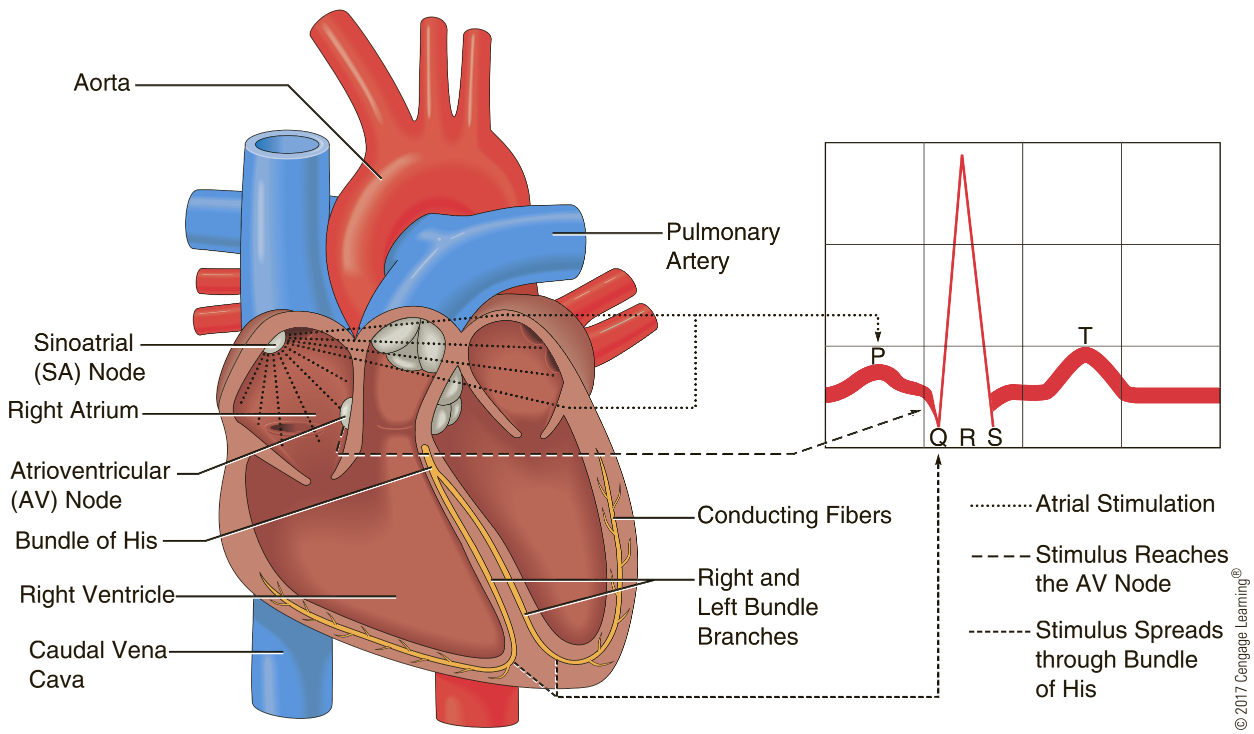

FIGURE 4–13 A typical ECG tracing and its relationship to the heart conduction system.

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or conduction within the heart. Severe arrhythmias may be corrected with an artificial pacemaker. This electronic device delivers an electrical signal to the heart muscle overriding the inherent pacemaker. Many changes in rate and rhythm can occur (Figure 4–14). Common descriptive terms include the following:

- Sinus **tachycardia**: This indicates a heart rate that is faster than normal, with a normal rhythm that originates in the SA node.
- Sinus bradycardia: This term denotes a heart rate that is slower than normal, with a normal rhythm that originates in the SA node.
- Sinus arrhythmia: In this condition, the heart rate increases with inspiration and decreases with expiration. Every complex looks normal; there is just a change in the rhythm with every breath.
- Atrial fibrillation: In this state, the SA node no longer acts as the pacemaker. Another site in the atria is irritated and fires very frequently. With this condition, the P waves occur very close together instead of in a clean peak. The atria no longer contract normally, but instead quiver. Because the cardiac muscle cells have a refractory period, only a small percentage of the P waves reach the ventricles to cause the contraction. The heart rate in this condition is described as being irregularly irregular and is very rapid.
- Ventricular fibrillation: In ventricular fibrillation, one of the most serious arrhythmias, a site within the ventricles fires extremely rapidly. The ventricles no longer contract normally, but quiver uncontrollably. This is the classic arrhythmia that requires the animal to be shocked with a defibrillator (commonly seen on medical television programs).
- Asystole: The tracing in this condition is basically a flat line. The heart is no longer contracting. The animal is described as being in cardiac arrest. Depending on the cause, external stimulation may be able to start the heart. **Cardiopulmonary resuscitation (CPR)** can be used to stimulate the heart to deliver oxygen to the lungs.

The stethoscope is used to amplify heart sounds, allowing them to be heard much more clearly. The rate and rhythm of the heart can be determined with the stethoscope. Changes in the normal heart sounds can also be identified. Normal heart sounds have been described by the words *lub-dup*, heard when the valves close. The valves and surrounding heart wall vibrate during closing. These vibrations spread through to the chest wall and are picked up by the stethoscope. The first heart sound, *lub*, is created as the ventricles contract. During contraction, the AV valves close rapidly to prevent blood from flowing back into the atria. The closing of the AV valves creates the first heart sound.

The second heart sound, *dup*, occurs when the ventricles relax. In diastole, the valves close at the point where pressure in the aorta and pulmonary arteries becomes greater than the pressure within the ventricles. At this point the pulmonary and aortic valves close. The valves and the surrounding vessels vibrate, creating the noise. When listening to the heart, veterinarians evaluate several features. First the heart rate in beats per minute (bpm) is counted. The heart rate is then compared with the normal rate for that species. Several factors may influence heart rate. Many diseases can cause an elevated heart rate (tachycardia). In the veterinary office it is important to realize that stress, fear, and nervousness can elevate the heart rate. It is very common for a healthy cat or dog to have an elevated heart rate just because it is afraid.

The rhythm of the heart can also be determined. In normal sinus rhythm the *lub-dups* occur at a very regular rate. In many disease conditions the heart may beat irregularly, skipping beats or adding extra beats. When changes are heard, an ECG is often used to determine the exact cause. When listening to the heart, a pulse is often felt at the same time. It is useful to feel whether the pulse is strong and consistent with the heart sounds. The pulse is created as the blood surges through the circulation with higher pressure in systole and lower pressure during diastole.

Finally, the stethoscope is used to detect any changes to the normal *lub-dup* sounds. **Heart murmurs** occur when there is a defective valve or an abnormal flow of blood (Figure 4–15). A murmur is a prolonged sound described as a swishing noise. If an AV valve leaks, the sounds become *lub-swish-dup*. This is called a systolic murmur, because the murmur noise occurs during the contraction of the ventricles. If the aortic valve leaks, the sounds become *lub-dup-swish*. This diastolic murmur happens when blood leaks back into the ventricle as it relaxes.

The pacemaker within the heart tissue establishes the basic heart rate (Table 4–3). The heart rate and strength of contraction are controlled by other means. Stroke volume is the amount of blood that is ejected with each contraction of the heart. The stroke volume is in part controlled by the percentage of blood that is ejected from the ventricles. This ejection fraction is calculated by dividing the stroke volume by the total amount of blood in the ventricle at the end of diastole. In a resting dog, the ejection fraction may be as low as 50%.

Ejection fraction = Stroke volume ÷ End diastolic volume

The volume of blood that the left ventricle pumps in one minute is called the cardiac output and is calculated by multiplying the heart rate by the stroke volume.

Cardiac output = Stroke volume × Heart rate

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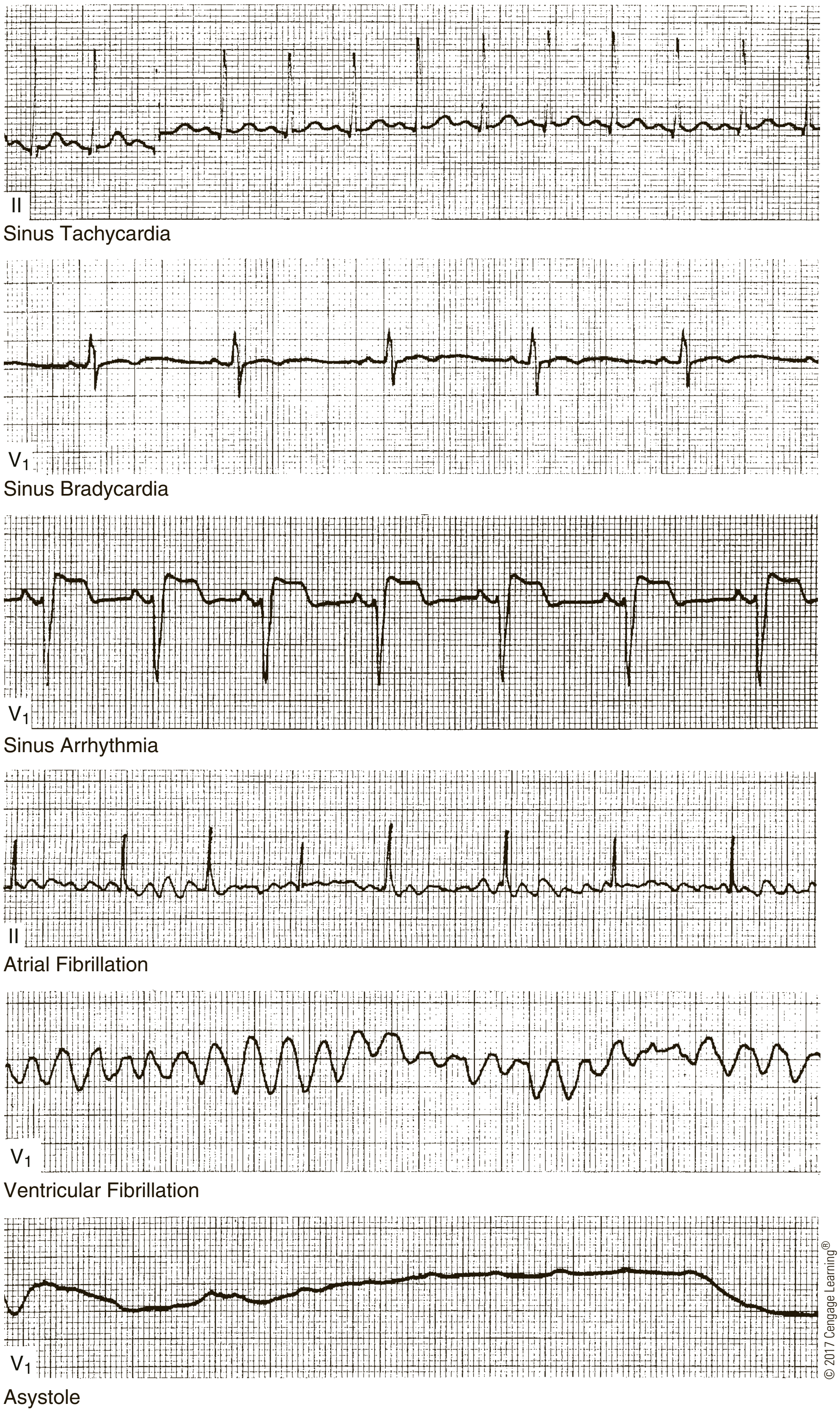

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FIGURE 4–14 ECG tracings of common arrhythmias.

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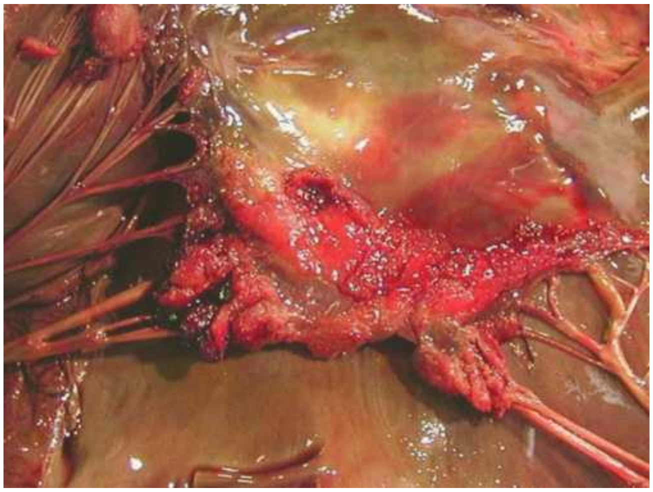

FIGURE 4–15 A diseased valve (endocarditis). This valve would not create a tight seal, resulting in a murmur.

Table 4–3 **Typical Heart Rates (beats per minute)**

Species	Typical Range
Cat	110–140
Cow	60–80
Dog	100–130
Goat	70–135
Hamster	300–600
Horse	23–70
Human	58–104
Sheep	60–120
Swine	58–86

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It is important to recognize that the cardiac output of the left and right ventricles must be equal. The cardiac output can increase dramatically when the body needs it. For example, when a horse runs a race, the increase in muscular activity greatly increases the need for blood flow. The heart rate increases significantly, and there is an increase in contractility, which increases the ejection fraction and therefore stroke volume. The net effect is a dramatic increase in cardiac output.

The autonomic nervous system aids in this control of the heart rate. During exercise, the amount of carbon dioxide from the muscles increases in the blood. Special receptors detect this change, and the brain sends a signal, causing the heart rate to increase. The sympathetic branch of the autonomic nervous system is responsible for this increase in heart rate. Fear and stress can also cause the same type of increase in heart rate. In addition, the adrenal glands release the hormone epinephrine in response to fear and stress. The adrenal glands are small endocrine glands located very close to the kidney. The hormone is carried to the heart in the bloodstream, causing an increase in heart rate as well. The sympathetic nervous system and circulating epinephrine both increase cardiac contractility, improving the ejection fraction.

The parasympathetic branch of the autonomic system causes the heart rate to slow. The signals for this branch are carried in the vagus nerve. Special receptors detect an elevated blood pressure, and the brain returns the signal through the vagus nerve. This causes the heart rate to slow and results in a decrease in blood pressure.

Blood pressure is maintained within a tight range. It is controlled by more than just the heart rate. Pressure receptors in the walls of some major arteries detect changes in blood pressure. These receptors are critical for sudden changes in blood pressure and have a rapid response (< 1 second). They are not designed for monitoring long-term blood pressure levels, as the set point can be readjusted. As discussed earlier, when pressure increases, the vagus nerve causes the heart rate to decrease. In addition, nerves stimulate vasodilation (relaxation or increase in the size of a vessel). The combination of these two events results in a decrease in blood pressure.

When pressure declines, the opposite events occur—heart rate increases and vasoconstriction (narrowing of the vessel as the muscles in the wall of arterioles contract) in nonessential organs occurs. In addition, hormones are used to control blood pressure (Figure 4–16). The kidneys produce an enzyme called renin. Renin is released when the kidney detects a decrease in blood pressure. Renin breaks down a protein found in the blood, forming angiotensin. Angiotensin causes vasoconstriction, resulting in a higher blood pressure. Angiotensin also causes the adrenal glands to produce a hormone called aldosterone. Aldosterone causes the kidney to retain higher amounts of sodium and water. The resulting increase in the amount of blood causes the blood pressure to increase.

There are also stretch receptors in the walls of the atria. Instead of measuring pressure, these receptors measure the distension of the wall of the atria. A decrease in blood volume, from a sudden blood loss, would result in less distension of the atria and therefore less stretch in the walls. This indirect measure of blood volume has an effect similar to that of the pressure receptors. A decrease in blood volume results in increased sympathetic stimulation and a decrease in parasympathetic activity. The resulting increase in cardiac output is a response to compensate for the lower blood volume.

Blood pressure is much higher in arteries than veins. During surgery, when an artery is cut, the blood pumps from the vessel. The surgeon can easily tell if

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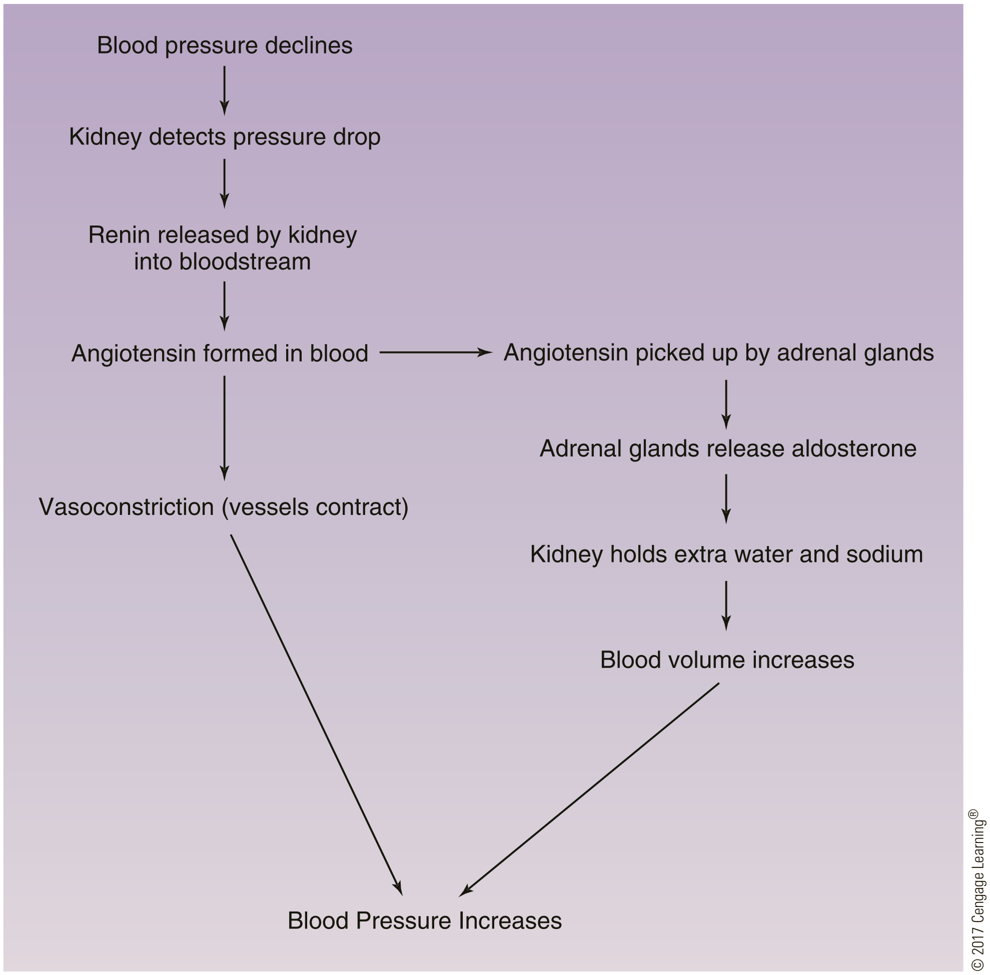

FIGURE 4–16 Pathways for the regulation of blood pressure.

the cut vessel is an artery. The bright red blood (high in oxygen) will shoot out, spurting forth with each contraction of the heart. When veins are cut, the dark red blood flows in a steady stream. (These blood colors assume that the surgery is not on the pulmonary artery and veins. Pulmonary circulation is the one instance in which arterial blood is low in oxygen and venous blood is high in oxygen.)

Because of the lower pressure in the veins, mechanisms are in place to help fight gravity. With low pressure, it is difficult to pump the blood upward from the feet and legs. Movement can help with this. As the muscles contract in the legs, the veins are squeezed, forcing the blood upward. The veins that contain blood flowing against gravity have simple valves in them. These valves allow the blood to flow freely toward the heart but prevent the blood from flowing backward.

This system can be overcome when there is no movement. In soldiers forced to stand at attention, the blood can begin to pool in the veins of the legs. The veins overfill to the point that not enough blood returns to the heart. In turn, the heart cannot supply enough blood to the brain. If the brain is deprived of blood, the soldier faints and subsequently lands flat on the ground. The heart is then no longer battling gravity and the blood supply is restored to the brain. Soldiers learn to prevent this by contracting and relaxing the muscles in the legs. Even without motion, the muscle contractions help to pump the blood back to the heart.

The mechanisms for controlling blood pressure usually respond quite quickly. However, there are instances in which these measures are not quite adequate. Again humans serve as useful examples. If one suddenly jumps up from a lying position, dizziness can occur. While lying, the heart is not working against gravity to pump blood to the brain. When the person jumps upright, there is an instantaneous need for higher pressure. The body quickly responds by constricting vessels, pushing more blood to the brain. Many students reading this will have experienced the mild dizziness associated with sudden changes in posture. Usually the effects are very short lived as the body reacts. In the most severe instances, fainting can occur.

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CLINICAL PRACTICE

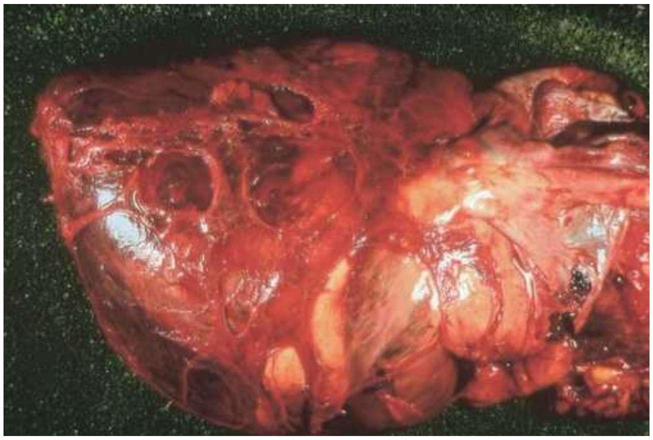
Objective

- Discuss the Clinical Significance of the Academic Material Learned in This Chapter

Sonic had stopped the blood supply to his foot by inadvertently wrapping it with string. All the functions of blood no longer were provided to his foot. No oxygen or nutrients were being delivered. The wastes and carbon dioxide from the cells could not be removed. As a result, the tissues in Sonic's foot had died. My only option was to amputate the foot above the level of the string. I selected a level where there was healthy tissue and surgically removed the foot and sutured the skin.

The cow with hardware disease was developing pressure as pus and fluid accumulated around the heart. The metal that the cow had eaten had exited from the stomach, moved through the diaphragm (the thin sheet of muscle that separates the thorax from the abdomen), and worked its way toward the heart (Figure 4–17). The cow's body reacted to the metal once it left the stomach, fighting the infection that the metal drags along. After the metal punctured the diaphragm, it quickly came into contact with the pericardium. The metal easily pierced the pericardial sac. WBCs, especially neutrophils and monocytes, also moved into the sac. Pus, the accumulation of body fluids and huge numbers of WBCs, eventually filled the sac, putting pressure on the heart.

The heart was less able to expand because of the outside pressure. This cow also had very large jugular veins. These large veins carry blood from the head, leading into the cranial vena cava. Because the heart could not expand easily, the pressure increased in all the veins leading into the heart. The jugular veins are positioned just under the skin where the enlargement is quite obvious. With every heartbeat, the fluid around the heart was disturbed, causing the washing machine



Photograph courtesy Dr. Arthur Hattel, Pennsylvania State University.

FIGURE 4–17 Diseased heart with pericarditis, which occurred in this cow from hardware disease. A large amount of inflammation is present between the heart and pericardium.

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FIGURE 4–18 Balling gun used to administer oral medication to cattle. The rectangular gray magnet remains in the reticulum, where it can trap ingested metal.

noise. The cow was developing heart failure. **Heart failure** is a general term describing a condition in which the heart is unable to meet the demands of the animal. It is not practical to treat this condition, and this animal was culled (removed from the herd). A magnet can be placed in the cow's stomach to prevent hardware disease or to treat early cases. The magnet is designed to trap the metal against it, to prevent it from puncturing the stomach (Figure 4–18).

Blood can be very useful in diagnosing diseases and is often tested to give veterinarians information on an animal's condition. A tremendous number of tests are available. In general, the laboratory reports a reference range for a given test. The reference range gives the variation that is expected in normal animals for that laboratory (Table 4–4).

Good diagnosticians must understand the vast array of common terminology used in veterinary medicine. Learning prefixes and suffixes often allows an entire term to be interpreted.

The prefix **hypo-** is used for many items when the blood value is below normal. The prefix **hyper-** is often used when the value is above normal. The suffix **-emia** is used to describe levels in the bloodstream. Examples include the following:

Item Tested	Low	High
Calcium	Hypocalcemia	Hypercalcemia
Sodium	Hyponatremia	Hypernatremia
Glucose	Hypoglycemia	Hyperglycemia
Potassium	Hypokalemia	Hyperkalemia
Chloride	Hypochloremia	Hyperchloremia

Changes in blood cells are described differently. The suffix *-penia* is used when the white blood cell count is less than normal (e.g., *leukopenia*, low total WBC count; *neutropenia*, low neutrophil count; *lymphopenia*, low lymphocyte count). The suffix *-cytosis* is often used for an elevated count (e.g., *leukocytosis, lymphocytosis*). The suffix -ia is added to certain other cells when elevated (e.g., *neutrophilia*, *eosinophilia*).

Anemia is the term used to describe a low RBC count. With anemia, the blood supplies less oxygen to the tissues. The earliest signs include fatigue during

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Table 4–4 **Normal Ranges for Blood Chemistry**

	Adult Dog	Adult Cat	Adult Cattle	Sheep	Goats	Swine	Horses
Albumin (g/dl)	2.8–3.9	2.4–3.5	3.0–3.6	2.7–3.9	2.7–3.9	1.8–3.3	2.9–3.8
Calcium (mg/dl)	9.4–11.7	8.7–11.9	8.0–11.0	8.2–11.2	9.0–11.0	8.6–11.0	11.2–13.8
Carbon dioxide (mEq/L)	11–27	10–21	24–33	20–27	–	18–27	22–32
Chloride (mEq/L)	108–131	115–125	95–110	95–103	99–110	94–106	99–109
Globulins (g/dl)	2.6–4.4	2.9–5.5	3.0–3.5	3.5–5.7	2.7–4.1	5.2–6.4	0.7–1.3
Glucose (mg/dl)	63–110	46.8–151	35–55	35–60	45–60	65–95	60–100
Phosphorus (mg/dl)	2.8–6.2	3.7–9.3	4.0–7.0	4.0–6.0	–	6.7–9.3	3.1–5.6
Potassium (mEq/L)	4.1–5.4	4.3–6.1	3.9–5.8	3.9–5.4	3.5–6.7	4.4–6.7	2.4–4.7
Total serum protein (g/dl)	5.7–7.6	5.3–8.5	6.0–8.5	6.0–7.5	6.4–7.9	6.0–8.0	5.5–7.5
Sodium (mEq/L)	143–168	147–161	132–152	139–152	142–155	135–150	132–146

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exercise. As the anemia worsens the animal becomes very weak and lethargic (sluggish and inactive). Anemia is a sign of an underlying disease, not a disease itself. The three basic causes of anemia are excessive blood loss, shortened life span of the RBCs, and decreased production of RBCs.

The most obvious cause of blood loss is trauma. When a major vessel is cut, a large amount of blood can be lost in a short period. Sometimes this blood loss is external and very obvious. In other instances the blood loss can occur within the abdomen or thorax. Animals hit by cars (HBC) often present to veterinarians with internal injury. If the trauma causes an organ such as the spleen or liver to rupture, the animal can lose a tremendous amount of blood. HBC is a much too common presentation in private practice. Pet owners are cautioned to keep pets under close supervision to prevent such accidents.

Blood loss can also occur much more slowly. The intestinal parasite hookworm can cause a chronic (long duration) blood loss. The hookworm attaches to the lining of the intestine and feeds on the blood of the animal. Anemia is more common in young puppies with a high number of hookworms. The parasites consume more RBCs than the puppy can produce. If not treated in time, chronic anemia can be fatal.

The life span of RBCs was discussed earlier in this chapter. If RBCs are destroyed at a much higher rate than normal, the bone marrow cannot produce enough to maintain levels. Certain toxins and parasites can cause this increased destruction. The toxin can even be a drug. Chapter 1 mentioned that acetaminophen can be toxic in cats. One of the effects is the destruction of RBCs. Several parasites can specifically attack RBCs. The body then destroys these cells in an attempt to eliminate the parasite.

The body's immune system sometimes malfunctions, targeting and destroying its own cells. This condition is called an **autoimmune disease** (the prefix *auto-* is used to describe *self*). The RBCs can be the target of an autoimmune disease. Again, in this condition the RBCs are destroyed faster than they can be produced.

In all the anemias just described, the body attempts to correct the low count. The bone marrow responds by releasing as many RBCs as possible. This includes some immature RBCs (still containing a nucleus). Other anemias do not present with immature cells; in these situations, the bone marrow is not producing enough RBCs. The bone marrow itself can be damaged by certain toxins and drugs, infections, and cancers. Animals in long-term kidney failure also develop anemia. As the kidneys fail, erythropoietin is not produced, and the bone marrow production of cells slows down.

Most commonly, anemia is treated by correcting the underlying cause. This includes treatments such as stopping the bleeding and eliminating any parasites or toxins. In the most severe cases, animals can receive a transfusion.

At times, blood loss occurs because animals cannot clot normally. A common reason for abnormal bleeding is consumption of rat poisons. Many of the commonly used mouse and rat poisons kill the rodents by causing bleeding disorders. Unfortunately, they are quite dangerous to domestic pets as well. If detected early, these animals can be treated. Vitamin K is important in the process of blood clotting. The poisons hinder the function of vitamin K. Animals that have consumed these poisons are often treated with vitamin K at high doses for long periods.

During **shock** not enough blood is pumped to the vital tissues. Hypovolemic shock occurs when there is not enough blood volume. Blood loss from severe

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injury can cause shock. The lack of blood volume can also occur with severe fluid loss associated with vomiting and diarrhea. Fluid is lost in both the vomitus and stools. Further, vomiting prevents adequate water intake to replace the losses. A second type of shock occurs when the heart does not pump adequately. This can occur in the later stages of heart failure. A third cause is when too many blood vessels dilate or open. When this happens, there is not enough blood to fill every vessel in the body. In the normal animal, the vessels dilate where the demand is highest. Septic shock is an example of this type, caused by a severe infection spreading through the body. Factors associated with infectious agents, such as bacteria, can cause dramatic vasodilation and resulting shock.

Animals in shock are weak and depressed. The heart rate is rapid and pulses are weak. Respiratory rates are typically increased and urine production declines. The body temperature of animals in shock can drop below normal. In addition to feeling the strength of the pulses, examining the gums can help detect shock. Normal gums (mucous membranes) should be a pink color. When the gum is pressed with a finger, it turns white. When the finger is released, the gum should return to the normal pink color within a second. This is called capillary refill time. Animals in shock have a much slower capillary refill time.

Treatment for shock is to stop the underlying problem. In addition, fluids are given intravenously (in the vein) to raise the blood volume and improve the flow of blood to the tissues. Other medications may be used to improve blood pressure as well.

Many diseases in addition to shock can cause changes in blood pressure. Disorders of the heart, kidneys, and endocrine system can affect an animal's blood pressure. Depending on the type of disease process, the pressure may be higher or lower than normal. Prolonged exposure to elevated blood pressure can create secondary damage to organs such as the eyes, heart, kidneys, and central nervous system. For example, a cat with kidney failure may have such high blood pressure that the presenting complaint may be blindness. The elevated pressures can create a condition in which the retinas detach from the underlying connective tissue.

Just as in human medicine, monitoring blood pressure is a tool to protect the health of companion animals. One technique for measuring the blood pressure of an animal is called the oscillometric system (Figure 4–19). A cuff is wrapped around the leg of the animal. This cuff is similar in design to the type of cuff used in human medicine. The blood pressure machine automatically inflates the cuff to a pressure that stops the flow of blood through the artery in the region of the cuff. The cuff then begins to deflate slowly. As blood begins to flow through the artery, vibrations are created. Sensors in the cuff are able to detect these disturbances and the machine determines at what pressure this begins.


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FIGURE 4–19 A technician restrains a dog while measuring blood pressure. Note the pressure cuff around the front leg.

To measure blood pressure, the limb being tested is held at the heart level. As much as possible, the animal is made to relax. Excitement, fear, and muscle trembling all can result in inaccurate results. If abnormalities are discovered, appropriate medications are administered to either elevate or decrease the blood pressure. It is essential to monitor the pressure of the animal while on treatment to ensure that the levels have returned to normal and not progressed too far.

In the day-in-the-life section, Lucky was introduced as a dog with a slow and irregular heart rate. The next step was to perform an ECG. The ECG confirmed the presence of an arrhythmia and bradycardia. The problem was prolonged intervals between many of the P waves. This indicated that the problem was originating in the SA node. The pacemaker was not stimulating a heartbeat on a regular basis. At times in the ECG, the delay between P waves was so long that the ventricle stimulated its own impulse. The resulting QRS complex was very irregular in appearance.

The owners described episodes in which the dog had collapsed, subsequently urinating and defecating. The owners saw this occur following times of excitement for Lucky. Although we were not present to observe these episodes, it is likely that the episodes were fainting spells. The excitement of barking and running increased the circulatory demands. With such a slow heart rate that did not increase normally, the blood supply to the brain was not adequate. As a result, Lucky fainted and fell flat on his side. This put the brain at the level of the heart and decreased the other demands from the muscle tissue. This survival feature allowed Lucky to recover and return to his normal condition.

Heart failure commonly affects elderly pets and develops when the heart is unable to distribute blood to keep adequate oxygen in the tissues. Many of these older animals have developed a severe heart murmur. Remember, a leaky valve causes a heart murmur. Consider a dog with a heart murmur caused by a leaky left

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AV valve. During ventricular contraction, a percentage of the blood leaks back into the atrium. To compensate and pump the same amount of blood, the heart beats faster and enlarges.

For mild leaks, the heart is able to compensate quite well. Over a long time, the animal will show no clinical signs of the enlarging heart. As the murmur worsens, the heart continues to enlarge and beat rapidly. Often the animal develops exercise intolerance and a cough. The coughing occurs as the heart enlarges to the point that it puts pressure on the airways. In the case of a leaking left AV valve, the left ventricle goes through hypertrophy (enlargement) in attempt to compensate. As the heart becomes less efficient, the pressure in the left atrium increases, which then forces an increase in the pulmonary venous circulation. This increase in hydrostatic pressure causes the increased leakage of fluid into the interstitial space of the lungs. If the condition worsens the fluid can actually accumulate within the alveolar space. The excessive fluid in the lungs may be called congestion or pulmonary edema. This decreases the efficiency of gas exchange in the lungs, further increasing the exercise intolerance and potentially the coughing. As the heart failure progresses, fluid accumulates in the lungs or the abdomen (in right-sided heart failure). Eventually, the condition becomes fatal.

In addition to listening to the heart with a stethoscope, radiographs can be helpful in diagnosing heart failure. If pulmonary edema is present the lungs will have a whiter appearance. On a radiograph, air is black, whereas tissues with increasing density become whiter. (For example bone is much more white than fat.) The increase in fluid in the lung tissue increases the density of the tissue, which is evident on the radiograph.

On a lateral radiograph the size of the heart can be measured and compared to the animal's vertebral column to determine if the heart is significantly enlarged. With this method the long axis of the heart is measured from the junction with the main bronchi to the tip of the apex, as follows:

1. Beginning at the cranial aspect of the fourth thoracic vertebra, measure how many vertebrae this length will cover (L = long axis).
2. Repeat this process by measuring the widest part of the heart and again measuring the number of vertebrae (S = short axis).
3. Total the number of vertebrae to determine the vertebral heart score (VHS = L + S).

Although there is some variation between different breeds of dogs, a VHS of 8.5 to 10.9 is considered normal (Figure 4–20). The VHS not only provides a measure of heart size for an initial diagnosis, but it can also be used to measure the progression of heart size over time using subsequent radiographs.

There are times when neither auscultation nor radiographs confirm a diagnosis. Additional testing is available. One example is a blood test that measures a marker released from cardiac muscle cells when they are stretched. An elevation in this marker in the bloodstream confirms the diagnosis of cardiac involvement.

Most people are familiar with the use of ultrasound to evaluate fetal well-being in pregnant women. Ultrasound can also be used to evaluate the heart in an echocardiogram. This allows the veterinarian to evaluate the beating heart for size of the walls, functioning of

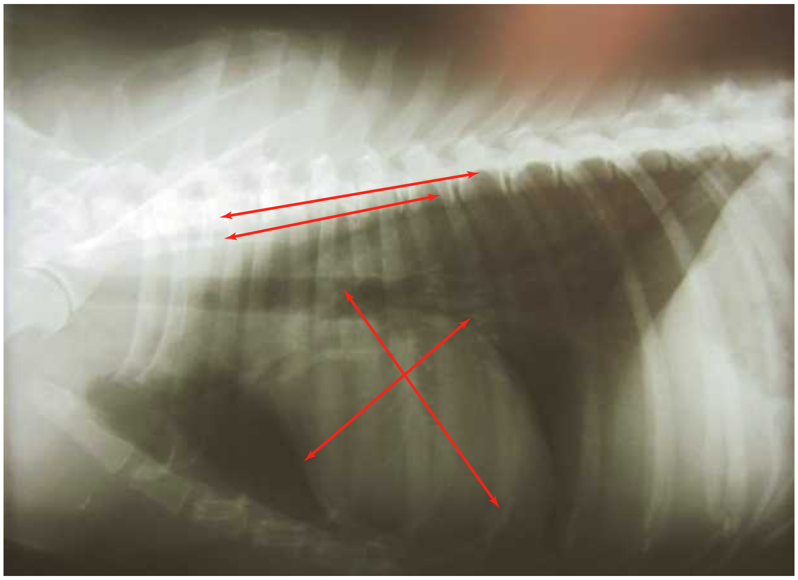

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FIGURE 4–20 Vertebral heart score (VHS): On a lateral radiograph the long and short axes of the heart are measured. The length of each axis is then measured on the spinal column beginning at the fourth thoracic vertebrae. VHS = Long axis + Short axis (number of vertebrae). VHS = 5.5 + 4.5 = 10. Normal range is 8.5 to 10.9.

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the chambers, and contractility of the heart muscle. An echocardiogram can also be used to evaluate the valves of the heart and determine the presence and degree of any heart murmurs. At this point, echocardiography is typically done at a specialty practice.

The duration of heart disease varies dramatically among animals. There is no cure for heart failure, but medications can be used to improve the clinical signs. The medications are used to strengthen the contractility of the heart (which increases the ejection fraction), lower the pressure in the arteries to lessen the work required by the heart, and remove excess fluid that is accumulating in the tissues. The medications are used to make the animal more comfortable.

SUMMARY

Blood separates into fluid and cellular parts. Blood carries much-needed nutrients to the body and removes unwanted waste as well. Two circulatory pathways allow blood to exchange oxygen and carbon dioxide in the pulmonary system while the systemic circulation takes the oxygen-rich blood to the whole body. Knowledge of blood and blood pathways provides a deeper understanding of the four-chambered mammalian heart and its functions. Practitioners rely on this information to successfully identify and treat problems associated with the circulatory system.

REVIEW QUESTIONS

1. Define any 10 of the following terms:

   hardware disease
   centrifuge
   serum
   erythropoiesis
   cranial
   caudal
   arteries
   veins
   pacemaker system
   cardiac cycle
   systole
   diastole
   electrocardiograph
   electrocardiogram
   arrhythmia
   tachycardia
   cardiopulmonary resuscitation (CPR)
   heart murmur
   heart failure
   hypo-
   hyper-
   -emia
   autoimmune disease
   shock

2. True or False: The atrium is a portion of the auricle.
3. Blood can be divided into fluid and _______ parts.
4. Leukocytes help to fight _______.
5. Arteries carry blood _______ (direction) the heart.
6. _______ provide sites of nutrient/gas transfer in the circulatory system.
7. *Tachycardia* describes an _______ heart rate.
8. Name one of the three types of protein found in plasma.
9. What purpose do heart valves serve?
10. Is the cranial vena cava referred to as inferior or superior in humans?
11. Which of the four heart chambers has the thickest wall?
12. Give another name for the sinoatrial node.
13. What sound does a systolic murmur make?
14. Is blood pressure higher in the arteries or veins?
15. Describe the electrocardiograph during an asystole condition.

ACTIVITIES

Materials needed for completion of activities:

calculators
light microscope
blood smear slides from a laboratory supply company
stethoscope

1. Adult dogs have 6 to 8 million RBCs per microliter of blood. A client brings in a 45-kg chocolate Labrador retriever and asks how many RBCs it has. Assume there are 7 million RBCs per microliter. A dog's blood volume is about 80 milliliters per kilogram of body weight. How many RBCs does this dog have in its body?

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2. If still available, examine the blood slides which can be obtained from a laboratory supply company. Using the pictures in this text, identify the different white blood cells. To identify the cells, evaluate the shape of the nucleus, the color of the cytoplasm, and the appearance of any granules within the cells.
3. The veins of the arm can be used to demonstrate the presence of valves within the veins. Place arms at sides, allowing the blood to pool in the veins. The visibility of the veins will vary between individuals. Find a straight section of vein without branches entering it. Press down on the vein with a finger and push the blood out of the vein, moving toward the hand. The vein will collapse and not refill (assuming that the pressure is maintained and there are no deep branches entering this section). The blood does not fall down the vein because of the valves located within it. If the vein is pressed in the opposite direction, it immediately refills. The blood is returning from the hand and will fill the vein.
4. Stethoscopes are readily available at a reasonable cost. Using the stethoscope, listen to your heart. Concentrate on identifying the two heart sounds present with each beat. Feel a pulse at the same time. The feel of the pulse should coincide with each heart cycle and will reinforce the action of the heart associated with each sound.
5. Capillary refill time (CRT) is typically tested on the gums in animals. In humans the fingernail provides a location where CRT can easily be tested. The tissue under the nail should be a rich pink color. Press the nail bed (the underlying tissue turns a very pale pink or white). Release the pressure and observe the time required to return to pink. In a healthy animal this should be less than 1 second.
6. A client brings in Flash, a 6-year-old basset hound, for you, the veterinarian, to examine. Flash has been weak and vomiting. You order a blood chemistry analysis to identify any problems. As you have plans to attend a conference, you elect to refer this case to another veterinarian. You have received the following blood test results:

	Flash's Results	Reference Range
Albumin	3.2	2.4–4.3 g/dl
Calcium	10.1	7.9–12.0 mg/dl
Carbon dioxide	22	15–28 mEq/L
Chloride	115	105–120 mEq/L
Glucose	98	65–120 mg/dl
Phosphorus	3.4	2.1–6.8 mg/dl
Potassium	6.2	3.4–5.4 mEq/L
Serum protein	7.0	5.2–7.2 g/dl
Sodium	124	140–151 mEq/L

The veterinarian asks what abnormalities you found on the blood work. Using the correct technical terms, describe the dog's condition.

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CHAPTER 5

The Respiratory System

Objectives

Upon completion of this chapter, you should be able to:

- Identify the basic components of the respiratory tract.
- List and discuss the function and control of breathing.
- Discuss the clinical significance of the academic material learned in this chapter.

Key Terms

respiration	inspiration	pneumonia	roaring
palpated	expiration	pleural friction rub	heaves
endotracheal tube	cyanosis	contagious	bronchodilators

Introduction

Chapter 4 dealt with the role of the circulatory system and included discussion on the transport of gases. **Respiration** is the exchange of gases between the animal and its environment. This chapter examines the function of the respiratory system.

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A Day in the Life
When is an Emergency Really an Emergency?

Right in the middle of small-animal office hours, the receptionist told me that an emergency case had arrived—a sneezing cat. My initial reaction was to question how much of an emergency sneezing could be. Even so, I finished the current appointment and then called in the emergency. Although the cat was in no immediate medical danger, it was really irritated. The cat sneezed frequently and was obviously quite annoyed. On physical examination, I found something was lodged in the cat's nose. I really could not see very far into the cat's nose. I told the owner I would keep the cat and anesthetize it for further review.

Emergencies are typically quite apparent. A client rushed into the office with a dog that had been hit by a car. The dog was showing evidence of shock (discussed in Chapter 4). After initiating treatment for the shock, I performed radiographs in an attempt to evaluate the extent of the dog's injuries. Radiographs showed that the dog was experiencing abdominal bleeding and there was free air in the chest. The trauma to the lungs had ruptured the tissue and was allowing air to escape into the chest cavity. The lungs no longer filled the chest cavity as they had partially collapsed. Unfortunately, this was a case without a positive outcome. Owing to the severity and extent of the injuries, the owners elected for euthanasia.

The same day, I was called to a farm to examine a cow that labored to breathe and was not eating well. As soon as I saw her, I knew she was severely ill. The cow had been treated with antibiotics by the farmer but was not responding. This case was particularly memorable because air had leaked out of her lungs and tried to escape from the body but became trapped in the fatty connective tissue, which lies under the skin. The skin on top of her back rose in a domelike fashion, making her look fat. When I pressed on this skin, I could hear and feel air popping. It reminded me of popping packaging bubbles. When I listened to the cow's breathing with a stethoscope, I heard quite dramatic sounds. Each breath made a sound like a creaking saddle. No doubt this cow was in real danger.

Every spring I see many kittens as I travel from farm to farm. The young kittens play in the barn, anxiously awaiting their drinks of milk. My associates and I frequently treat numerous respiratory infections in these young kittens (Figure 5–1).

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FIGURE 5–1 A young kitten suffering from an upper respiratory tract infection. Note the sore eyes and the thick nasal discharge.

THE RESPIRATORY TRACT

Objective

- Identify the Basic Components of the Respiratory Tract

The nose provides the opening for air to enter the inside of the animal. The nostrils open into the nasal cavity, which is divided by many scroll-like sheets of bone (Figure 5–2). Epithelium lines the bone. Mucus covers and protects the epithelial linings. The nasal anatomy increases the amount of surface area present and allows the air to come in contact with a large amount of epithelium. Through this contact, the inhaled air is warmed and humidified to protect the lower airways.

The upper airways fulfill several important functions that are designed to protect the lower airways. First, the mucus-covered epithelium filters incoming air. Particles in the air, such as dust, dirt, or pollen, become trapped in the mucus. The epithelium that lines the airways is covered with cilia. These cilia work to move the mucus toward the pharynx. The mucus accumulates and eventually is swallowed, thus protecting the lower airways. Watch hunting dogs walk. The dogs constantly sniff the ground in an effort to detect odors.

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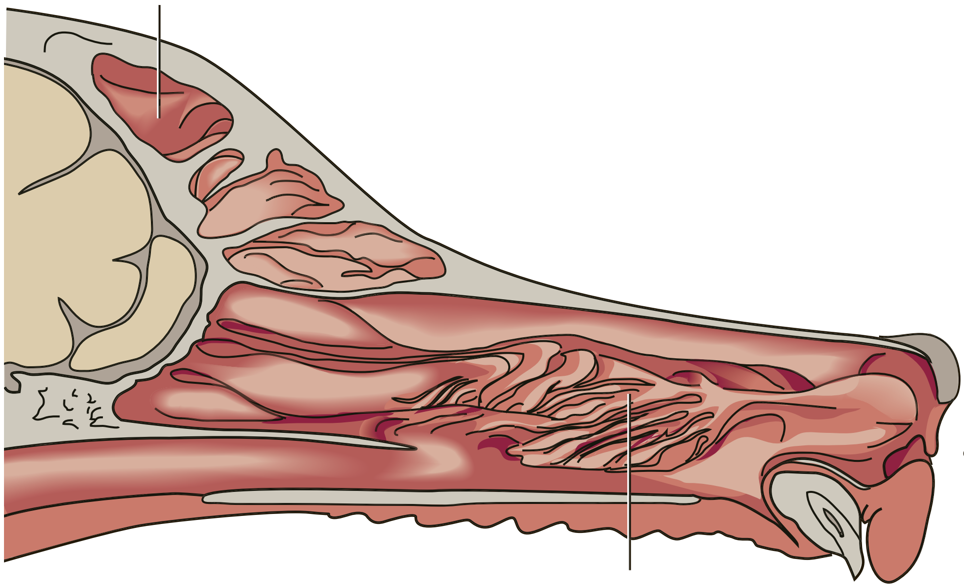

FIGURE 5–2 The internal structures of the nasal cavity of a dog.

In addition to smelling, these animals inhale many dust particles that the nose helps to filter.

As mentioned, most of the trapped particles are eventually swallowed. If the particles cause irritation to the lining of the nose, the animal sneezes. Sneezing is a reflex action that occurs when there is irritation in the nose. During a sneeze, a large amount of air is rapidly forced through the nose and mouth. The sneeze physically forces the trapped and irritating particles from the nose.

The previously mentioned sneezing cat was obviously trying to clear its nose. Once the cat was anesthetized, I could see the edge of something green inside the nasal cavity. I reached in with a pair of forceps and removed a 3-inch piece of grass. The cat's sneezing was unable to dislodge such a long blade. The sneeze is protective. Had this blade of grass slipped into the lower airways, the cat could have choked. In addition to helping to force out trapped particles, mucus adds moisture to inhaled air, thus preventing incoming air from drawing too much moisture from the lining of the lungs. By passing over the large surface area of the nasal passages, the air is also brought close to body temperature, which protects the lungs from extremes of temperatures.

The air passes from the nasal cavity into the pharynx. The pharynx is the common area shared by the nose and mouth. A portion of the pharynx is divided by the soft palate. Air then passes through the pharynx, whether it is brought in through the nose or mouth. Food being swallowed also passes through the pharynx.

Because the pharynx functions in both swallowing and breathing, special structures are present to help ensure that food is not inhaled. The larynx is the firm cartilage structure at the opening to the major airways. This structure can be **palpated** (felt) at the top of the neck. In humans this structure is also called the Adam's apple. The hyoid apparatus, a collection of small bones, supports the larynx and the base of the tongue. Muscles attached to these structures are involved in the swallowing process. The larynx contains the vocal folds, which are the structures that allow vocalization in animals and humans. Intrinsic muscles associated with the larynx can increase the tension on the vocal folds, resulting in a higher pitched sound. Male hormones such as testosterone thicken the vocal folds, resulting in a lower pitch. The opening in the larynx, between the vocal folds, is called the glottis. A cartilage flap, the epiglottis, protects the opening during swallowing (Figure 5–3). The epiglottis hinges at the base of the larynx and folds to cover the opening of the larynx during swallowing. When breathing occurs, the epiglottis does not cover the opening, thus allowing for free exchange of air. This action is entirely an involuntary process, automatically protecting the airways.

The anatomy of the pharynx becomes significant when administering anesthesia. Many surgeries are performed using inhalant anesthetics in animals. These drugs, delivered through the lungs, lower the consciousness of the animal. An ensuing deep sleep keeps the animal from sensing the pain associated with surgery. To deliver the anesthetic, the drug is

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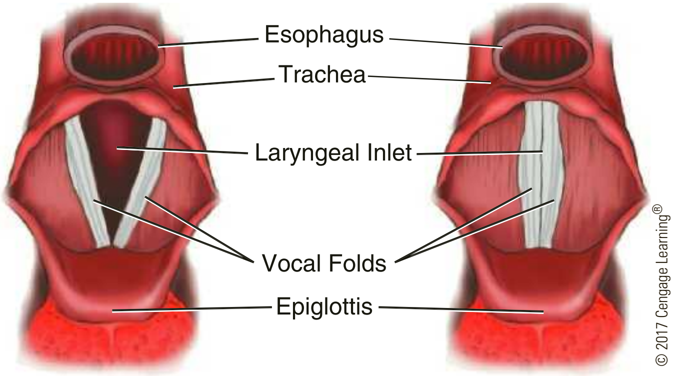

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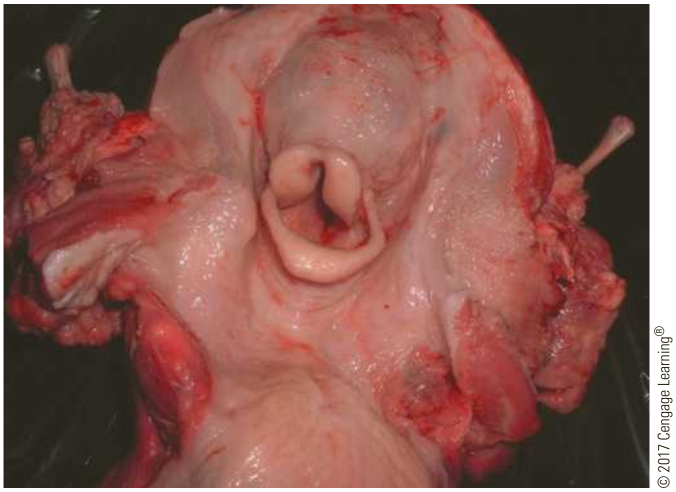

B

FIGURE 5–3 A. Illustration of the anatomy of the epiglottis and larynx. B. Photograph of the epiglottis and larynx.

given through an **endotracheal tube** into the trachea (Figure 5–4). To place this tube, the technician or veterinarian opens the animal's mouth wide and then identifies the epiglottis. The epiglottis is pushed downward to expose the larynx and vocal folds. The tube is inserted between the vocal folds. The tube connects to the anesthetic machine, which then sends the anesthetic through the airway of the animal.

Occasionally, foreign particles are able to slip into the larynx and trachea. Any particles or irritating gases initiate the coughing reflex. The cough is designed to further protect the airways. When coughing occurs, air is initially inhaled. Then the epiglottis and vocal folds close as the animal begins to exhale forcefully. Pressure builds in the airways. The epiglottis and vocal folds open suddenly, allowing for air to rush out with great force. This reflex helps to force any irritant from the larynx and trachea.

FIGURE 5–4 Endotracheal tubes and a laryngoscope. Endotracheal tubes come in varying diameters. Note the inflated cuff on the center tube, which is used to seal the trachea. The laryngoscope includes a light that is used to visualize the back of the pharynx. The blade is used to move the epiglottis to provide a view of the laryngeal folds.

The larynx leads into the trachea. The trachea consists of a series of cartilage rings joined by connective tissue. The cartilage rings are actually **C** shaped, not completely joining in a circle. Like the larynx, the trachea can be palpated in the neck. The individual rings can be identified by sliding a finger gently along the length of the trachea. This structure provides a rigid airway that also allows for movement. The neck can be bent sharply without narrowing the opening of the trachea.

The trachea is lined with a smooth epithelium that has surface cilia. Tiny particles that are able to pass through the nasal passages are caught in the mucus coating this epithelium. The cilia then move the mucus to the pharynx, where it is swallowed, hence providing for one more protective mechanism of the respiratory system.

The trachea enters the chest at about the region of the heart. At this point the trachea branches into two major bronchi. (The singular form of bronchi is *bronchus*.) Each bronchus leads to a lung on opposite sides of the chest (Figure 5–5). These major bronchi branch into smaller bronchi, dividing and entering different areas of the lungs (Figure 5–6). The two lungs surround the centrally located heart.

The bronchi continue to divide into smaller and smaller airways, forming the bronchioles. The bronchioles have smooth muscle in their walls. This smooth muscle can cause the airways to open further or close more tightly. Irritants, such as smoke, can cause the bronchioles to constrict (bronchoconstriction). This protective reflex attempts to keep irritants from the

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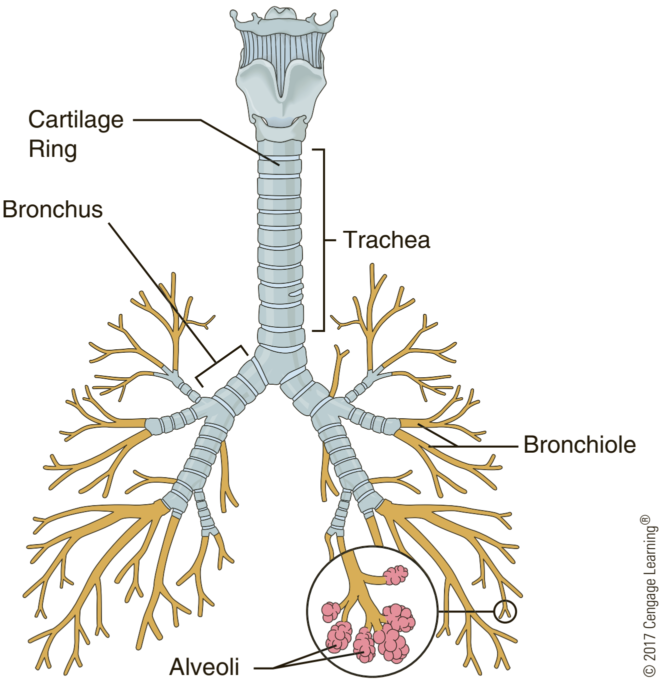

FIGURE 5–5 The lower respiratory tract.

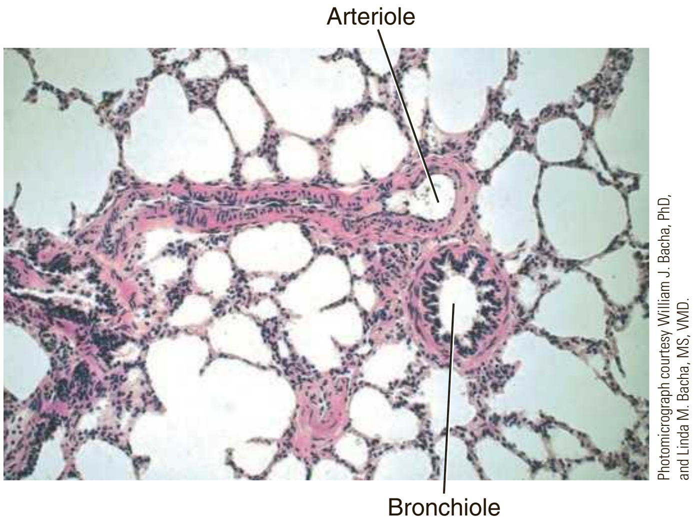

FIGURE 5–7 Photomicrograph of lung tissue showing a cross-section of a bronchiole and nearby arteriole. A large number of alveoli surround these structures. Note the thin wall of the alveoli, which is closely associated with a capillary.

lungs. In contrast, during physical exertion the airways open to allow greater airflow (bronchodilation).

The bronchioles then form into the smallest openings, the alveoli. Gas exchange occurs in these microscopic pouches. A very thin simple squamous epithelium lines the alveoli (Figure 5–7). Capillaries, which also have a very thin epithelium, surround the alveoli. Therefore, the inhaled air comes in close proximity to the circulating blood.

The blood being delivered in the pulmonary circulation is low in oxygen and high in carbon dioxide. The gases exchange readily, with the alveoli delivering the oxygen and retrieving the carbon dioxide. As discussed in Chapter 4, at this location the hemoglobin absorbs the maximum amount of oxygen. The blood entering the pulmonary veins has a high amount of oxygen and minimal carbon dioxide.

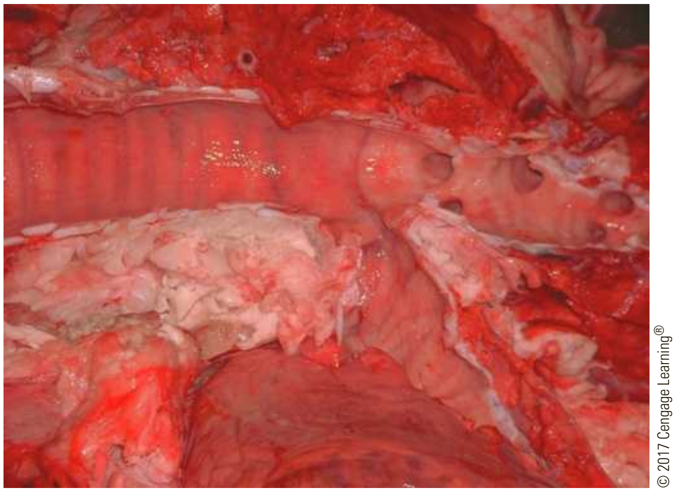

FIGURE 5–6 Trachea opening into the bronchi. The trachea and lung tissue have been incised to expose the openings. Note the tracheal rings and the openings into smaller bronchi.

The lungs produce a product called surfactant, which coats the alveoli. The surfactant, a mixture of lipid and protein, keeps the alveoli from collapsing and makes them much easier to inflate. Consequently, very little pressure is needed to keep the alveoli filled with air. Animals born prematurely may lack adequate amounts of surfactant. This makes the lungs very difficult to inflate, which eventually can be fatal because adequate oxygen is not provided to the tissues. In humans, premature babies are often put on respirators, which deliver oxygen under pressure to the lungs. These babies require the additional external pressure because they are unable to inflate their own lungs. As the babies mature, the lungs produce more surfactant. Eventually, the lungs function without the respirator.

The lungs contain an enormous collection of alveoli, bronchioles, and bronchi. The lungs appear and feel quite spongy because of all the entrapped air. Although many tissues sink when dropped into a beaker of water, lung tissue floats (Figure 5–8). The entrapped air provides the buoyancy to keep the tissue floating. The spongy feel also occurs because of elastic tissue within the lungs. The elastic connective tissue holds all the enclosed airways together. The elastic tissue proves essential in lung function.

A smooth epithelium called the visceral pleura covers the lungs and the parietal pleura lines the inside of the thorax. This anatomy is similar to the two layers

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FIGURE 5–8 The buoyancy of a section of lung.

of the pericardium. A very small amount of fluid is present in the space between the lungs and the wall of the thorax. This fluid provides lubrication as the lungs expand and contract within the chest cavity. In a healthy animal the lungs come in close contact with the chest wall.

MECHANISMS OF BREATHING

Objective

- List and Discuss the Function and Control of Breathing

Breathing allows air to be exchanged between the animal and the environment. This two-step process includes **inspiration**, in which air is taken into the lungs, and **expiration**, in which the air is forced out. When inhaling, the chest cavity increases in volume. This occurs in two ways: first, through movements of the diaphragm, and second, through actions of the intercostal muscles. The diaphragm is the muscular separation between the thorax and abdomen. In a relaxed state, the diaphragm is arched or domed into the thorax. During contraction the diaphragm flattens and pushes toward the abdomen, enlarging the space within the thorax (Figure 5–9). In addition, muscles between the ribs (the external intercostal muscles) contract to raise the ribs, expanding the chest. The effect of the external intercostal muscles can be visualized by raising the handle on a bucket. As the handle is raised there is an increase in the space between the handle and the side of the bucket.

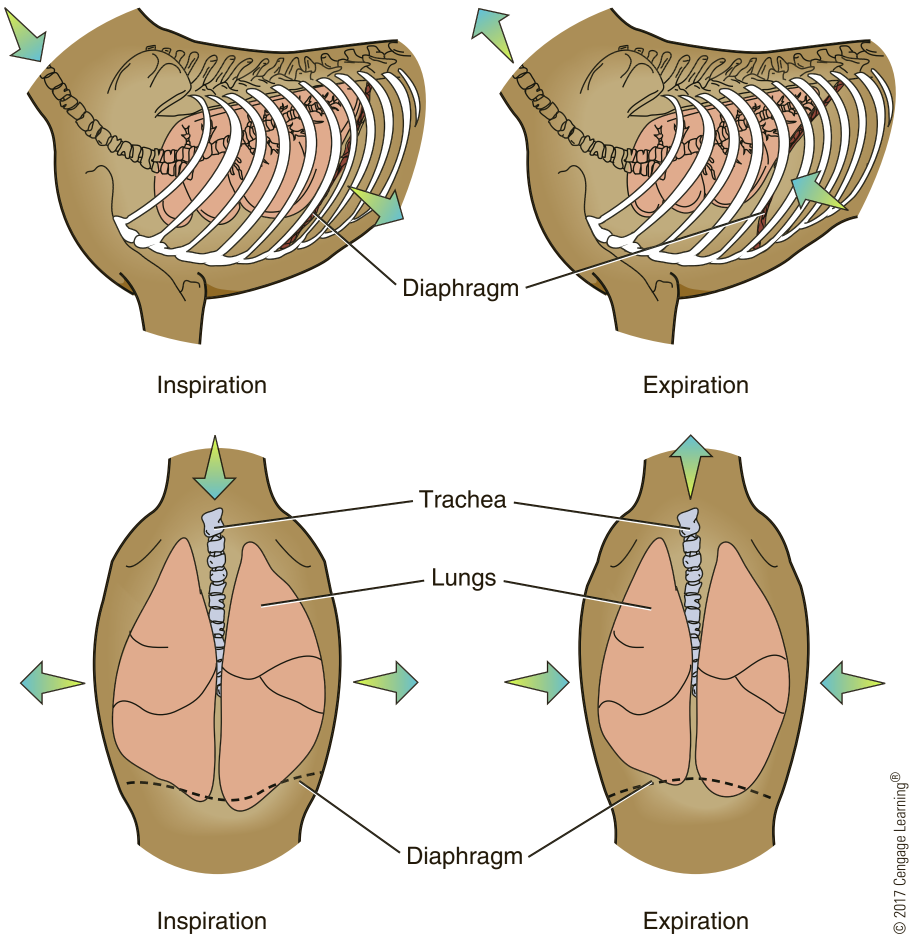

FIGURE 5–9 The mechanisms of breathing. The chest cavity can be expanded by flattening the diaphragm or expanding the rib cage.

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Because all the ribs are connected, this contraction increases the volume within the thorax. Enlarging the thorax lowers the pressure within the space below the level of atmospheric pressure. This in turn allows air from the environment to flow into the lungs. During this entire process the lungs maintain close contact with the lining of the thorax. Inspiration is energy dependent, requiring the activity of muscles.

When the external intercostal muscles relax, the ribs lower. As the diaphragm relaxes, it arches forward toward the chest. The elastic tissue in the lungs recoils, driving out the air. Expiration can be a passive process. By relaxing, the process automatically forces air out. Contracting the internal intercostal muscles and the muscles of the abdomen expends energy to voluntarily increase expiration. This happens during periods of high activity, when the demand for oxygen increases. By initiating this muscle activity, air can be forced outward more quickly and more completely. Even with full expiration there is still air in the lungs as the pressure within the thorax remains slightly lower than atmospheric pressure. This functional residual capacity keeps the alveoli inflated.

The brain controls the normal rate of respiration (Table 5–1). Many factors influence respiratory rate. A hot day or a trip to the veterinarian raises the rates for many otherwise normal animals. Dogs rely on panting for cooling. When panting, the dog breathes very rapidly, which works to evaporate the moisture in the pharynx. Evaporation has a cooling effect. The blood in the vessels of the pharynx is cooled. This cooler blood then circulates through the body to help maintain a normal body temperature.

This basic respiration rate changes in response to the demands of the body. When an animal is more active, the muscles produce more carbon dioxide. The pH of the blood declines as much of the carbon dioxide is converted to carbonic acid. Special receptors in the carotid and aortic arteries detect the decline in oxygen levels, the increase of carbon dioxide, and the decline of pH in the blood. These receptors send signals to the brain. Centers in the brain also detect changes in carbon dioxide levels and a decline in pH. The brain then stimulates a faster respiration rate. The increase in carbon dioxide also stimulates the bronchioles to dilate. This opens the airways and improves the delivery of air to the alveoli.

Surprisingly, oxygen plays only a minor role in the control of respiration. Oxygen levels must fall very low before they stimulate respiration. However, even minor changes in carbon dioxide levels are quite effective in changing respiration rates.

Breathing, an involuntary process, occurs without thought by the animal. Even so, the process can be consciously controlled. For example, humans can intentionally hold their breath. The longer the breath is held, the stronger is the urge to breathe. One evening during small-animal appointments, a young boy proved this point quite effectively. For some reason, he had become upset and held his breath. He overcame the urge to breathe until he passed out! (Most people succumb to the need to breathe long before fainting.) The involuntary process of breathing then took over as soon as he fainted and he recovered. Fortunately, the parents were used to such behavior and did not panic. They understood the natural protection that the body offered. However, the veterinarian's heart and respiratory rates both increased dramatically during that episode!

Table 5–1 Normal Respiration Rates

Animal	Respiration Rate (breaths per minute)
Cat	26
Dog	22
Sheep	19
Cow	30
Horse	12
Human	12
Guinea pig	90
Hamster	74

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CLINICAL PRACTICE

Objective

- Discuss the Clinical Significance of the Academic Material Learned in This Chapter

In the last chapter, mucous membranes were discussed as a means to evaluate the circulatory system. The mucous membranes can also offer information on the respiratory system. If the level of oxygen falls too low, the blood takes on a much darker appearance. When observed through the tissues, it appears bluish. The blue color is termed **cyanosis**. Cyanosis is a definite indication that inadequate oxygen is being delivered to the tissues.

Pneumonia is a disease that produces inflammation in the lungs (Figure 5–10). Usually it is caused by an infection, either bacterial or viral. The differences between bacterial and viral organisms are discussed later in the text. In cattle, a number of viruses and bacteria commonly cause pneumonia. Once the infection invades the lungs, the body's immune system attempts to fight it. White blood cells move into the lungs to attack these invading organisms. Cells and tissue fluid

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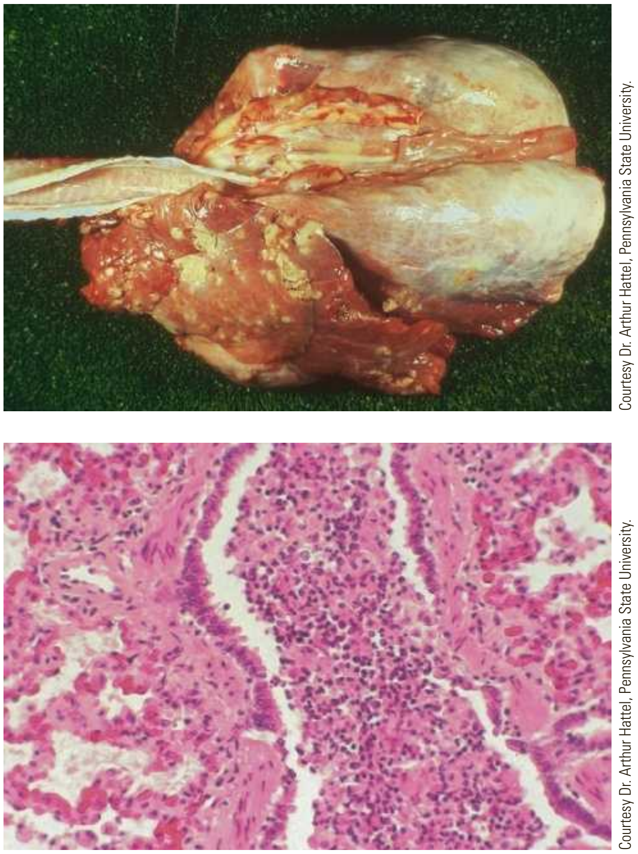

B

FIGURE 5–10 A. Cow lung displaying severe pneumonia. B. Photomicrograph of a cow lung with severe pneumonia. Large numbers of white blood cells are seen in a major airway.

accumulate in the alveoli. This decreases the amount of lung tissue that effectively transfers gases. To compensate, the animal breathes faster and harder.

The cow discussed in the beginning of this chapter had pneumonia. The infection had attacked the lungs and caused such damage that some of the airways had actually opened into the chest cavity. The air from the lungs entered the chest cavity and then diffused into the tissues under the skin. It was one more indication of how severe the damage had become.

The abnormal noise that I heard when I listened to her breathing is called a **pleural friction rub**. The creaking saddle noise told me that the pleurae, the linings of the lungs and chest, were inflamed and irritated. Normally the smooth pleura slides silently without irritation. This cow had pleura that rubbed painfully with each breath. I treated this cow with medicine to reduce inflammation and switched to a different antibiotic. The last time that I spoke with the farmer, the cow was still alive but her productivity remained quite poor.

The stethoscope is used to evaluate breathing. The normal lung sounds are a quiet, wispy noise created by the airflow through the airways. Normal breath sounds can be heard by listening over the trachea or the side of the thorax. The changes that occur with pneumonia can produce abnormal lung sounds. In addition to the pleural friction rub, there are sounds described as crackles, wheezes, and rhonchi. These sounds must be heard to truly appreciate the specific noises.

Crackles are a short, nonmusical sound. Rotating a lock of hair between fingers can give a close appreciation of what a crackle would sound like. The wheeze is a longer, higher pitched noise that has a musical note quality. Rhonchi are a longer sound, similar to a wheeze but without the musical quality. This noise has more of a "snoring" quality. All these noises are very quiet and can only be detected with a stethoscope. Abnormal sounds indicate that there is inflammation, fluid, or both within the lungs themselves.

Much like cattle, cats have their own group of disease-causing organisms. I commonly see cats and, especially, kittens that develop runny eyes, nasal discharge, sore throat, coughing, and sneezing. These animals often spike a high fever and do not eat well. The organisms causing these signs can be highly **contagious**. It is not unusual for all the cats in a household to develop these signs. Most kittens are able to survive with treatment. (It is interesting to note that these signs are quite similar to the common cold in humans. Humans have their own organisms that also attack the respiratory tract and are highly contagious.)

It is not surprising that clinical signs often start in the nose. The nose's ability to filter the incoming air means that it is susceptible to incoming organisms as well. The organism can become trapped in the mucus and then invade the epithelium lining the nasal passages. The hope is that the organism remains localized in the upper airway and does not move into the lungs. Infections in the upper airways can be quite severe at times, but pneumonia is, in general, a more life-threatening problem.

Breathing occurs as the diaphragm contracts and expands the volume within the chest. The diaphragm is a relatively thin sheet of muscle that can be damaged by trauma (for instance, being hit by a car). The muscle can be torn, allowing organs from the abdomen to enter the chest (Figure 5–11), a condition termed diaphragmatic hernia. These abdominal organs, such as the stomach, intestines, and spleen, take up space within the chest that is normally available for lung expansion. This prevents the lungs from expanding fully, and the animal has difficulty breathing.

Diaphragmatic hernia requires surgery to repair the tear in the muscle. An incision made in the abdominal wall helps to locate the tear. The abdominal organs are moved back into the abdomen to their normal location, and the diaphragm is sutured. Once the abdomen is opened, the animal cannot breath on its own. As the animal tries to move its diaphragm, the lungs do not expand, because air is drawn into the chest cavity. The vacuum effect that allowed the lungs to expand is not possible when the chest cavity is open to the

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FIGURE 5–11 Radiograph of a diaphragmatic hernia. Intestinal organs are visible within the chest cavity.

outside air. Once the incision is made, the anesthetist must control the breathing for the animal. Applying pressure to the air entering the lungs does this. The anesthesia machine allows the air to be forced into the lungs (Figure 5–12).


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FIGURE 5–12 An anesthesia machine.

Horses have a well-developed respiratory system that allows them to be excellent athletes. Proportionately, horses have much larger lungs than do similar-size cattle. To be a productive racehorse, the entire respiratory system must work efficiently. In a normal breath the vocal folds open wide to allow air to flow into the trachea without obstruction. Horses can develop a problem in which one of the vocal folds fails to open. This condition of laryngeal paralysis is called **roaring**. As the horse exerts itself, the air being forced through the half-open larynx creates a roaring noise. This condition develops when the nerve stimulating that side of the larynx stops working properly. Occasionally the cause can be traced to some sort of trauma. However, the cause often goes undiscovered. Surgery is required to hold the vocal fold open, once again allowing the air to travel without obstruction.

In Chapter 4, increased cardiac output was discussed in relation to exercise. During racing, a horse's cardiac output can increase six to eight times the output at rest. This change is designed to meet the needs of the active muscle. The pulmonary circulation must handle the same amount of cardiac output. To handle the increased blood volume, the pulmonary vessels dilate and the pressure increases. As a result of the dramatic increase in pressure, red blood cells can leak from capillaries and enter the alveoli. With the horse breathing so heavily, the blood is forced up into the trachea and even out through the nose. Often these horses have decreased performance in their races. This condition has been termed exercise-induced pulmonary hemorrhage. The diagnosis is easy to make if the blood is forced out of the nostrils. In other cases, an endoscope can be passed through the nasal passages after exercise to observe the opening to the trachea and determine if there is bleeding at that level.

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Horses may also develop a disease called **heaves**. Affected horses have coughing, nasal discharge, and labored breathing, and tire easily. This condition could be confused with pneumonia, but it is not infectious. Heaves begin very slowly and are a long-lasting problem. The exact cause is not clear, but exposure to dusts and molds often brings on the clinical signs. Microscopically, horses with heaves show an accumulation of mucus and white blood cells within the bronchioles. In addition, the walls of the bronchioles become thickened. The net effect is that less air is able to enter the alveoli. Medications to open the airways (**bronchodilators**) and decrease inflammation are often quite helpful. It is essential to minimize the exposure of the horse to the potential dusts and molds that initiate the problems. Keeping a horse on pasture can be very effective when attempting to avoid the aforementioned irritants.

As described earlier, the pleura lining the lungs is not attached to that lining the thorax. The space between the pleura is called a potential space, meaning it normally shows very little gap but can become much larger. In a healthy animal, the lungs stay inflated and maintain a close association with the walls of the thorax. However, some disease processes and trauma can cause the lungs to partially deflate, allowing the potential space between the pleura to fill with air or fluid. The dog mentioned in the introductory section had been hit by a car, and air subsequently leaked from its lungs into the pleural space. The lungs partially deflated in a condition termed pneumothorax (Figure 5–13). This condition occurs most commonly with severe trauma or a puncture wound, such as a gunshot. Because the mediastinum does not offer a complete separation of the two halves of the chest, the air is often present on both sides.

The pleural space can also become filled with fluid. In addition to causing pneumothorax, trauma can cause bleeding into the pleural space. An accumulation of blood causing a decrease in the space that the lungs can occupy is called *hemothorax*. Animals that ingest rat or mouse poison are at high risk of developing hemothorax. Many of these poisons cause a clotting disorder. Minor trauma can then result in bleeding into the thorax.

When infection enters the pleural space, a pyothorax can result. In a pyothorax, an accumulation of white blood cells, cellular debris, and inflammatory fluid is found in the pleural space. This condition may develop secondary to a severe pneumonia when bacteria escape the lung tissue and invade the pleura. All of these conditions, in which fluid or gas fills the pleural space, result in a decrease in the space available for the lungs. As a result the animal is less able to oxygenate the blood. Typically, these animals will be quite depressed and have rapid respirations. As the conditions progress, respiratory distress often develops as the animal gasps in an attempt to expand the lungs. Untreated, these conditions can be fatal. Initial treatment is to aspirate the fluid or gas through a needle or tube. This provides immediate relief by allowing the lungs to expand more fully. The underlying condition must then be treated. It is not uncommon for repeat aspirations to be needed.

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FIGURE 5–13 Pneumothorax: Radiograph of a dog that had been hit by a car. Free air in the chest has floated the heart dorsally, no longer showing contact with the sternum.

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SUMMARY

Being able to identify respiratory structures and their associated functions, from the nose to the lungs, allows veterinarians to diagnose and treat such disease conditions as pneumonia and roaring. Moreover, respiratory rate provides a key piece of information to practitioners when assessing the overall health of animals. The status of the respiratory system affects the breathing and therefore the total health of animals.

REVIEW QUESTIONS

1. Define any 10 of the following terms:

   respiration
   palpated
   endotracheal tube
   inspiration
   expiration
   cyanosis
   pneumonia
   pleural friction rub
   contagious
   roaring
   heaves
   bronchodilators

2. True or False: Mucus lines the epithelial tissue in the nostrils.
3. True or False: The cartilage rings of the trachea are shaped like an **O**.
4. The ________ is the common area shared by the nose and throat.
5. The human larynx is sometimes called the ______ .
6. The trachea branches into two ________ .
7. Gas exchanges occur in the smallest openings of the respiratory system. These openings are called the ________ .
8. The muscles between the ribs are called the ______.
9. Name the reflex action that occurs when there is an irritation in the nose.
10. What substance lines the lungs, making them easier to inflate?
11. What controls the rate of respiration?
12. What is the normal respiration rate for a dog?
13. What plays a more significant role in the control of respiration, oxygen, or carbon dioxide?
14. What medical tool is used to evaluate breathing?
15. What species can develop a condition referred to as roaring?

ACTIVITIES

Materials needed for completion of the activities:

stethoscope
balloons
Y-shaped polypropylene connecting tubes

1. Use the stethoscope to listen to normal lung sounds. Have the "patient" take deep, slow breaths. The patient should breathe quietly, not making noise through the nose and mouth. The stethoscope can detect these noises. Listen to different areas on the chest, from both the front and the back.
2. Take two identical balloons and inflate them to different sizes. Slip a balloon onto an end of **Y**-shaped polypropylene connecting tubes. Do not release the balloons yet. Plug the third opening of the **Y** piece. Hypothesize what will happen when the balloons are released. Will the large balloon deflate and fill the smaller balloon to equalize the size? Or will the smaller balloon deflate into the other balloon? Surfactant prevents this problem from occurring between alveoli. Even though the alveoli may be of different sizes, the pressure in each is similar. Without it, the small alveoli would deflate.
3. Observe the respiratory rates of classmates and pets or livestock. Compare to the normal rates listed in Table 5–1.

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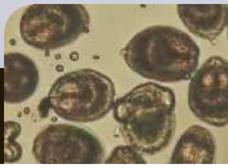

CHAPTER 6

The Renal System

Objectives

Upon completion of this chapter, you should be able to:

- Identify and name the basic structures in the renal system.
- Name and explain the functions of the renal system.
- Identify structures within the kidney and detail the formation and regulation of urine.
- Evaluate urine and blood as a measure of the health of the animal and the urinary system.
- Discuss the clinical significance of the academic material learned in this chapter.

Key Terms

buck	spayed	specific gravity	acute
doe	gout	refractometer	chronic
dorsal	mastitis	free catch urine	subcutaneous
ventral	intravenous	azotemia	skin turgor
retro-	isotonic	parvovirus	
urinary incontinence	urinalysis	uremia	

Introduction

The by-products of metabolism are eliminated from the animal through excretion. In this chapter we investigate the renal system, in which the kidneys produce urine as a means of this elimination.

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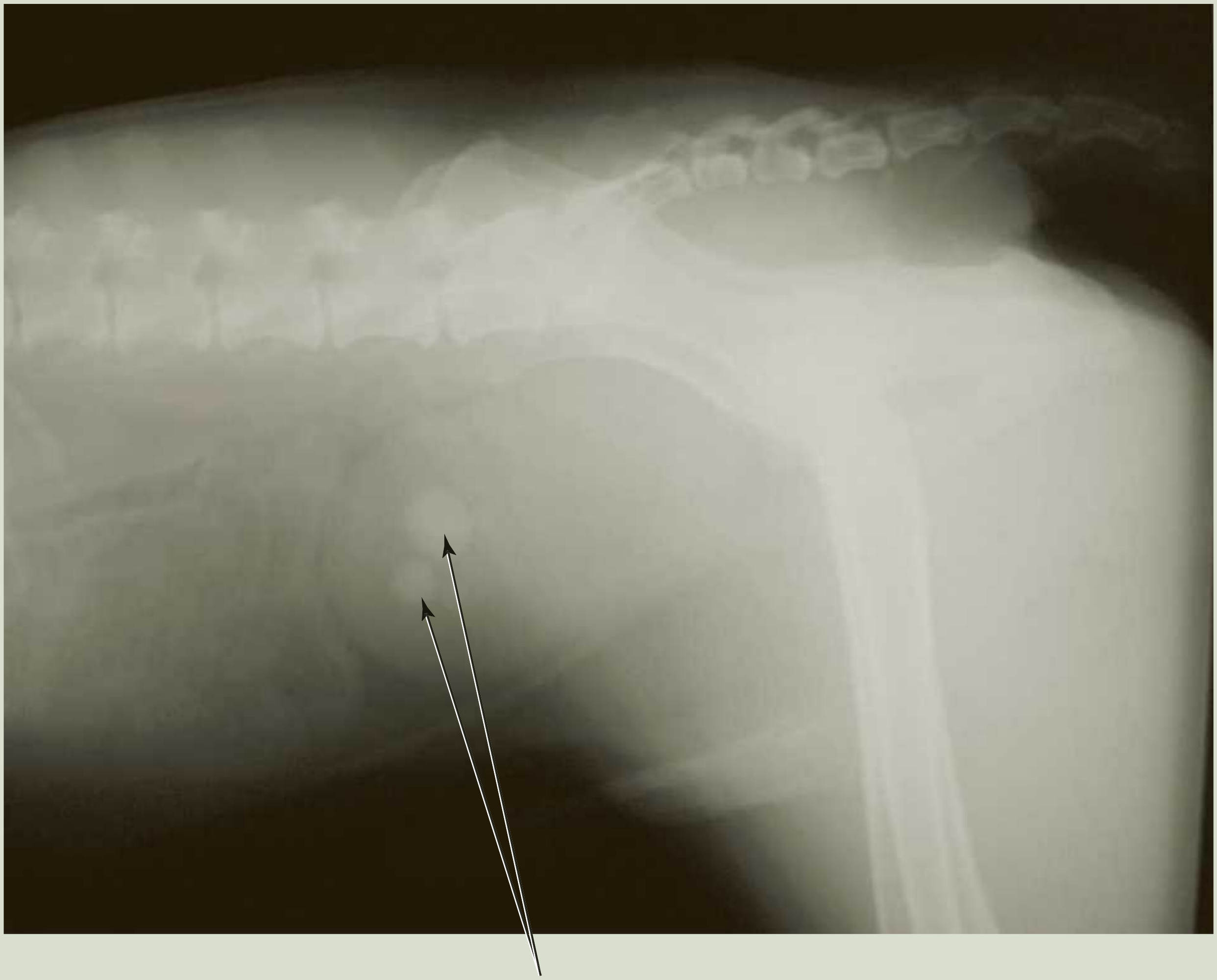
A Day in the Life
Some Procedures are a Group Effort...

It was Friday afternoon. I felt very good as I finished my farm calls. By mid-afternoon I was done for the weekend. I sure was happy to be finished so early in the day, or so I thought. Just before I got back to the office, I received a call. The message stated that Rufus had returned to the office and was having difficulty urinating again. Everyone at the office knew Rufus. A 9-year-old Dalmatian, Rufus had undergone multiple surgeries for stones, which formed in his bladder (urinary calculi). The stones prevented him from urinating properly. My partner, Dr. Brofee, had examined Rufus and found that he had bladder stones once again (Figure 6–1). Dr. Brofee was busy with other appointments for the rest of the day, and the staff let me know that Rufus might need surgery.

When I arrived at the office, Dr. Brofee and I examined Rufus again. We both agreed that Rufus needed surgery. Rufus had suffered from this condition before and had been through two prior operations. With the aid of my assistants, I opened Rufus's abdomen and exposed the urinary bladder. I then incised the bladder and removed three large stones and many tiny pebbles (Figure 6–2). Dalmatians happen to have a much higher incidence of certain stones as a result of their metabolism. Understanding the urine production mechanism and urine products aids in understanding how Rufus's problem developed.

Veterinarians' animals are not exempt from problems. Several years ago, Barney, Dr. Deppen's pygmy goat, was straining to urinate (Figure 6–3). Goats can



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Bladder Stones

FIGURE 6–1 Radiograph of Rufus's abdomen, showing bladder stones.

continues

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A Day in the Life continued

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FIGURE 6–2 Bladder stones removed from Rufus. The rough texture of the stones causes severe irritation to the lining of the bladder.

also develop bladder stones, causing urinary tract obstruction. **Bucks** (male goats) are more susceptible to obstruction than **does** (female goats). The anatomy of these animals makes them prone to this condition. Understanding the differences in the anatomy between males and females helps to explain why the genders are affected differently.

Vanna came to the clinic because she was having accidents in the house. Vanna is a 10-year-old Basset hound. I can understand why the owners were so upset, because Vanna is such a sweet dog. My initial thought was that because Vanna was an old spayed female dog, she was losing control of her ability to hold urine. But as I talked with the owner and examined her, I discovered that Vanna had developed a tremendous

Photograph courtesy Dr. Debra Deppen.

FIGURE 6–3 Barney the goat.

thirst. Any time the owner would fill the water dish, Vanna would drink until she emptied the bowl. I became concerned that a more serious health condition might be causing the problem. I took a sample of blood from Vanna and submitted it to the lab for analysis.

Blood tests and urine tests are common methods used to investigate disease affecting the urinary tract. Understanding how the kidneys function and are controlled aids in interpreting lab test results. This chapter examines the normal function of kidneys and discusses many of the problems that can result from disease conditions. Fortunately, the blood tests did not show any significant problems for Vanna.

RENAL SYSTEM STRUCTURES

Objective

- Identify and Name the Basic Structures in the Renal System

The kidneys produce urine and are located in the **dorsal** part of the abdomen, just **ventral** to and on either side of the spine (Figure 6–4). The peritoneum, a thin sheet of connective tissue, lines the entire abdominal cavity. The peritoneum has a similar structure to the pleura that lines the thoracic cavity and lungs, discussed in Chapter 5. The kidneys actually lie between the peritoneum and the muscles that are adjacent to the spine. Technically, the kidneys are not in the abdomen but are located in the retroperitoneal space (**retro-** means behind).

The kidneys are reddish brown bean-shaped organs. The surface of the kidney in most animals is very smooth (Figure 6–5). The kidney of a cow is as an exception because it has multiple lobes, separated by a groove in the surface of the kidney (Figure 6–6). In the center region of the kidneys, the renal artery and vein, plus the ureter, are present. The renal artery branches from the abdominal aorta and supplies blood to the kidney. As much as 20% to 25% of the blood pumped from the heart each minute travels through the kidney. The renal vein returns the blood that has traveled through the kidney to the caudal vena cava.

A ureter emerging from each kidney is the tubular structure that carries urine to the urinary bladder. Transitional epithelium lines the ureter, allowing for changes in diameter of the opening. The wall of the

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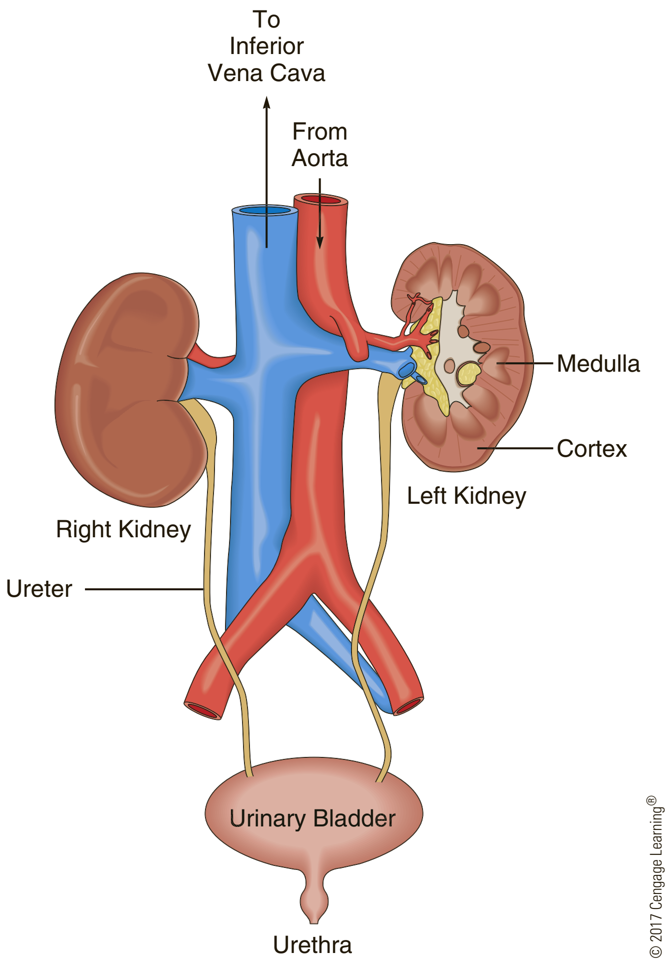

FIGURE 6–4 The renal system.

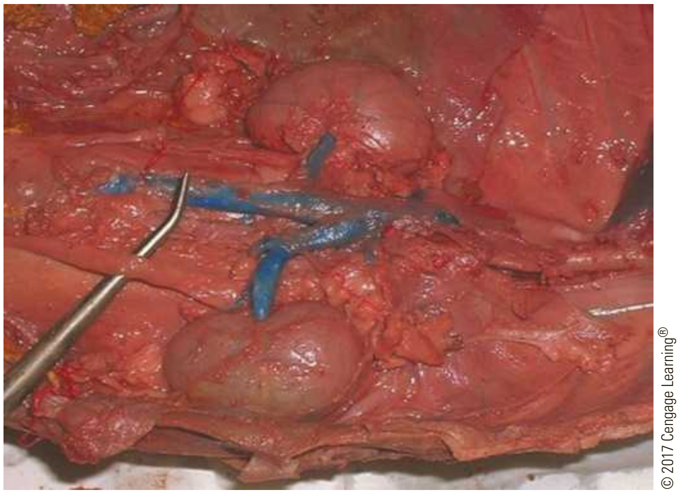

FIGURE 6–5 External appearance of feline kidney. This photograph is of a prepared specimen. The blue vessels are the renal veins and caudal vena cava injected with latex. The ureter passes over the probe.

ureter contains smooth muscle. The urine is actually pushed from the kidney to the bladder by an organized series of contractions. Peristalsis describes this type of contraction. This mechanism allows urine to flow to

FIGURE 6–6 External appearance of bovine kidney.

the urinary bladder regardless of the position of the animal. The ureters enter the bladder at a sharp angle and have a muscular sphincter at the opening. This combination ensures that there is no reverse flow from the bladder toward the kidneys. This physiologic anatomy is very important in protecting the kidneys when the animal has a bacterial infection in the bladder.

The urinary bladder, a hollow organ, has a great ability to expand for storing urine. Transitional epithelium lines the bladder. This epithelium provides the bladder with the ability to stretch as it fills with urine. In the empty bladder, this epithelium appears to be at least six or seven cell layers thick. In the fully distended bladder the same epithelium appears to be only a couple of cells thick. The bladder epithelium also prevents any urine from penetrating into the underlying tissues.

The wall of the bladder contains layers of smooth muscle and surrounding connective tissue. This muscular wall also provides the bladder with the ability to stretch and is responsible for providing the contraction force necessary to empty urine from the bladder. The bladder of an 11-kg dog can easily hold more than 100 ml of urine.

The bladder functions in the collection and storage of urine, but also controls the release of urine. The bladder narrows as it approaches the urethra. The neck of the bladder is encircled by a band of skeletal muscle in the wall, forming a sphincter. This muscular sphincter is under autonomic control but is also controlled consciously. As the pressure increases within the bladder, stretch receptors signal the urge to urinate. The animal can then consciously relax the sphincter. Simultaneously, the smooth muscle in the wall of the bladder contracts, forcing urine into the urethra. The process of releasing urine to the outside is termed urination or micturition.

From the bladder the urethra carries urine to the outside of the body. The urethra also has a muscular wall that allows for control of urine flow. The urethra of a male is much longer than that of a female, which plays a significant role in practice. Females have a

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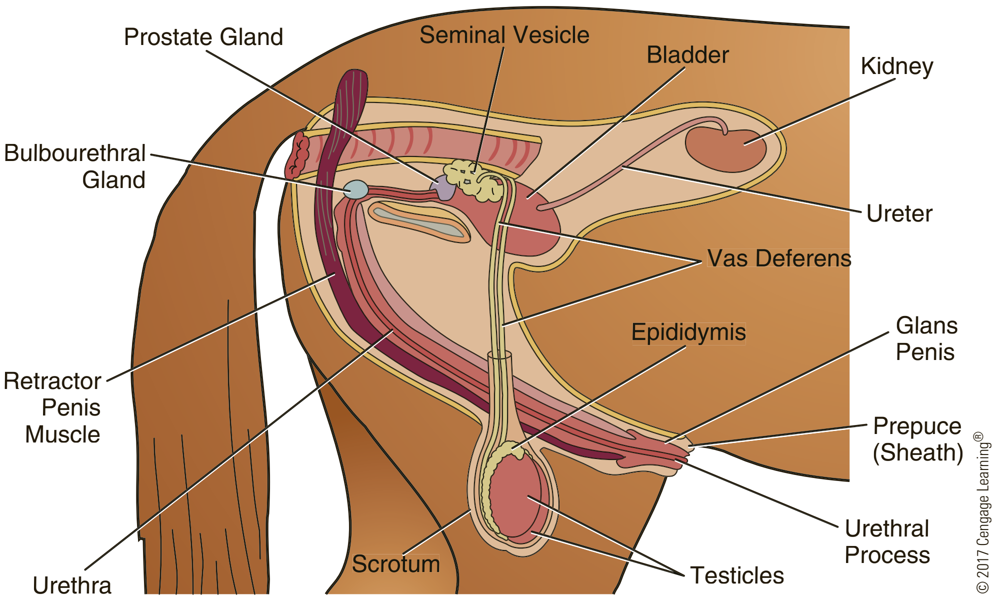

FIGURE 6–7 Urinary and reproductive structures in a male horse (stallion).

higher incidence of **urinary incontinence**. Animals with this condition leak urine at inappropriate times. One common example occurs in elderly female dogs when they are **spayed** (the ovaries and uterus have been removed). These dogs often leak urine while sleeping. Fortunately, they respond to a supplement of estrogen, a hormone normally produced by the ovaries. Vanna, the Basset hound described earlier, responded very well to this medication. Because she was no longer having accidents in the house, she returned to the owners' bedroom to sleep. Likewise, females are more prone to developing bladder infections. Bacterial contamination from the skin near the urethra can migrate into the urethra, causing infection in the bladder.

Males, with their longer and narrower urethra, are much less likely to have bladder infections (Figure 6–7). But as Rufus and Barney illustrate, males are much more prone to having urinary obstruction from small bladder stones. Male dogs have a bone in the penis (called the os penis), through which the urethra passes (Figure 6–8). This portion of the urethra is the narrowest. A small stone can travel from the bladder and through the urethra until it reaches this point. Then the stone becomes trapped, preventing the dog from emptying the bladder. The first surgery that Rufus had was to correct this problem.

Bucks do not have an os penis, but have two regions that may obstruct a stone. The end of a goat's penis has a narrow extension of the urethra. This narrowest portion of the goat's urethra often traps stones. Fortunately, this urethral process can be surgically removed and may relieve the obstruction. Unfortunately, this did not work for Barney.

FIGURE 6–8 Radiograph showing the os penis of a dog. A positive contrast medium had been placed into the bladder to help identify bladder stones.

As the urethra exits the pelvis in goats, it makes a sharp bend in the form of an **S** curve. The sharp curve narrows the urethra to an extent that it, too, may obstruct a bladder stone. A radiograph showed that Barney had a stone lodged in this location. In a team effort, Dr. Griswold and I made an incision directly above where the stone was lodged. This incision was ventral to (below) the anus and directly over the penis. The surgery became relatively bloody as we opened the penis and cut into the urethra to remove the stone. Dr. Deppen then sutured the lining of the urethra directly to the skin. Barney was quite fortunate that the

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incision healed well. After surgery, Barney urinated from the surgical site directly below his anus.

RENAL SYSTEM FUNCTIONS

Objective

- Name and Explain the Functions of the Renal System

The kidneys are often thought of solely as organs that rid the body of metabolic waste. Of equal importance is the critical role of the renal system in maintaining homeostasis. The kidneys are essential in maintaining the balance of water and electrolytes in the body and contribute to the control of acid–base balance. In addition, the kidneys are endocrine organs and aid in the control of blood pressure regulation and red blood cell production.

A primary function of the renal system is to excrete nitrogen-containing wastes from the body. The majority of these wastes arise from the breakdown of proteins and amino acids. As the amino acids are metabolized, ammonia (NH_3) is produced. Ammonia is extremely toxic to tissues. The liver converts ammonia to urea, which is much less toxic to the animal (Figure 6–9). In this process, ammonia combines with carbon dioxide to produce urea.

Nucleotides are also nitrogen-containing compounds. The breakdown of nucleotides results in the formation of uric acid. Mammals have an enzyme that further breaks down the uric acid. Dalmatian dogs are much less able to metabolize uric acid. As a result, the kidney excretes significantly higher amounts of uric acid. The higher amount of uric acid in the urine can crystallize and form a bladder stone. Rufus suffered from this problem. The stones that I removed from his bladder were sent to a laboratory and determined to be urate stones. As a follow-up, Rufus was placed on a special diet that limits the amount of uric acid produced. In addition, Rufus is taking a medication daily that limits uric acid production.

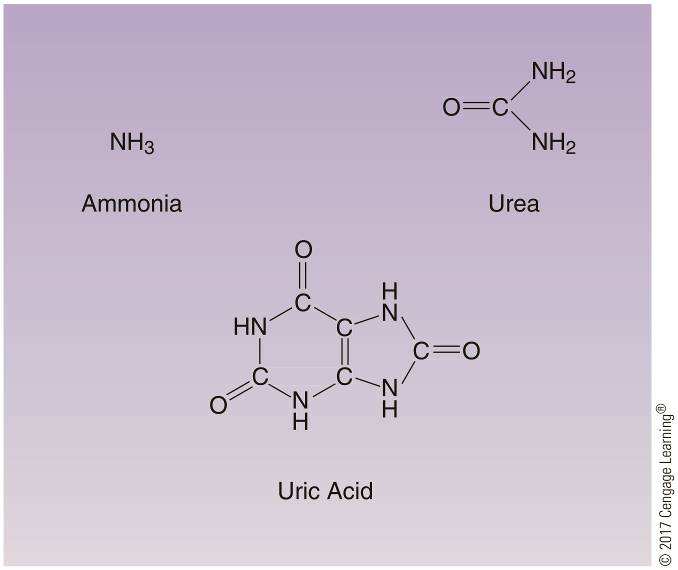

FIGURE 6–9 Chemical structure of nitrogenous waste.

It is interesting to note that although Dalmatians may have serum levels of uric acid up to four times those of non-Dalmatian dogs, human levels reach even higher. Uric acid is relatively insoluble, and when concentrations reach adequate levels, crystals precipitate. This process results in stone formation in the urine. In humans, serum levels can be so high that the crystals deposit in joints. The resulting painful condition is called **gout**.

A third waste product is creatinine, which results from the daily activity of muscles. Creatinine is not significantly affected by dietary intake. However, muscle makeup of the animal does influence the concentration. Males and well-muscled active animals tend to have higher levels of creatinine. Creatinine is almost entirely filtered from the blood in the glomerulus. The level of creatinine in the blood can be a very helpful indicator of kidney function.

As noted, the kidneys help to regulate water balance in the body. In times of need, the kidneys conserve water, making concentrated urine. This need to conserve water may arise because of limited intake or disease condition. Veterinarians often examine animals that are suffering from vomiting, diarrhea, or both. Many of these sick animals take less water into their system and have much higher fluid losses from the vomiting and diarrhea. In these situations the kidneys work to conserve a maximum amount of water.

The kidneys also are essential in regulating the amounts of sodium, chloride, and potassium in the bloodstream. Again, vomiting and diarrhea can increase the loss of these electrolytes, and when this happens the kidneys work to conserve the electrolytes in the blood. Conversely, when intake of electrolytes is excessive, the kidneys allow higher amounts to be excreted in the urine.

Along with the respiratory system, the kidneys aid in the control of pH in the blood. When the blood pH declines (becomes more acidic), the kidneys excrete a higher amount of hydrogen ions. The pH of urine can vary from acidic to basic, as the kidneys help to maintain the blood pH in a normal range.

In addition to producing urine, the kidneys produce hormones that are responsible for controlling blood pressure and red blood cell production. A more complete discussion of this control was presented in Chapter 4. The kidneys are also involved in the regulation of calcium. The kidneys convert vitamin D into its active form, which increases calcium absorption in the intestinal tract. This topic will be further discussed

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in the Chapter 10. Although for purposes of instruction textbooks separate organ systems into distinct entities, there are significant interactions among them. It is the collection of organ systems that makes up the complete functional animal.

KIDNEY STRUCTURES AND URINE FORMATION AND REGULATION

Objective

- Identify Structures within the Kidney and Detail the Formation and Regulation of Urine

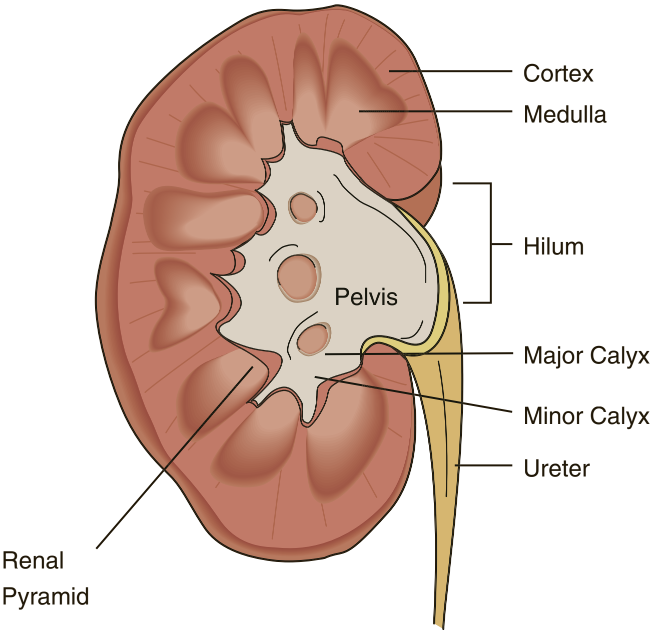
Sectioning through the kidney shows three distinct regions (Figure 6–10). The kidney visually divides into the outer cortex, the medulla, and the innermost renal pelvis. The cortex and medulla of the kidney consists of microscopic nephrons. The nephron, a structural unit, produces the actual urine. The kidney makes urine by filtering the blood in the nephron. Small molecules are passively forced into the filtrate. Large protein molecules, such as albumin, and blood cells do not pass into the filtrate. The final urine produced is controlled by a large amount of reabsorption and secretion performed in the tubules of the nephron.

The nephron is a tubular structure that is closed at one end and opens at the opposite end (Figure 6–11). The closed end of the nephron in the cortex is folded into the structure called Bowman's capsule. Bowman's capsule is wrapped around a bundle of capillaries called the glomerulus. The nephron continues as a tubular structure that divides into three sections.

The first section is called the proximal convoluted tubule. This leads into the long, thin loop of Henle, which reaches into the renal medulla. The loop of Henle makes a sharp turn and returns to the region of Bowman's capsule in the cortex. The tubule then expands into the highly coiled distal convoluted tubule. Many nephrons empty into a collecting duct, which drains the final urine into the renal pelvis.

The entire nephron is tightly associated with blood vessels. In addition to providing the blood that is filtered, these vessels help to reabsorb any useful materials into the bloodstream. Blood enters the kidney through the renal artery. This main artery branches into smaller vessels, forming a huge number of afferent arterioles. The afferent arterioles supply blood to the capillaries of the glomerulus, the site of filtration. These capillaries re-form into an efferent arteriole. This is the only site in the body where an arteriole branches into capillaries and re-forms into another arteriole. The blood in the efferent arteriole is still high in oxygen. The efferent arteriole then supplies blood to capillaries surrounding the tubules of the nephron. It is through these capillaries that oxygen is delivered to the tissue and much reabsorption occurs. These capillaries lead into venules and eventually return blood to the vena cava through the renal vein.

The nephron produces urine through a complicated process. The process begins in the glomerulus, where the afferent arteriole delivers blood into the glomerular capillaries. The pressure within these capillaries forces water and small molecules into Bowman's capsule. The filtrate must pass through the capillary endothelium and the basement membrane of Bowman's capsule.



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A


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FIGURE 6–10 A. Structures of the kidney. B. Sectioned sheep kidney.

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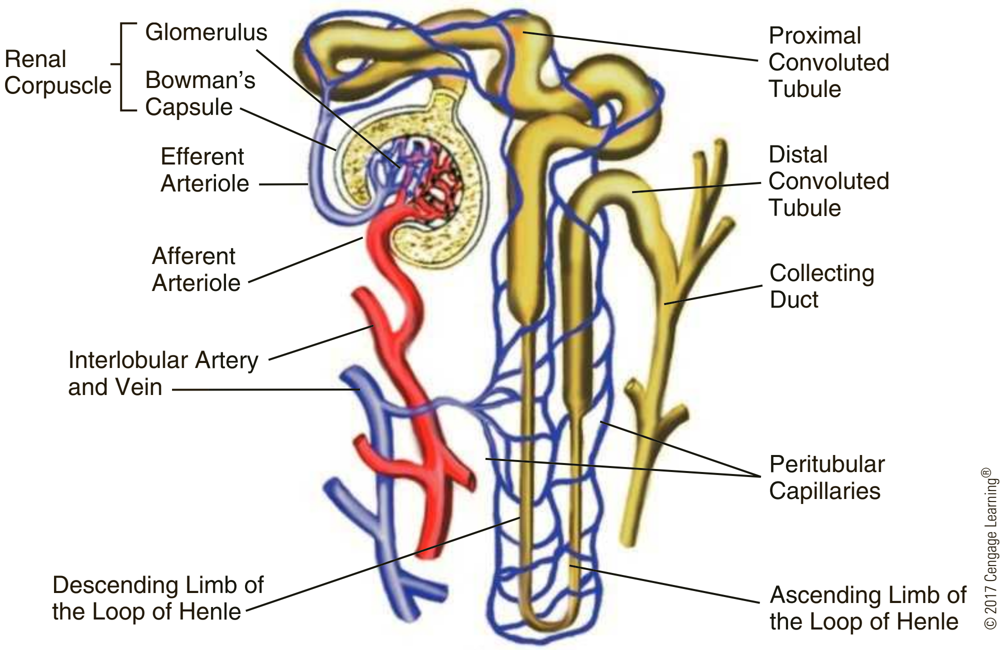

FIGURE 6–11 Structure of a nephron.

Within Bowman's capsule are cells called podocytes, which have footlike processes that wrap around the capillaries. The blood pressure in the afferent arterioles is the driving force for filtration. Oncotic pressure (osmotic pressure caused by the larger protein cells) within the blood and the pressure within Bowman's capsule counteract some of that pressure. The difference between these forces controls the rate of glomerular filtration.

Waste products, water, glucose, amino acids, and the ions of sodium, chloride, potassium, calcium, magnesium, and bicarbonate are all found in this filtrate. Large proteins and cells within the blood are not passed into this filtrate. In this respect the fluid is much like plasma without the blood proteins. It is important to recognize that not all of the water is removed from the blood. Enough liquid needs to be maintained to allow the blood to flow freely through the efferent arterioles and subsequent capillaries.

The filtered fluid then passes into the proximal tubule. The proximal tubule reabsorbs many of the essential molecules. The epithelial cells lining the proximal tubule are rich in mitochondria. These cells use a large amount of energy in the process of active transport. The proximal tubule reabsorbs much of the glucose, amino acids, vitamins, and ions that have made it into the filtrate. Table 6–1 summarizes much of the reabsorption that occurs in the nephron. These products are returned to the capillaries that surround the proximal tubule (Figure 6–12). The proximal tubule is also the region where creatinine and certain drugs and toxins are secreted. The excretion of certain antibiotics

Table 6–1 **Summary of Reabsorption in the Nephron**

Sodium: In the proximal convoluted tubule, sodium attaches to a carrier protein. With energy expenditure the sodium is transported out of the tubule. Glucose and amino acids attach to the protein and are passively transported. Additional sodium absorption occurs in the ascending loop of Henle. In the distal convoluted tubule sodium is exchanged for hydrogen, ammonium, or potassium ions. This is an important site of acid–base regulation.
Potassium: Much of the absorption occurs via diffusion in the proximal convoluted tubule, ascending loop of Henle, and distal convoluted tubule.
Calcium: Similar to potassium, absorption occurs in the proximal convoluted tubule, ascending loop of Henle, and distal convoluted tubule. Calcium absorption is regulated by vitamin D and parathyroid hormone.
Magnesium: Much of the magnesium is recaptured in the proximal convoluted tubules, ascending loop of Henle, and collecting ducts. Parathyroid hormone also controls the amount reabsorbed.
Chloride: Most of the chloride absorption occurs passively to maintain electrical balance with the positive sodium ions absorbed.
Water: Water follows sodium, chloride, glucose, and amino acids by osmosis.
Urea: Because the concentration becomes so high in the filtrate, some urea diffuses into the blood.

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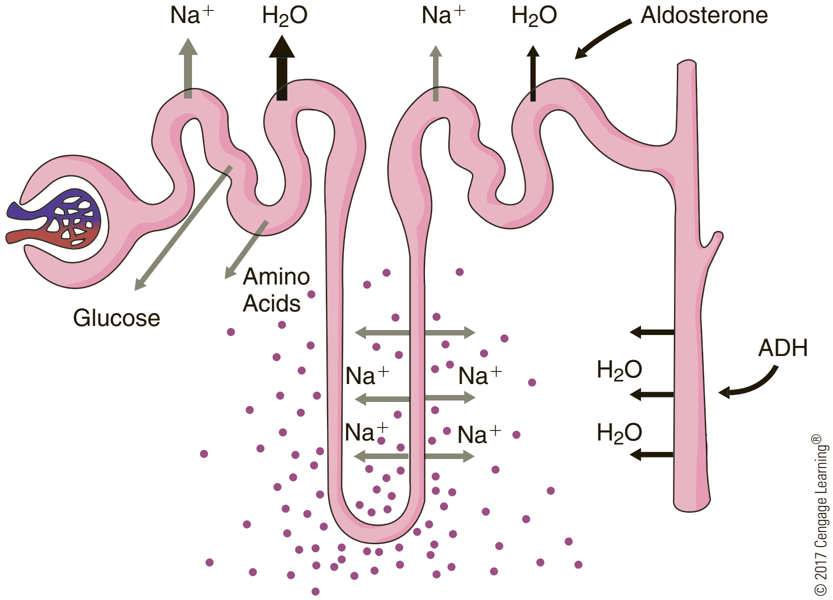

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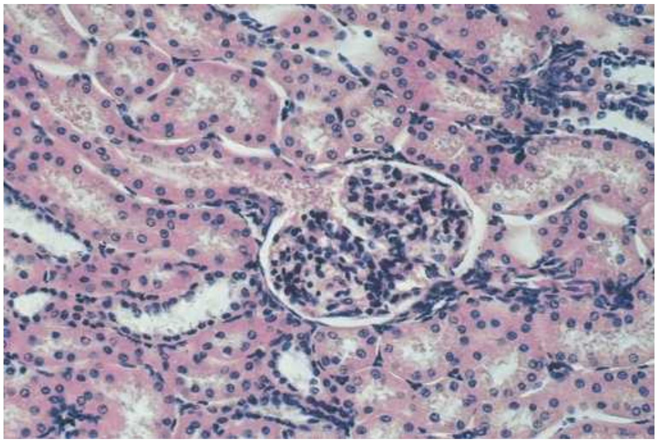
FIGURE 6–12 Function of the nephron. The illustration shows the sites of activity, as well as the target regions for the hormones aldosterone and antidiuretic hormone (ADH).

is used in selecting the appropriate drug for treating a urinary tract infection.

As the solutes return to the bloodstream, water follows by osmosis. More than 80% of the water, sodium, chloride, and bicarbonate ions are reabsorbed at this point. Nearly 100% of the glucose and amino acids are recaptured. Not all the solutes within the filtrate are removed. The concentration of wastes such as urea becomes much higher in this filtrate. As a result, some of these products diffuse into the bloodstream. This is the source of the normal blood levels of urea and other waste products.

The fluid then passes into the loop of Henle, where much more sodium is pumped out of the solution. The epithelium lining the loop of Henle does not allow water to follow the sodium. The extracellular fluid (ECF) in the medulla of the kidney, surrounding the loop of Henle, becomes very salty or hypertonic. The fluid within the tubules, however, becomes highly diluted.

The fluid continues into the distal tubules, where even more sodium is pumped into the ECF. The cells lining the distal tubules and collecting ducts control how much water may leave (Figure 6–13). The ECF in this region exerts a high osmotic force, trying to draw water out of the tubules. The epithelium is made more permeable when the body needs more water conserved. For example, the kidneys of a draft horse pulling a plow all afternoon in the hot sun will attempt to conserve a maximum amount of water. In this horse, the walls of the distal tubules and collecting ducts become very permeable to water, allowing osmosis to pull water into the ECF. In such situations, the urine becomes very concentrated, containing a minimum of water. The kidneys are capable of making urine that is almost four times as concentrated as blood.



Photograph courtesy William J. Bacha, PhD, and Linda M. Bacha, MS, VMD.

FIGURE 6–13 Photomicrograph of kidney tissue showing sections through many of the tubules of nephrons and a region of glomerulus.

The discussion of urine formation to this point has been of filtration followed by reabsorption. The kidney also has the capability of secretion. The distal tubules help to control the pH of blood by secreting either hydrogen ions (H^+) or ammonium ions (NH_4^+). The pH of blood is kept in a very tight range, usually 7.3 to 7.4. In situations in which the blood pH begins to decrease, the distal tubules secrete additional H^+. For each ion that is secreted, a sodium ion (Na^+) is absorbed. Likewise, if the blood becomes more basic (increases in pH), the kidneys secrete additional NH_4^+. Although the pH of blood stays in a very tight range, the pH of urine often ranges from 5 to 8. It is important

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to recognize that the kidneys work in concert with the buffers in the bloodstream (e.g., bicarbonate) and the respiratory control of carbon dioxide levels to maintain the tight control of blood pH.

The distal tubules also secrete excess potassium ions and another form of nitrogen-containing waste, creatinine. In addition, the kidneys remove many drugs and toxins from the bloodstream by secretion.

The collecting ducts empty into the renal pelvis. The pelvis collects the final urine produced and allows it to drain into the ureter. At this point, the urine no longer changes in composition. It moves to the urinary bladder for storage.

As mentioned earlier, more than 80% of the water produced in the filtrate is reabsorbed by the proximal tubule. The amount that is absorbed is selectively controlled in the kidney. Antidiuretic hormone (ADH) is responsible for this control. Receptors in the brain detect when an animal begins to dehydrate (lose too much fluid) by sensing an increase in concentration in the blood. When this occurs, ADH is released by the pituitary gland, which is located at the base of the brain. ADH is carried in the bloodstream to the kidneys, causing the distal tubules and collecting ducts to become more permeable to water. As a result, more water is reabsorbed and the urine produced becomes much more concentrated.

In addition to controlling the kidney by adjustments to ADH level, receptors within the brain stimulate the sensation of thirst. When sodium levels increase, the animal is stimulated to drink. The thirst center can be used to aid in the treatment of animals. Veterinarians may use this technique in cows with severe **mastitis** (infection of the mammary gland). These cows would benefit from large volumes of **intravenous** (in the vein; IV) fluids. Unfortunately, administration of fluids is time consuming and often very difficult to do on a farm. As a substitute, a much smaller volume of a product called hypertonic saline (salt solution; NaCl) may be administered. Normal saline is 0.9%, which is **isotonic** with blood (having the same concentration). When hypertonic saline (7.2%) is administered, the brain detects the increased sodium concentration. The animal is then stimulated to drink. Cows given a hypertonic solution often drink sizable volumes of water, which then is absorbed into the bloodstream. This procedure lets the cow do the work for the vet!

In Chapter 4 the renin-angiotensin system was discussed as a mechanism to help control blood pressure. As blood pressure declines, which might occur with dehydration, the kidney releases renin. This causes angiotensin to be formed and aldosterone to be released from the adrenal glands. (Review Figure 4–16.) The overall result is that the kidneys reabsorb more water and sodium, while excreting higher levels of potassium. This scenario increases the blood volume and, when combined with vasoconstriction, results in increased blood pressure. The net effect is also less urine production.

URINE AND BLOOD EVALUATION

Objective

- Evaluate Urine and Blood as a Measure of the Health of the Animal and the Urinary System

Veterinarians can evaluate urine (**urinalysis**) as a guide to assessing many aspects of the health of an animal. Obviously, the urine reflects the health of the urinary system. Remember that the products of metabolism by other organ systems are also excreted in the urine. Therefore, urinalysis can provide many clues about the overall health of the animal.

Table 6–2 lists the commonly evaluated characteristics of urine along with the normal results expected for dogs and cats. Visually, urine can be judged by color and appearance. Urine is typically yellow and should be clear. The intensity of the yellow color can vary with the concentration of the urine, but the urine should always be clear. Cloudy urine can be an indication of a urinary tract infection.

Specific gravity is the measure of urine concentration. Technically, specific gravity is the weight of a liquid as compared with distilled water. The more concentrated the urine becomes (i.e., the more solute in the urine), the higher the specific gravity. A special tool called a **refractometer** is used to measure specific gravity (Figure 6–14). A drop of urine is placed on the refractometer. The technician holds the refractometer to the light and looks through the viewer. A shadow line is created across a scale that is read as the specific gravity. The number for dogs typically ranges from 1.015 to 1.045. A specific gravity of 1.025 is read as "ten twenty-five."

Table 6–2 Normal Urinalysis

	Dog	Cat
Color	Yellow	Yellow
Transparency	Clear	Clear
Specific gravity	1.015–1.045	1.035–1.060
Volume (ml/kg body wt/day)	20–40	20–30
Glucose	Negative	Negative
Ketones	Negative	Negative
Bilirubin	Negative to trace	Negative
Protein	Negative to trace	Negative to trace
Blood	Negative	Negative
pH	5.0–7.5	5.0–7.5

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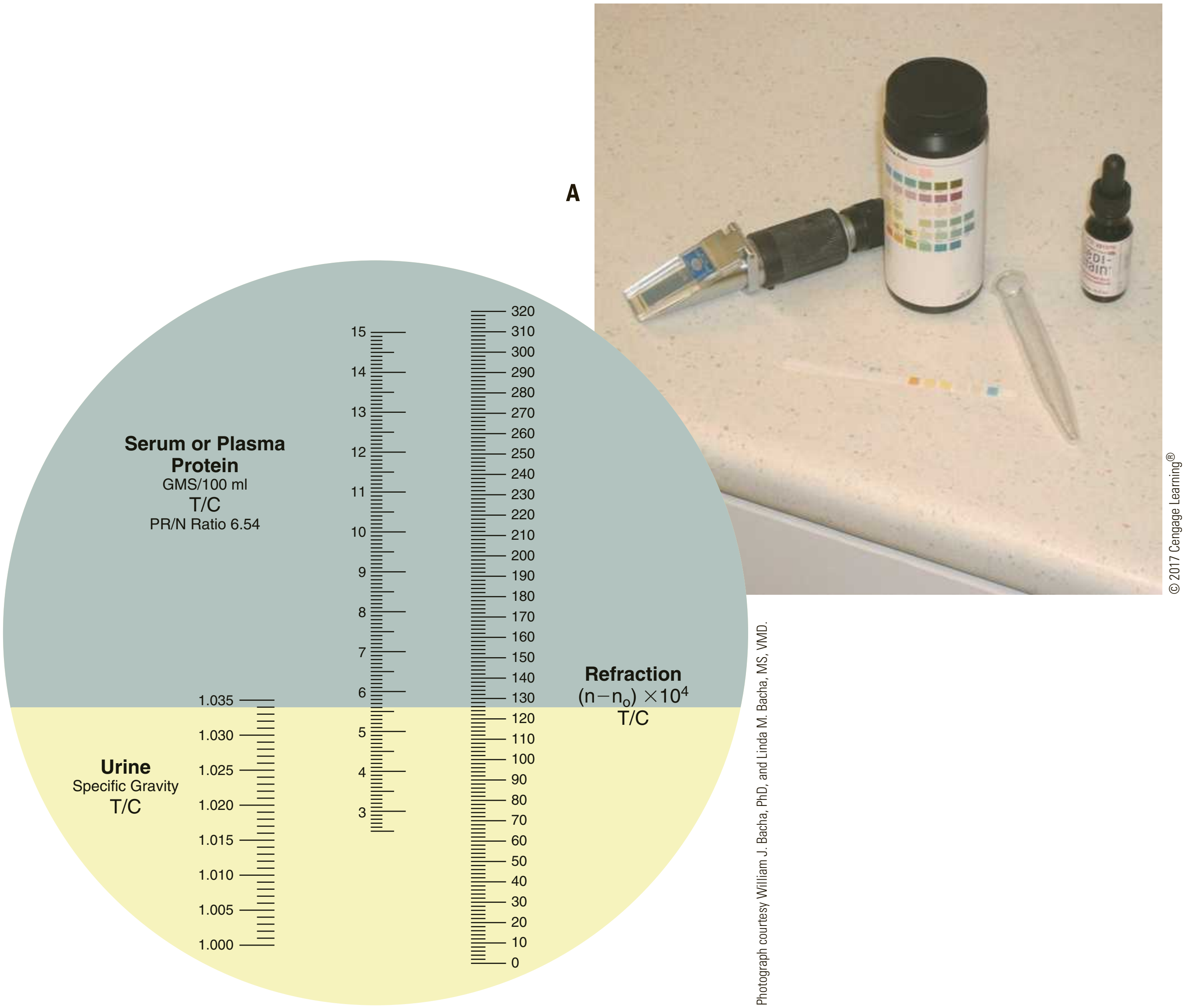

FIGURE 6–14 A. Equipment used in urinalysis. B. A refractometer scale showing a urine specific gravity of 1.034 (far left scale). When measuring protein in serum or plasma, the center scale is used.

Figure 6–14 also shows a standard urine test strip. The strip is dipped into a urine sample, and at the appropriate interval (usually 30 to 60 seconds) the color of the small blocks is compared with a scale on the container. Table 6–3 shows tests that are evaluated with one brand of commercially available strips. A brief description of the significance of each test is included.

Recognize that testing urine reflects the condition of the entire urinary tract and body. The presence of blood, protein, or both in the urine is a very common sign of a bladder infection. However, a positive test does not localize the source to the bladder. The blood could be a result of kidney disease or a clotting disorder in the circulation.

Microscopic evaluation of urine is also performed. The urine is placed in a centrifuge tube and spun for 5 minutes at 1,500 to 2,000 rpm. When it is removed, a small plug of sediment rests on the bottom of the tube. The liquid portion is removed, and a drop of stain is added to the sediment. A drop of this stained sediment is then applied to a microscope slide and examined. A normal urine sample contains a few red and white blood cells, epithelial cells, and crystals (Figure 6–15).

The method by which the urine is collected can influence the number of cells present in the urine. **Free catch urine**, collected while the animal is urinating, may easily contain increased numbers of bacteria. These bacteria are added to the urine by contamination

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Table 6–3 Urine Test Strips: Common Tests and Significance

Test	Significance
Urobilinogen	Used more commonly in human medicine to evaluate liver disease or the breakdown of red blood cells. This test is less useful in veterinary medicine. (The test strips used are designed for human urinalysis.)
Glucose	Used to screen for diabetes. Diabetic animals have elevated blood sugar. The kidneys are unable to conserve all the sugar once the level becomes too high. The test is also used to monitor control of blood sugar once treatment has been started.
Ketones	In dogs and cats, the presence of ketones is typical of an animal with uncontrolled diabetes. Ketones result when metabolism is shifted from carbohydrates to lipids.
Bilirubin	Aged red blood cells are removed from the circulation in organs such as the spleen. Bilirubin is formed in the breakdown process of hemoglobin. Normally, bilirubin is cleared from the blood by the liver and excreted in bile (see Chapter 7). Bilirubin is found in the urine in animals with liver disease or excessive blood cell breakdown.
Protein	Proteins are large molecules that are not normally filtered into the urine. Protein in the urine can be present with a disease of the glomerulus (making it leaky) or with inflammation of the urinary tract (such as a bladder infection). A small amount of protein may normally be detected in very concentrated urine.
Blood	The test strip detects occult blood (i.e., blood that cannot be visibly seen in the urine). Blood can be present in diseases that cause inflammation of the urinary tract, much like protein. Bladder infections, stones, tumors, and trauma (e.g., hit by car) can all cause blood to be present in the urine. Bleeding disorders may also cause the test to be positive.
pH	Urine pH is influenced by diet and disease states in the body. Acidic pH is typical of animals with a meat diet or with acidosis (the kidney attempting to rid the body of excess acid). Basic or alkaline pH is typical of animals with a cereal grain diet, some urinary tract infections, and alkalosis in the body.

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with the skin of the genital region. To avoid this problem, urine may be collected by inserting a hypodermic needle into the bladder and aspirating urine with a syringe. This technique avoids the problem of bacterial contamination but makes an increased red blood cell count much more likely.

A small number of crystals can be a normal occurrence in urine. Excessive numbers of crystals can indicate that bladder stones are much more likely to form. The crystals can be made of molecules of calcium oxalate, ammonium urate, and magnesium ammonium phosphate (struvite). Crystals form when the concentration of a molecule is too high to stay dissolved. Numerous crystals can form.

The presence of crystals in the urine can help to identify animals at higher risk for bladder stones as well as the type of stones present. Some animals with bladder stones do not have serious clinical signs. Certain stones may be able to be dissolved by using special diets and medications. These diets restrict the mineral found in the stone and also adjust the pH of the urine. The pH of the urine influences the solubility of crystals. Proper identification of the stone is important to correctly adjust the urine pH. For example, struvite crystals are high in magnesium and more likely to form in basic urine. A corrective diet would restrict the intake of magnesium and lower the pH of the urine, making the formation of struvite crystals much less likely. Evaluating the urine while treatment is in progress can help monitor the success of that treatment.

In addition to urinalysis, many blood tests are available to test kidney function. Both urine and blood tests can be significant aids in evaluating the condition of the animal. Many laboratories offer a group of tests as a standard evaluation. Commonly, veterinary practices utilize commercial laboratories, which call this group of tests a chemistry profile. However, many practices have this type of testing equipment available at their facilities.

Table 6–4 shows a partial list of the chemistry profile results for Symba, a patient seen at our practice. Along with the test results, laboratories report a reference range—numbers that are normal or average for healthy animals evaluated with that test equipment. A reference range is important because variation occurs with the equipment used and results may vary slightly among laboratories.

With an understanding of how kidneys function and what role they play, interpretation of blood values is possible. Notice that many of the tests have a direct relationship to kidney function. Urea and creatinine are both compounds cleared from the bloodstream by the kidney. Urea nitrogen is measured to determine the urea level in the blood. The kidney also plays a critical

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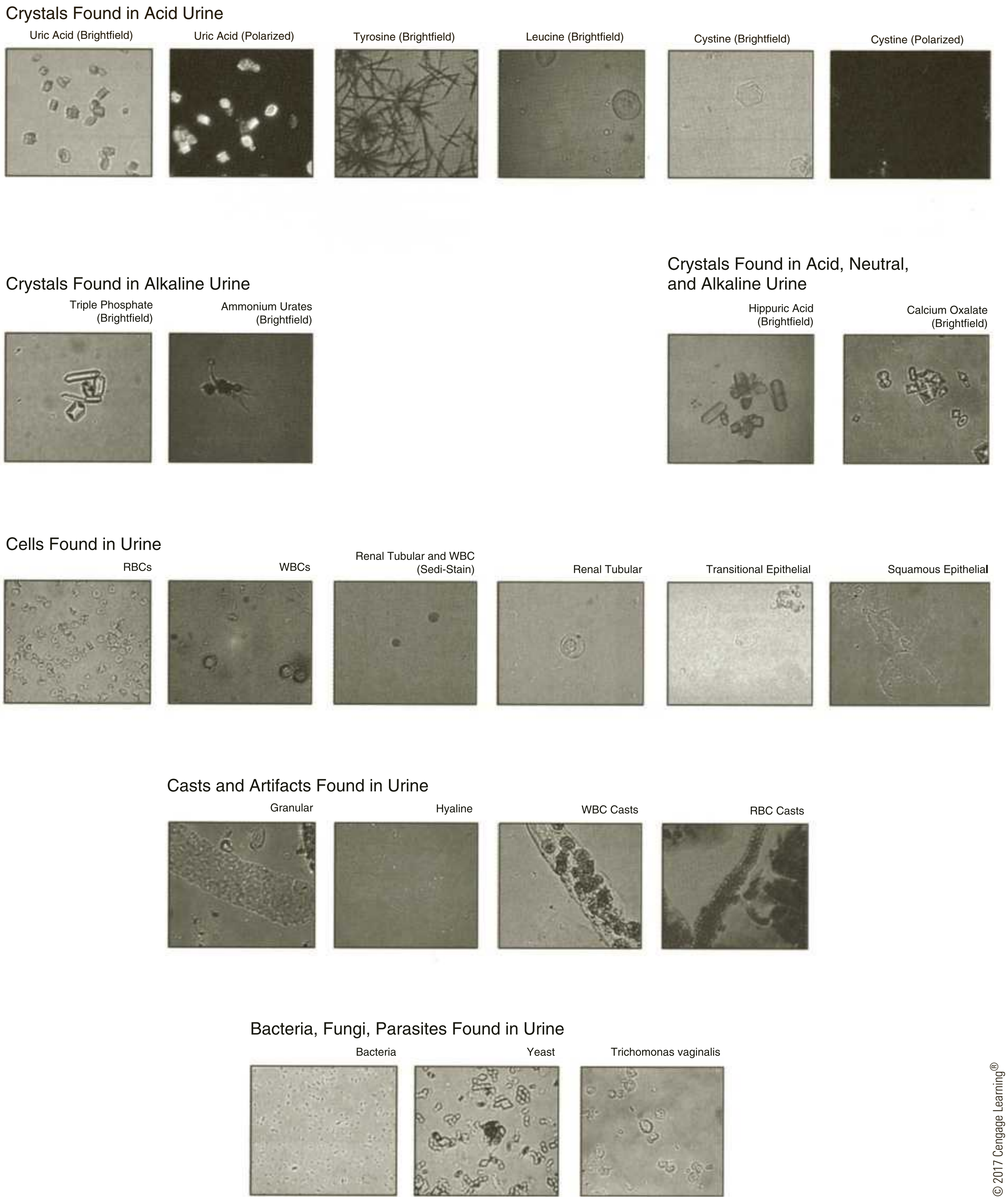

FIGURE 6–15 Microscopic structures commonly found in urine. RBC = red blood cell; WBC = white blood cell.

role in maintaining a normal blood level for the electrolytes (Na^+, K^+, Cl^-, bicarb, Ca_2^+, PO_4^{2-}).

Symba's blood report shows an elevation of both urea nitrogen and creatinine. This is defined as **azotemia**. Azotemia does not necessarily mean that the kidneys are damaged. It can occur when adequate blood flow is not delivered to the kidneys. This prerenal azotemia can result from severe dehydration in the animal. Consider animals with vomiting and diarrhea. These animals lose extra water and cannot take in water naturally, especially when vomiting is severe. The animals often have an increased concentration of protein in the blood. The total amount of protein has not increased, but because there is less water in the blood, the concentration is increased. Urinalysis helps to confirm the diagnosis of prerenal azotemia.

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Table 6–4 Chemistry Profile Results for Symba

	Test Result	Reference Range	Unit*
Glucose	114	65–120	mg/dl
Urea nitrogen	229	6–24	mg/dl
Creatinine	19.7	0.4–1.4	mg/dl
Na^+	144	140–151	mEq/L
K^+	5.7	3.4–5.4	mEq/L
Cl^-	95	105–120	mEq/L
Bicarbonate ion	12	15–28	mEq/L
Cholesterol	233	110–314	mg/dl
Total bilirubin	0.1	0.0–0.4	mg/dl
Total protein	6.6	5.2–7.2	g/dl
Albumin	3.2	2.4–4.3	g/dl
Globulin	3.4	0.9–4.0	g/dl
Ca^{2+}	11.9	7.9–12.0	mg/dl
Inorganic phosphorus	24.1	2.1–6.8	mg/dl

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Numbers highlighted in red are above the normal reference range.

Numbers in blue fall below the normal reference range.

*mg/dl = milligrams per deciliter; mEq/L = milliequivalent per liter; g/dl = grams per deciliter.

If the kidneys are functioning normally, water will be conserved. As a result, the specific gravity of the urine should be high (i.e., very concentrated).

Azotemia can also occur when the urine produced cannot be eliminated from the body. Animals with urinary obstruction develop this postrenal azotemia. We have already discussed dogs and goats with stones causing obstructions. These animals develop postrenal azotemia. As the pressure increases in the bladder, the kidneys are unable to continue producing urine. Eventually, the kidneys themselves will be damaged from this pressure. In this situation, even when the obstruction is relieved, the animal will continue to be azotemic.

Kidneys that are not functioning normally often cause azotemia. This is called primary renal azotemia. The kidneys have a tremendous reserve of nephrons. For primary renal azotemia to occur, more than 75% of the nephrons must be damaged. This reserve allows removal of a kidney in an otherwise normal animal. A dog that has a kidney damaged by trauma or by a tumor can have that organ removed. This dog will function quite normally as long as the remaining kidney is healthy. Blood tests on such an animal would be normal. This remarkable ability also allows kidney transplant patients to receive only one kidney. The newly transplanted kidney has adequate function to support the animal. Kidney transplantation has increased in companion animals, especially cats, in recent years.

The kidneys play a critical role in regulating the mineral content of the blood. When diseases occur within the urinary tract, the concentration of these electrolytes is often disturbed. There is some variation in whether the concentration increases or decreases. The changes are influenced by how quickly the disease develops, where the disease is attacking, and other systems affected (such as vomiting and diarrhea).

CLINICAL PRACTICE

Objective

- Discuss the Clinical Significance of the Academic Material Learned in This Chapter

Symba's blood results show severe azotemia (see Table 6–4). The urea nitrogen, creatinine, and phosphorus are extremely high. Symba, a 2-year-old male mixed-breed dog, was brought to our clinic with vomiting and diarrhea. Symba was up to date on vaccinations, and therefore infectious diseases such as **parvovirus** (a viral disease in dogs causing severe vomiting and diarrhea) were much less likely. The history showed that Symba had been free to roam the neighborhood, which raised the concern that Symba had eaten something that had upset his stomach or gotten into some sort of poison.

The blood tests were taken while we treated Symba for the vomiting and diarrhea. He did not respond to the medications, and the blood results helped to show why. **Uremia** describes the group of clinical signs associated with azotemia. Although Symba presented with what appeared to be a disease of the intestinal tract, the actual problem was caused by kidney disease. Indications of uremia may include one or more of the following: vomiting, diarrhea, poor appetite, bad breath, and lack of energy. The signs that occurred in the intestinal tract were due to the increased concentration of waste products (urea and creatinine). These waste products are toxic to the lining of the entire gastrointestinal tract and may cause the development of ulcers (a defect in the surface), which may even be seen in the mouth.

Symba's presentation was classic for antifreeze toxicity. Many types of antifreeze contain the active ingredient ethylene glycol. The animal metabolizes the ethylene glycol in an attempt to eliminate it from the body. Unfortunately, the breakdown products are toxic to the kidney. Animals find the antifreeze quite

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palatable and are very willing to drink it. Only a small amount of antifreeze is necessary to cause toxicity to pets. The lethal dose of ethylene glycol is 4.4 ml/kg in a dog and 1.4 ml/kg in a cat. Based on this a mature 10-pound cat would have to drink only a little over 6 ml for it to be fatal (10 lb ÷ 2.2 lb/kg × 1.4 ml/kg = 6.4 ml). Care must be taken when antifreeze is changed in a car or if there is a leak in the automobile's system.

The damage can be prevented if the ingestion is detected in time. If the animal is caught drinking the antifreeze, it can be made to vomit. Activated charcoal can also be administered to help prevent more antifreeze from being absorbed into the system. Two antidotes are also available that can be administered to the animal. These keep the ethylene glycol from being metabolized but are helpful only if the problem is detected before the damage to the kidneys is already done.

Symba was in renal failure. Renal failure happens when the kidneys are no longer able to maintain normal function. This function obviously presents as an increase in the nitrogenous wastes and electrolytes within the blood. In addition, the endocrine functions are also affected. Erythropoietin production may also decline, resulting in anemia.

Renal failure can be either **acute** (of sudden onset) or **chronic** (long term). Symba was in acute renal failure. His condition developed very suddenly and was likely due to a toxin. The list of toxins that can cause kidney damage is quite long and includes medications such as acetaminophen. Any factor causing severe inflammation, infection, or loss of blood flow to the kidney can cause acute renal failure. Table 6–5 lists only a small portion of the causes of acute renal failure.

When detected early, the predisposing cause of the kidney damage can be corrected. This correction is specific to the cause. For example, with antifreeze poisoning as previously noted, an antidote can be given to prevent further damage. If the underlying cause is corrected, the kidney may heal. With acute renal failure, it is possible that the animal can recover with supportive treatment.

Lyme disease is commonly reported in humans and dogs in certain regions of the country. A small percentage of dogs that test positive for the Lyme organism (*Borrelia burgdorferi*) develop a severe kidney disease known as a protein-losing nephropathy. In this condition, the integrity of the glomerulus is damaged, allowing protein to escape into the filtrate. Affected dogs have all the evidence of acute renal failure, with elevated blood urea nitrogen (BUN) and creatinine. The dogs typically present with poor appetite, weight loss, and vomiting. The structure and function of the glomerulus is designed to prevent the passage of large blood proteins into the filtrate. Clinical evidence of protein loss by the kidney defines the location and severity of the renal damage. It is important to remember that protein in the urine may also result from damage to the urinary bladder, so a complete evaluation is important.

Table 6–5 Causes of Acute Renal Failure

Prerenal causes resulting in decrease blood flow to the kidney:
Severe blood loss
Dehydration
Heat stroke
Shock
Renal causes:
Toxins (certain antibiotics, cancer drugs, acetaminophen, lead, mercury, ethylene glycol, solvents, snake venom)
Autoimmune diseases
Trauma
Infection
Tumors
Postrenal causes:
Urinary outflow obstructions (e.g., bladder stones preventing urination)

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Chronic renal failure is much more common than acute failure. The classic presentation is an elderly pet that has begun to lose weight and has become lethargic. The owners often report that the pet's appetite has been poor but that it drinks a large amount of water. Along with the excessive thirst, the animal then has to urinate frequently. This is often the first hint to the owners that a problem is developing. A pet that has been housebroken for years and then begins to have accidents in the house or has to get the owners out of bed several times a night may be in the beginning stages of chronic renal failure. Many times, vomiting, diarrhea, or both are associated with the kidney failure as well.

Chronic renal failure develops over a period of months to years. The condition often occurs slowly without any visible indications. Although the animal would not be showing clinical signs, performing a chemistry profile would detect the earliest changes. Typically, urea nitrogen, creatinine, and phosphorus are the first components to increase above the normal reference range. With time, the animal becomes anemic due to the lack of erythropoietin production by the kidney. Over time the values on the profile continue to worsen.

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The failure of kidney function may develop in old age, as the organ's ability to function properly declines and then ceases. Much less commonly, animals may be born with conditions that cause malformed kidneys. These animals develop kidney failure at a young age.

With chronic renal failure, no specific medication corrects the damaged kidney. If detected early, the animal is often placed on a special diet. Remember that the urea nitrogen in the blood is formed from the breakdown of protein in the diet. Therefore, these diets often restrict the amount of protein. Phosphorus is also limited because it is typically elevated in renal failure. However, protein and phosphorus are present in these diets; they are just kept to minimal levels to support the animal. It is important to monitor blood pressure in these animals as well. Because the kidneys play a role in blood pressure regulation, disease conditions of the organ may result in an elevation of the pressure. Conversely, persistently elevated blood pressure will result in further damage to the kidney, speeding the course of renal failure.

A complete cure of chronic renal failure requires a kidney transplant or dialysis. The use of transplants has proven easier in cats than in dogs. Both procedures are quite expensive and at this point are still being performed only in specialty practices.

Dehydration may occur in either acutely or chronically dehydrated animals. In companion animals the two most common treatments are **subcutaneous** (subQ) or intravenous (IV) fluids. Dogs and cats have loosely attached skin that allows relatively large amounts of fluids to be given in one location. The fluid then slowly absorbs into the circulation. SubQ fluids are typically used when the treatment is expected to be of short duration. A catheter is used to enter a vein. The catheter has a needle to allow the vein to be punctured and a soft plastic tube that gets threaded into the vein. The softer portion prevents any damage to the animal, because the catheter remains in the body for extended periods.

Veterinarians are often faced with the need to evaluate the dehydration status of an animal. Laboratory tests are very helpful. When on a farm, vets normally do not have the luxury of these tests and often have to make decisions based on the appearance of the animal. Three factors are typically evaluated on the animal: position of the eye in the socket, skin turgor, and mucous membranes.

As the animal dehydrates, the eye sinks farther into the socket. There is a fat deposit behind the eye, and as the water leaves the fat, the eye settles deeper into the socket.

Skin turgor is a measure of how quickly the skin returns to its normal position when pinched. The more dehydrated the animal, the slower the skin returns to normal.

Table 6–6 Estimating Dehydration

Percent Dehydration	Clinical Presentation
6–7	Eyes slightly sunken, skin turgor slightly slower, moist membranes
8–9	Eyes obviously sunken, skin turgor obviously slower, membranes tacky
10–12	Eyes deeply sunken, skin very slow to return to normal position, membranes dry

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Feeling the mucous membranes on the gums is also helpful in detecting dehydration. Normal mucous membranes are moist. As dehydration worsens, they become tacky and then dry. Table 6–6 provides a guide to estimating dehydration.

Once the percentage of dehydration has been estimated, the amount of fluid required to correct the problem can be calculated:

Percent dehydration × Body weight in kg × 1,000 = Replacement volume (ml)

This volume is generally given over the first two to four hours after diagnosis. In addition, the fluid treatment must continue to meet the current demands of the animal. Maintenance in the normal animal is 20 to 25 ml/kg/day.

An example may help to illustrate the necessary calculations. Sparky, a 20-kg Australian shepherd, presents with a severe vomiting problem. The owners caught the problem early, and you estimate that he is 6% dehydrated. You decide that he should be kept from food and water for the next day to rest his stomach. How much fluid will he require over the next 24 hours?

Replacement volume = 20 kg × 6% dehydration × 1,000

Replacement volume = 20 × 0.06 × 1,000

Replacement volume = 1,200 ml

Maintenance volume = 25 ml/kg/day × 20 kg

Maintenance volume = 500 ml

Total first day requirement = Replacement volume + Maintenance volume

Total first day requirement = 1,200 + 500

Total first day requirement = 1,700 ml

This amount may actually have to be increased if there is excessive loss of fluid from vomiting or diarrhea.

Much of our discussion has revolved around bladder stones in dogs and goats. Male cats are commonly affected by urinary obstruction as well. Inexperienced

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cat owners often call, complaining that their cat is constipated. They see the cat sitting in the litter pan straining without success. The owner assumes that the cat is having trouble defecating. The more common problem is that these cats are straining to urinate. The narrow urethra in the penis becomes obstructed with a plug of crystals, blood, cells, and matrix. If left unattended, this condition can be life threatening.

The diagnosis is usually quite straightforward. The cat will present with a very painful abdomen and a huge bladder. These cats are generally sedated or anesthetized, and the urethra is flushed until the obstruction is relieved (Figure 6–16). The length of time that the cat has been unable to urinate then guides further treatment. In severe cases, acute renal failure is developing and must be treated. These cats must be monitored for recurrence, which can be quite common.

Prevention is aimed at controlling the diet. Diets are designed to control the mineral content of the urine and also maintain an acid pH. In addition, stimulating increased water consumption helps to dilute the urine. These features attempt to minimize the formation of crystals. Many cats develop the problem again even with a special diet. Special surgery is available for these problem cats. The surgery is called a perineal urethrostomy. The basic procedure is to amputate the penis, eliminating the narrowest part of the urethra. The remaining urethra is sutured to the skin, creating a much larger opening for the cat to urinate.

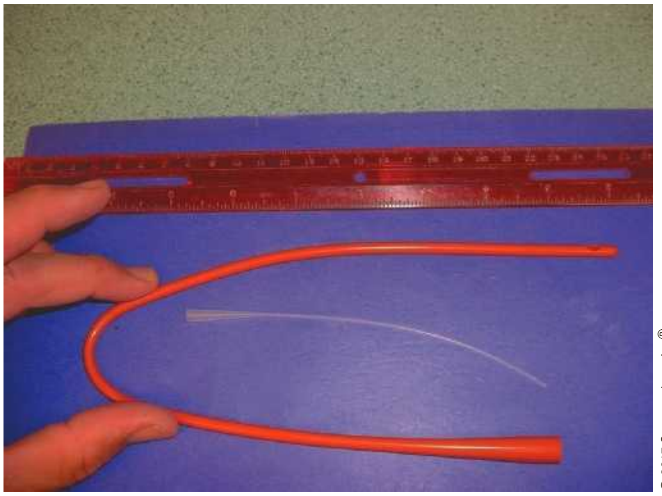

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FIGURE 6–16 Urinary catheters. The larger red rubber catheter would be used on a large dog. The small white catheter is a type commonly used to catheterize male cats.

SUMMARY

The renal system, including the kidneys and bladder, allow for waste products of body functions to be eliminated in the form of urine. Evaluation of urine can provide valuable insight into the status of the renal system and the total health of the animal. Veterinarians use knowledge of the renal system to successfully treat such problems as dehydration, acute and chronic renal failure, and bladder stones.

REVIEW QUESTIONS

1. Define any 10 of the following terms:

buck	urinalysis
doe	specific gravity
dorsal	refractometer
retro-	free catch urine
urinary incontinence	azotemia
spayed	parvovirus
ventral	uremia
gout	acute
mastitis	chronic
intravenous	subcutaneous
isotonic	skin turgor

2. True or False: Urine becomes more concentrated during times of excessive hydration.
3. When sodium levels increase, an animal is stimulated to ___.
4. When an animal's kidneys no longer function, the animal is said to be in ___ failure.
5. What tubelike structure connects the kidney to the bladder?
6. Do males or females have a higher incidence of urinary incontinence?
7. What breed of dog has a history of difficulty metabolizing uric acid?
8. What tool measures specific gravity?
9. What is the name of the test that evaluates urine?
10. What dietary component may be limited in animals with chronic renal failure?
11. Can azotemia result from dehydration?
12. What is the primary function of the renal system?
13. Dogs that test positive for the Lyme organism *may*/*always* show signs of severe kidney disease. Select one.
14. Name the two systems that control blood pH.
15. List two symptoms of parvovirus.

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ACTIVITIES

Material needed for completion of activities:

metric-to-English conversion (1 kg = 2.205 lb)
English-to-metric conversion (1 oz = 29.57 ml)
beaker, at least 100 ml
urinalysis kit with simulated urine

Earlier in this chapter, it was stated that the bladder of an 11-kg dog can easily hold more than 100 ml of urine. Convert the weight of the dog from kilograms to pounds. Look at a 100-ml beaker to see the potential size of the dog's bladder. Monitor your fluid intake for a 24-hour period. Calculate intake on a weight basis (i.e., divide the total fluid intake in milliliters by body weight in kilograms). Does this number come close to the 20- to 25-ml/kg/day requirement in animals? You may find you have consumed more or less fluid than the 20 to 25 ml/kg/day needed by the body. Voluntary consumption often exceeds this amount. The kidneys are able to excrete the excess volume. Remember that water is also taken in during consumption of food. For example, soup adds fluid to the diet, much more than French fries.

1. Perform a urinalysis using a simulated urinalysis kit, which can be secured from numerous educational lab supply companies. These kits typically contain simulated urine along with the necessary supplies to test for color, pH, specific gravity, glucose, and protein. Many kits have simulated urine containing abnormalities as well.
2. You can test your own skin turgor by gently pinching a fold of skin on your arm. Normally, the skin snaps back into its normal position immediately. The more dehydrated you are, the slower the skin returns to normal.

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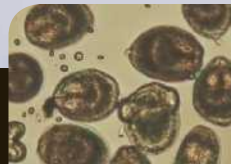

CHAPTER 7

The Digestive System

Objectives

Upon completion of this chapter, you should be able to:

- Identify the basic structures of the digestive system.
- Explain digestion in monogastrics, including:
  - exocrine secretions and function.
  - digestive tract function.
  - digestive tract absorption.
  - role of the liver in digestion and metabolism.
- Compare and contrast the specialization of dentition and digestive tracts found in the various domestic species.
- Define symbiosis and describe its significance in the ruminant.
- Discuss the clinical significance of the academic material learned in this chapter.

Key Terms

intussusception
colic
carnivore
herbivore
deciduous teeth
peristalsis
monogastric
phenobarbital
symbiosis
rumination
eructate
retching
vestibular system
bloat

Introduction

Digestion is the process in which food is taken into the body and broken down mechanically and chemically into small molecules. These building blocks can then be absorbed into the bloodstream and used for cellular metabolism. The process that accomplishes this is complex. The remnants of nonnutritious portions of the diet are then eliminated from the body.

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A Day in the Life
Rocks, Socks, and Underwear . . .

It is funny how my mind works sometimes. I was getting ready to do surgery this morning and I thought of my high school biology teacher. He introduced our class to the word *gravy-splasher*. When we were given a new large term to learn, he called it a gravy-splasher. He said that we could tell our parents about it at supper and they would be so impressed that they would drop their spoons in their gravy!

The gravy-splasher that came to mind today is **intussusception**. Toby, a year-old Jack Russell terrier, was on my list for neutering. I had seen Toby almost six months earlier for a severe vomiting problem. Toby had been vomiting all day and was noticeably uncomfortable. He was acting like his belly was hurting. When I palpated his abdomen, he winced. I was able to feel a thickening in one region of his intestine.

I was concerned that he might have eaten something that was trapped in his intestine. I obtained a radiograph of his abdomen but could not identify a foreign body. The thickening felt like a firm tube in the middle of his abdomen. His clinical signs, the vomiting and pain, along with the feel of his abdomen made me suspect an intussusception. An intussusception occurs when a region of the intestine begins to telescope into itself (much like the toe of a sock turned into the remainder). I discussed the options with the owner, and we elected to do exploratory surgery on Toby.

Dogs are incredibly intelligent animals, but sometimes they just do some dumb things. In the few short months since I began writing this text, veterinarians at our office have removed rocks, plastic wrap from packaged chicken, the tip of the nipple from a baby's bottle, and a pair of underwear—all from the gastrointestinal tracts of pets (Figure 7–1).

Buck is a 2-year-old Labrador retriever with an unusual desire to eat clothing. Dr. Griswold had received the call that Buck had vomited a sock two days earlier but was still not eating well. Buck continued to vomit even after getting rid of the sock. Buck eventually required surgery to have the underwear that he had also eaten removed from his small intestine. In the two months since his surgery, we have received two more calls from Buck's owner. In spite of the owner's best efforts to keep all clothes away from him, Buck has managed to eat socks twice more. Once we were able to make him vomit the sock, and the second time it passed through in the stool.

Vomiting and diarrhea are extremely common problems encountered in small animal medicine. There are numerous causes for these problems. Parasites, infectious agents, and poor diets can all contribute to vomiting and diarrhea. Dogs and cats often eat foods that upset their gastrointestinal tracts. A common source of stomach upset in pets is table scraps. This problem is especially common immediately after holidays, when families have big meals.

My practice does very little equine work. However, we still receive calls from owners whose horses are suffering from **colic**. *Colic* is a general term referring to

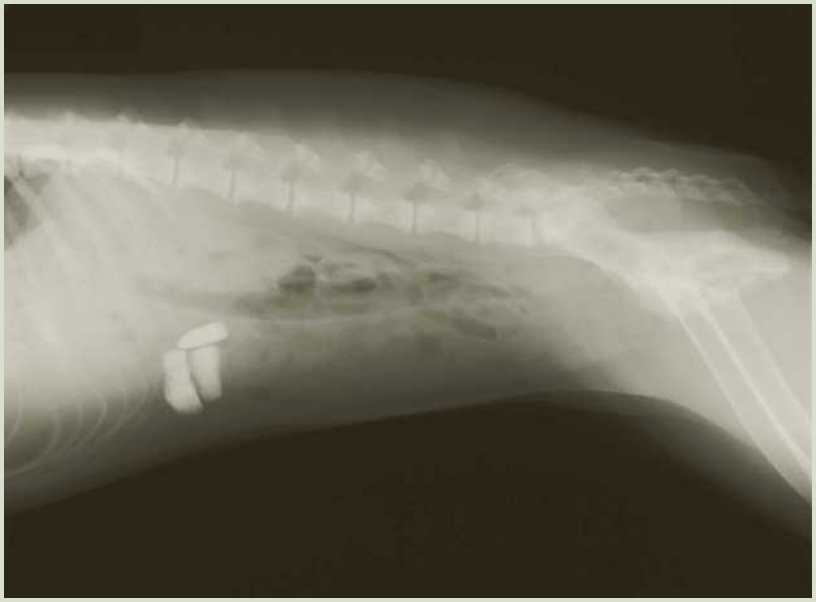

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FIGURE 7–1 Radiograph of dog that had ingested rocks.

continues

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A Day in the Life continued

abdominal pain. Colic generally reflects a problem with the gastrointestinal tract but is not a specific disease; it is a common problem in horses. Horses with colic kick at their abdomens, lie down, get up, or roll in an attempt to relieve pain. Often these horses sweat profusely and have very high heart and respiratory rates.

I see many animals every week and honestly I can't put a name with every case. But there are many cases that stand out. Often this is because the pet is extra special, or the owners are great, or the case is complicated and has an extensive workup. Morris's case was one that had all of these attributes. Morris, a 10-year-old domestic shorthair cat, was just as cool as his owners. I had been seeing Morris for many years and noticed on his yearly checkup that he was losing weight. The owners noted that he was slowing down a bit, but had attributed it to old age. I wasn't comfortable with his weight loss, and we elected to do some blood testing in an attempt to determine the cause of his weight loss. Unfortunately, Morris was showing evidence of liver disease on these blood tests. This weight loss was not just old age; Morris had a problem that we needed to treat.

DIGESTIVE SYSTEM STRUCTURES

Objective

- Identify the Basic Structures of the Digestive System

The mouth or oral cavity is the beginning of the digestive tract. The oral cavity includes the lips, teeth, tongue, hard and soft palates, and salivary glands. This combination of structures is essential for gathering food and beginning the process of digestion. The term *prehension* describes the act of taking food into the animal's mouth. Whereas carnivores may use their teeth to tear the flesh of an animal, horses have very mobile lips to gather food, and cattle use their tongues aggressively to pull food into their mouths.

Teeth are used to gather, cut, and grind the food. Differences in teeth are quite noticeable when comparing a **carnivore** (such as a dog or cat) with an **herbivore** (such as a cow or horse) (Figure 7–2). The wild carnivore must capture prey and tear the flesh from the carcass. In contrast, the herbivore grazes on plant material that must be ground extensively. The teeth and jaw structures are adapted to their diet. Table 7–1 compares the number of teeth present in each species.

The teeth are firmly embedded in bone, the upper teeth in the maxilla and the lower teeth in the mandible. The crown of a tooth is the portion above the gum line or the gingiva (Figure 7–3). The root is the portion below the gum line anchoring the tooth in the bone. Many teeth have more than one root. The crown is covered with enamel, which is the hardest substance in the body. Dentin lies below the enamel and makes up the majority of the crown and root. The mineral content of dentin is very similar to that of bone. The nerve, artery, and vein that supply each tooth enter through the end of the root and into the pulp cavity.

Some newborn animals have teeth erupted from the jaw at birth. Other teeth enter the mouth as the animals mature. The initial set are called **deciduous teeth**. As an animal matures, the deciduous teeth are replaced by larger permanent teeth. This process allows the

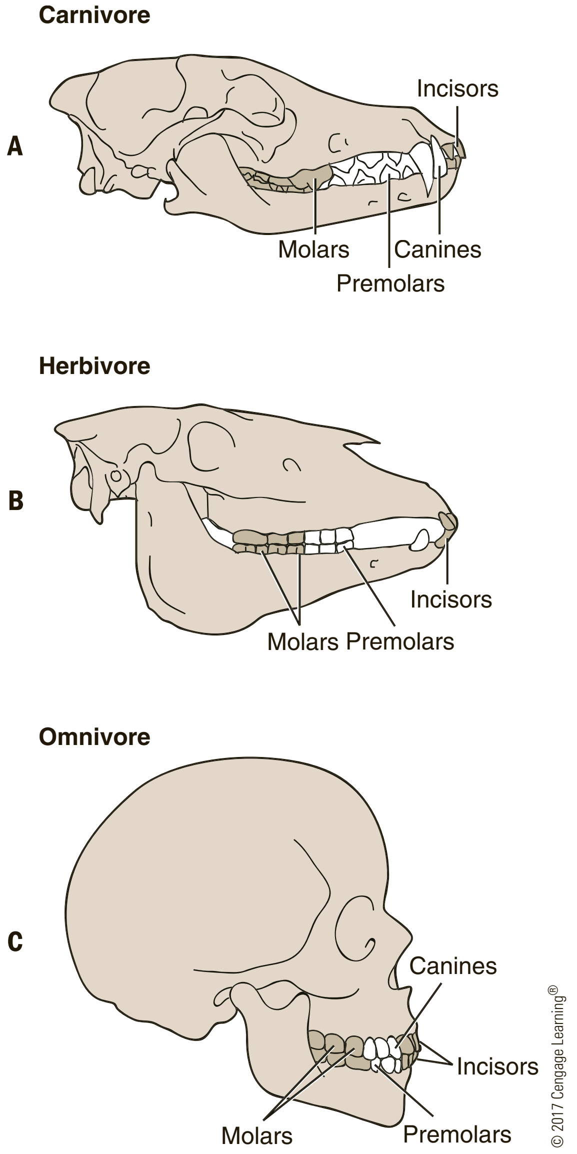

FIGURE 7–2 Comparison of skull and teeth. A. Carnivores (e.g., dogs and cats) have pointed canines and incisors for obtaining and tearing flesh. Sharp molars and premolars are essential for shearing flesh. B. Herbivores have teeth adapted to biting off plant material and then grinding the food into smaller pieces. C. Omnivores, such as humans, have teeth adapted for eating a variety of foods.

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Table 7–1 **Comparison of Dentition between Species***

		Deciduous				Permanent			
		Incisors	Canines	Premolars	Molars	Incisors	Canines	Premolars	Molars
Dogs	Upper	3	1	3	3	1	4	2	
	Lower	3	1	3	3	1	4	3	
Horses	Upper	3	0	3	3	1	3 or 4†	2	
	Lower	3	0	3	3	1	4	3	
Cattle	Upper	0	0	3	0	0	3	3	
	Lower	3	1	3	3	1	3	3	

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*The chart lists the number of teeth present on one side of the mouth. The total number of teeth is double.
†The mare (female horse) often does not have the canine tooth, and the first premolar is often absent.

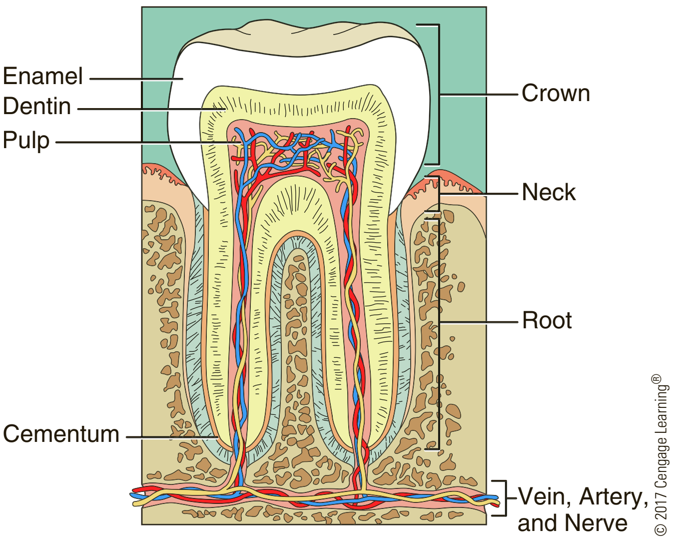

FIGURE 7–3 The structure of a tooth.

animal to grow and therefore have room in the jaw for the larger permanent teeth.

Teeth are classified as incisors, canines, premolars, and molars (Figure 7–4). The incisors are the foremost teeth, used to bite into the food. Canine teeth, if present, are the longest teeth and are used for tearing the food. The root of the canine tooth is about twice as long as the exposed crown. This can make removal of a damaged canine tooth very difficult. When removing a lower canine from the mandible, care must be taken not to fracture the jawbone. The root of the tooth can involve a large portion of the depth of the mandible.

Premolars and molars are used for crushing and grinding food. In the dog and cat the upper fourth premolar and the lower first molar are called the carnassial teeth. The shape and positioning of these teeth provide a shearing or cutting function. The muscles that close the jaws can exert a tremendous force across these teeth. Many people have seen dogs crush bone with their teeth. The carnassial teeth are the primary teeth used in this chewing in dogs and cats. There are times where the upper carnassial tooth will crack under the force applied. This can lead to an abscessed tooth. A typical presentation of this problem is a dog with a swelling under the eye. Often this abscess will break out at the surface, releasing the entrapped pus. Extraction of the affected tooth combined with antibiotic therapy is the treatment of choice.

The premolars and molars in herbivores are much flatter and more tightly packed. These teeth are designed for repetitive grinding of plant material. The jaw moves in a circular fashion, as the teeth not only press together but also slide across each other. This motion provides a very effective means of grinding the plant material into tiny pieces that are more easily digested.

This grinding action has a wearing effect on the teeth. The teeth of horses continue to erupt throughout their lives. The fully formed teeth move out of the jaw as they are worn down from the grinding action. As the teeth are worn down, the shape and appearance of the teeth also change. The appearance of the surface of the incisors can be used to approximate the age of a horse. The aging is not exact due to differences between individuals and diet. This process, though, can be very helpful in giving an estimate of the age of the horse, such as when a client is considering purchasing a new horse.

Saliva is produced by four major salivary glands in the dog (Figure 7–5). In other species such as the horse, the parotid, mandibular, and sublingual glands are the primary saliva producers. Salivary glands are the first of several exocrine glands necessary for digestion. These exocrine glands produce a product that is carried by an epithelial-lined duct into the digestive tract.

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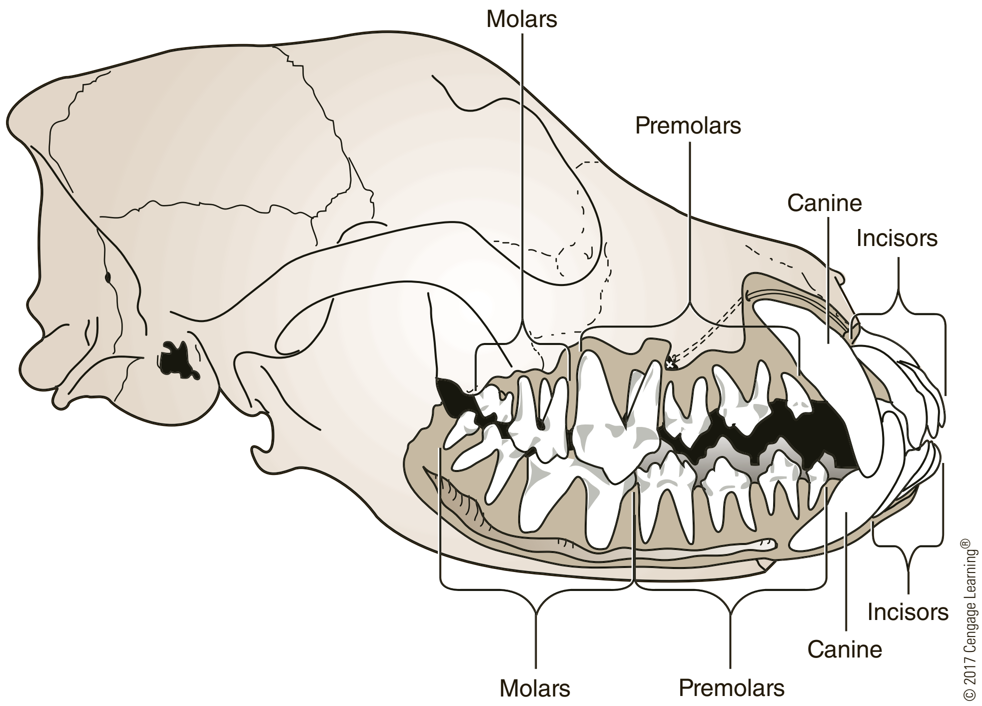

FIGURE 7–4 The types of teeth found in an adult dog.

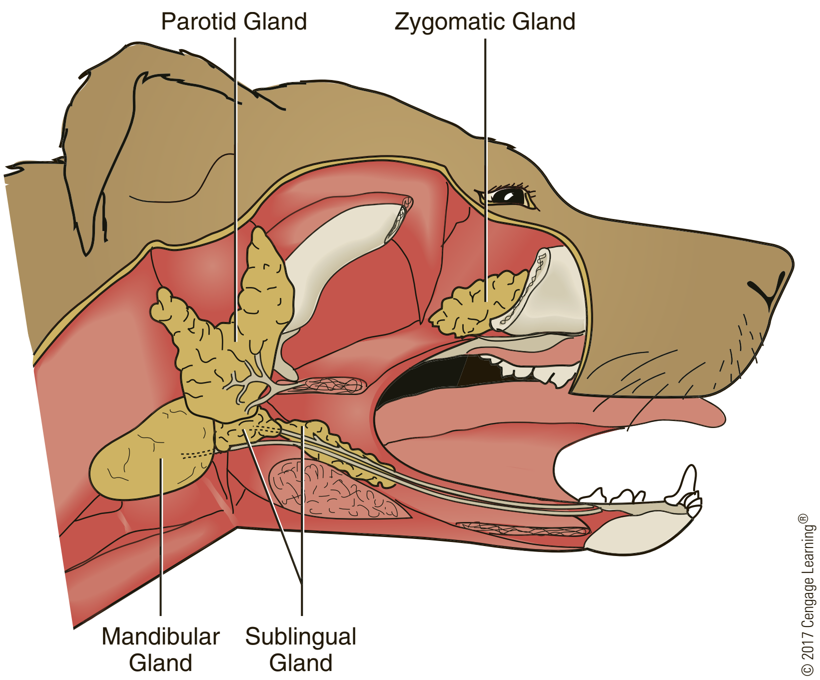

FIGURE 7–5 The salivary glands found in the dog.

The tongue, made of skeletal muscle, helps to obtain food and moves it around in the mouth to aid chewing. Once the food is adequately ground, the tongue forms a bolus. The central region of the tongue is pushed dorsally against the hard palate, moving the bolus of food toward the back of the pharynx. In the act of swallowing, the epiglottis covers the opening to the larynx, which temporarily stops respiration. The food passes through the pharynx and into the esophagus. It is important to recognize that the pharynx is shared by the respiratory and digestive systems and relies on a very controlled process to prevent inhalation of food. When the bolus of food reaches the back of the pharynx behind the raised portion of the tongue, the swallowing process occurs

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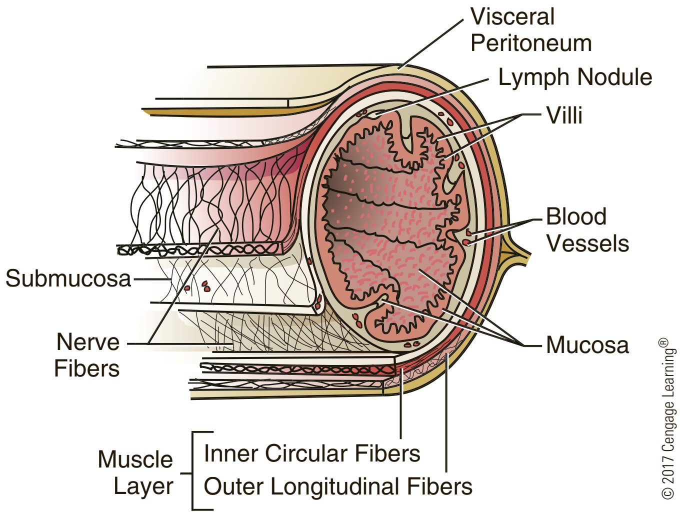

FIGURE 7–6 Typical wall structure found in organs of the digestive tract.

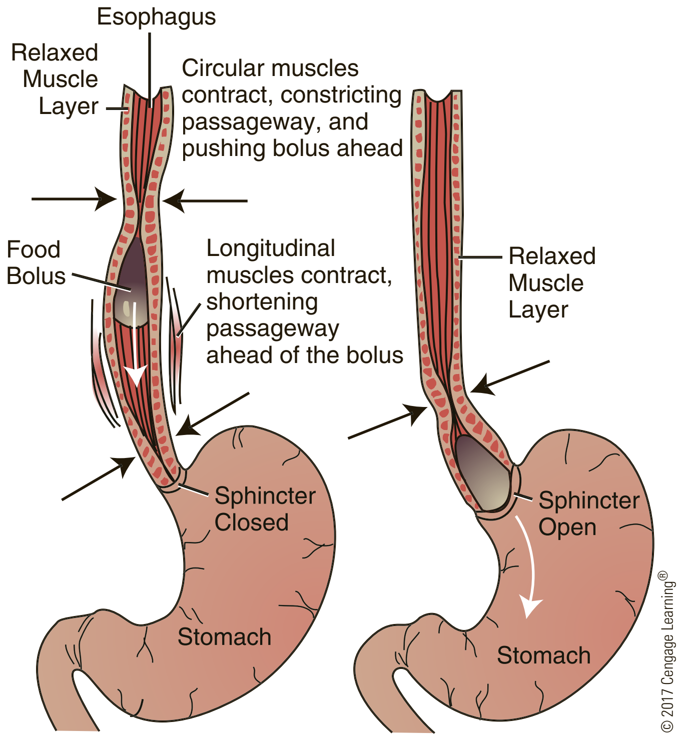

FIGURE 7–7 Peristalsis. Peristalsis actively propels ingesta through the intestinal tract.

through controlled reflexes and is no longer a voluntary process. Veterinarians take advantage of this reflex by placing medication deep into the pharynx to allow the animal to swallow. The principle is quite simple, but not easily accomplished in a fractious animal.

The wall of the esophagus divides into four layers (Figure 7–6). As with all the tubular structures, there is an epithelial lining, the mucosa, with an underlying connective tissue layer, the submucosa. There are two layers of smooth muscle in the wall of the esophagus. Finally, there is a connective tissue covering, called the serosa. All the regions of the gastrointestinal tract have this same basic structure. The appearance and structure of the epithelial layer varies significantly between each structure.

The food is propelled through the esophagus by **peristalsis** (Figure 7–7). This occurs with organized contractions of the muscles in the esophageal wall. The inner muscular layer is oriented around the esophagus in a circular manner. This layer contracts behind the bolus of food, forcing it toward the stomach. The outer layer of muscle is arranged lengthwise in the esophagus. This layer contracts, shortening the length of the esophagus. The inner layers of muscle contract farther down the esophagus, continuing to push the bolus of food into the stomach. *Peristalsis* describes this type of action, which occurs throughout the gastrointestinal tract.

The esophagus delivers the food through the neck, chest cavity, and diaphragm into the stomach. A sphincter controls the opening into the stomach. The sphincter is a circular muscle that remains closed until food is ready to enter from the esophagus, helping to prevent the acidic contents of the stomach from traveling backward into the esophagus. (If this backward flow occurs, it causes the uncomfortable feeling of heartburn in humans.)

The basic structures to this point are very similar among species. The teeth are specialized based on the type of diet, but the other structures are similar. The following is a basic description of the gastrointestinal tract of dogs and cats. Dogs and cats are **monogastrics**, meaning they have a single stomach. The variations in other species are discussed later in the chapter.

The stomach divides into five regions (Figure 7–8). The cardia is the inlet region associated with the esophagus. The major storage regions are called the body and fundus of the stomach. The fundus is the pouch-like end of the stomach that allows expansion. When empty, the stomach is very small and has folds in the lining, called rugae, which allow the stomach to expand when a large meal is eaten. The body of the stomach leads into the antrum. The antrum leads into the small intestine. Like the cardia, the pylorus is a sphincter that controls the flow of ingested food and fluid, called ingesta, into the small intestine and prevents backflow.

The stomach lies immediately behind the liver (Figure 7–9). The liver is important in digestion and also in processing the nutrients absorbed after digestion. The liver produces a secretion, bile, which is stored in the gallbladder. The liver and the gallbladder communicate with the small intestine through the common bile duct (Figure 7–10). Bile produced by the liver can be directly emptied into the small intestine or stored in the gallbladder.

The small intestine divides into three regions. The first relatively short section is the duodenum. The duodenum is closely associated with the exocrine gland,

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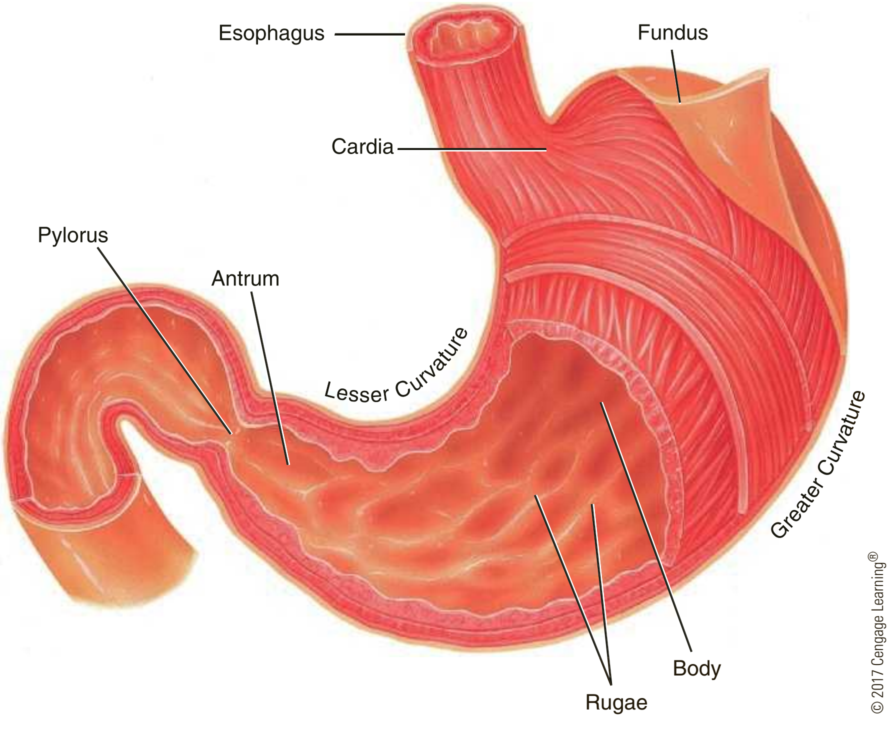

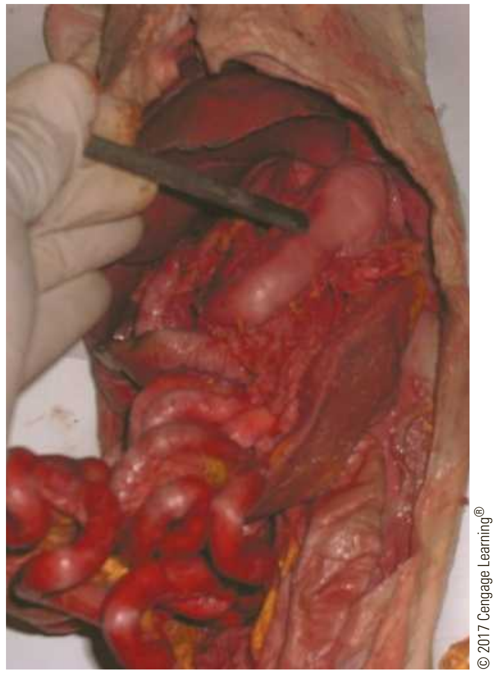

FIGURE 7–8 A. The parts of the stomach. B. Normal positioning of the stomach in a cat.

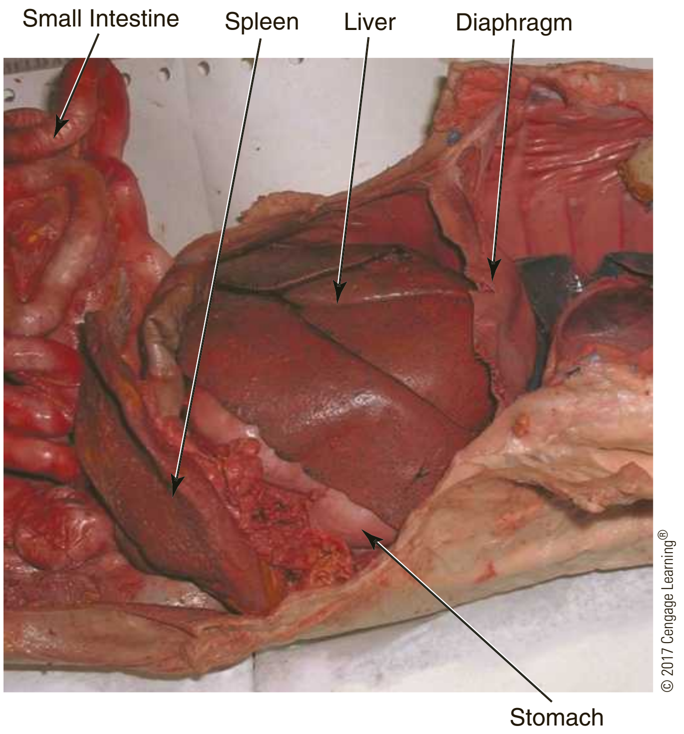

FIGURE 7–9 The liver of a cat.

the pancreas (Figure 7–11). This leads into the long middle region, the jejunum, and then the final region, the ileum. (Note the difference in spelling from the ilium of the pelvis.) Much of the digestion and absorption of nutrients occurs within the small intestine.

The ileum leads into the large intestine or colon (Figure 7–12). At the terminal end of the ileum is the ileocecal sphincter, which opens to allow movement into the colon but closes to prevent backward flow into the small intestine. At this level there is a blind pouch off the colon, called the cecum. The name *large intestine* describes the diameter of the organ. The large intestine is much shorter than the small intestine. The large intestine divides into the ascending, transverse, and descending colons. The descending colon leads into the rectum. The rectum is the termination of the intestinal tract as it exits the body at the anus. The anus has a muscular sphincter that controls the act of defecation. This sphincter has two rings of musculature. The internal ring is controlled by the autonomic nervous system, while the external ring is under voluntary control.

Numerous connective structures within the abdominal cavity help to support and protect the organs. The entire abdominal cavity is lined with the peritoneum. The peritoneum is a smooth, thin epithelial lining with an underlying connective tissue. The smooth peritoneum allows the organs to move freely within the abdomen.

The mesentery is an extension of the peritoneum that carries the blood vessels and nerves to the small intestines (Figure 7–13). The omentum also carries blood vessels and surrounds much of the abdominal organs. The greater omentum is often the first tissue observed when the abdomen is opened. The omentum helps to minimize the spread of infection and inflammation within the abdomen.

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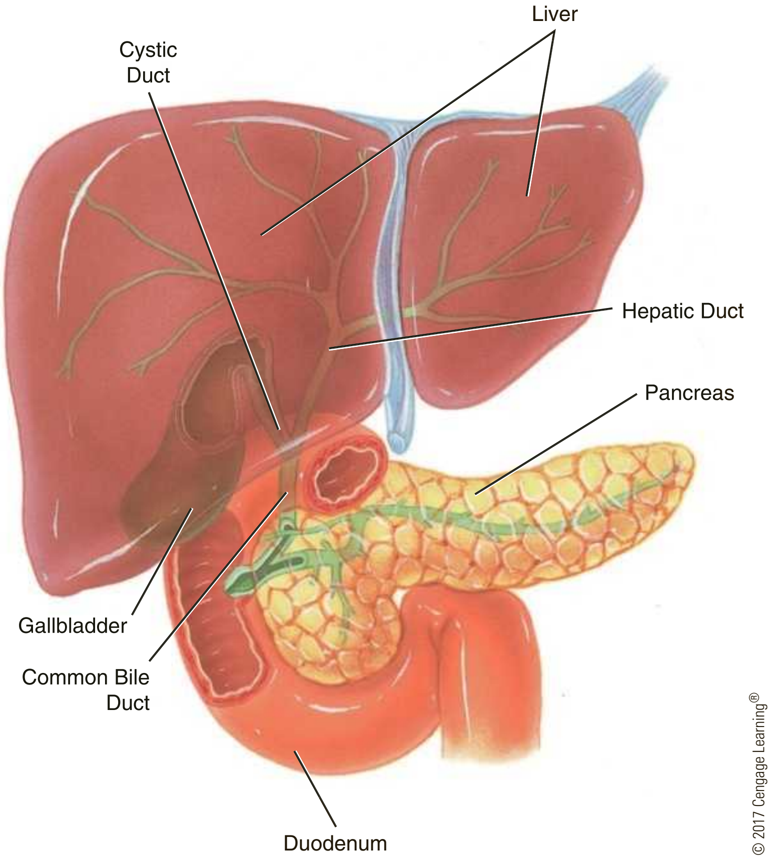

FIGURE 7–10 Gallbladder and bile ducts. Note the close proximity to the pancreas and duodenum.

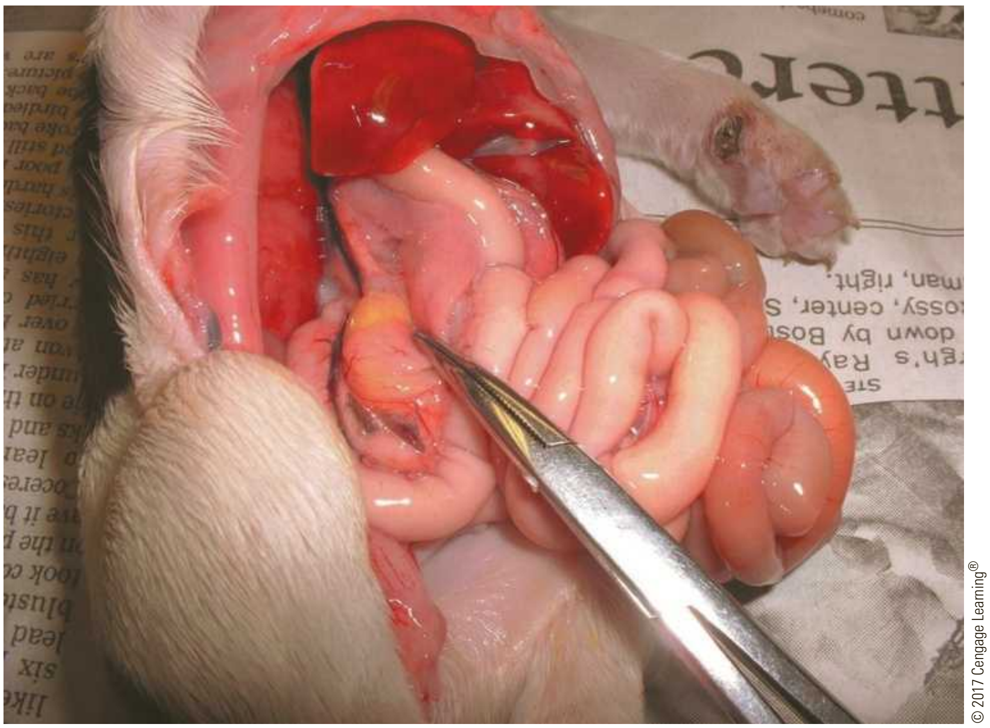

FIGURE 7–11 The small intestines and pancreas of a young puppy. The hemostat identifies the pancreas.

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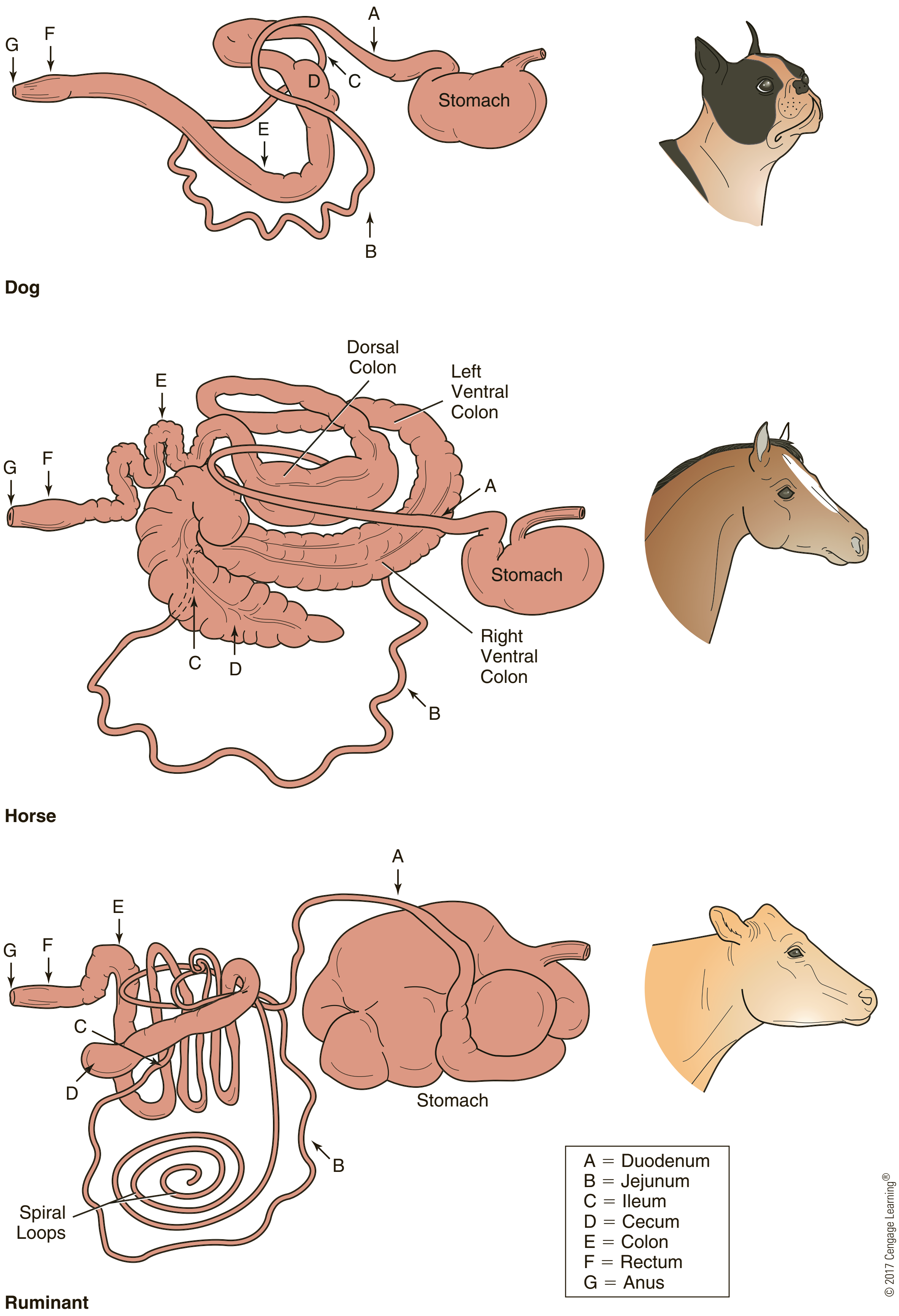

FIGURE 7–12 Comparison of the intestinal tracts of the dog, horse, and cow.

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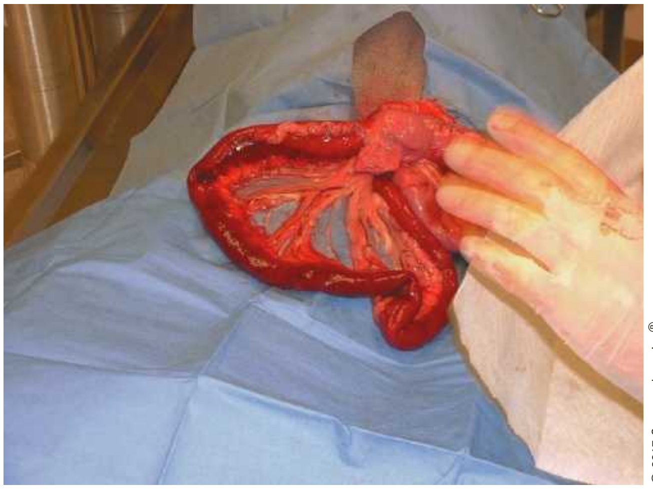

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FIGURE 7–13 Intraoperative photograph showing a loop of intestine with mesentery. The blood vessels enter the intestines via the mesentery. Regions of the mesentery are transparent. Other regions have visible fat and blood vessels.

MONOGASTRIC DIGESTION

Objective

- Explain Digestion in Monogastrics, Including Exocrine Secretions and Function, Digestive Tract Function, Digestive Tract Absorption, and Role of the Liver in Digestion and Metabolism (Table 7–2)

The mouth helps to obtain food and break it down mechanically. The sight, smell, and taste of food stimulates an autonomic nervous reflex (parasympathetic) for a release of saliva. The liquid saliva mixes with the food, making it much easier to swallow. In addition, the saliva has a protective effect, coating the epithelium in the mouth and pharynx. Saliva contains sodium bicarbonate, which helps to maintain a stable pH in the mouth. It also contains lysozymes, which have antibacterial properties, helping to minimize the growth of bacteria. Digestion actually begins with the addition of saliva. Saliva in many omnivore species (e.g. pigs and humans) contains the enzyme amylase, which begins to digest starch into the simple sugar maltose.

Table 7–2 **Summary of Digestive Enzymes and Hormones**

DIGESTIVE JUICES			
Secretion	**Source**	**Location of Action**	**Action**
Salivary amylase	Salivary glands	Mouth	Digests starch
HCl	Parietal cells (stomach)	Stomach	Degrades proteins Activates pepsin
Pepsin	Chief cells (stomach)	Stomach	Digests protein Activates pepsin
Trypsin, chymotrypsin, carboxypeptidase	Pancreas	Small intestine	Digests protein
Sodium bicarbonate	Pancreas	Small intestine	Raises pH of chime Inactivates pepsin
Lipase	Pancreas	Small intestine	Digests fat
Bile salts	Liver and gallbladder	Small intestine	Emulsifies fat
Amylase	Pancreas	Small intestine	Digests starch
Nuclease	Pancreas	Small intestine	Digests RNA and DNA
HORMONES (released into the bloodstream; effect occurs when returned to target organ)			
Hormone	**Source**	**Target Organ(s)**	**Action**
Gastrin	Stomach	Stomach	Increases HCl release
Secretin	Duodenum	Pancreas and liver	Increases bicarbonate release Increases bile production by liver
Cholecystokinin	Duodenum	Pancreas and gallbladder	Increases release of enzymes from pancreas Empties gallbladder
Gastric inhibitory peptide	Duodenum	Stomach	Decreases activity of stomach

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As food is swallowed, the bolus passes through the esophagus into the stomach. The sight, smell, and taste of food results in a nervous stimulation to the stomach. As food enters the stomach, the stretching of the stomach wall also stimulates activity. The stomach begins to contract and secrete gastric juices. The muscular contraction of the stomach wall helps to mechanically break down the ingested food. This primarily occurs in the antrum.

Much like the salivary glands, the cells in the lining of the stomach begin to secrete gastric juices in response to parasympathetic stimulation. Parietal cells, which secrete hydrochloric acid (HCl), contain many mitochondria, necessary to deliver the energy required for active transport of hydrogen ions into the stomach. The HCl lowers the pH within the stomach to 1 or 2. This very acidic pH helps break down protein and connective tissues. In addition, the low pH kills many of the bacteria that are ingested with the food. This is an important mechanism in helping to prevent disease.

The HCl also activates an enzyme called pepsinogen, which is secreted by chief cells that are also located in the lining of the stomach. The pepsinogen is converted to pepsin when it contacts the HCl. The pepsin enzymatically cleaves protein molecules into polypeptides and activates even more pepsinogen. Because pepsin digests proteins, it is secreted in an inactive form to protect the chief cells that secrete it. During this time, the stomach is going through contractions, which help to mix the ingesta with the stomach secretions as well as physically break down the particles.

The interior of the stomach is a harsh environment, with the low pH and the protein-digesting enzymes. Other lining cells in the stomach secrete a mucus that coats the epithelial lining of the stomach. The epithelial cells have a tight cell junction that prevents the stomach contents from penetrating between the cells. Even with the mucus protection and the tight cell junctions, the epithelial cells are very short-lived. Old cells are replaced every few days with new epithelial cells.

As proteins are broken down within the stomach, the resulting polypeptides stimulate the stomach to secrete the hormone gastrin, which is released into the bloodstream. As the blood returns to the stomach, the gastrin stimulates further HCl release.

Very little absorption occurs in the stomach. Only a small amount of water, electrolytes, simple sugars, and some medications are absorbed at this level. The remaining partially digested food, the chyme, leaves the stomach through the pyloric sphincter, entering the duodenum. The exit of chyme must be balanced so that the rate of exit from the stomach is matched by the rate of digestion.

The duodenum is essential for further digestion of the chyme. Ducts from the liver and the pancreas enter the duodenum. The liver and pancreas both secrete digestive enzymes that are necessary for the complete digestion of the chyme. The pancreas is a long, pale white gland that is closely associated with the duodenum. The pancreas secretes a variety of digestive enzymes into the duodenum through the pancreatic duct.

Sodium bicarbonate ($NaHCO_3$) is produced by the pancreas to neutralize the HCl of the stomach contents. The pH of the chyme is raised to a level of about 8 with the addition of the sodium bicarbonate. The elevated pH inactivates the pepsin from the stomach. The pancreas secretes several enzymes essential for the digestion of protein. Trypsin is one protein-digesting enzyme that is secreted in an inactive form. It is activated in the lumen when it contacts an enzyme (enterokinase) secreted by the epithelium of the duodenum. In the active form, trypsin begins to further digest protein. Trypsin also activates more trypsin, chymotrypsin, and carboxypeptidase. These three enzymes work to break down proteins into individual amino acids.

Salivary amylase is inadequate to completely digest all the starch. The pancreas also secretes amylase, which continues the digestion of starch and glycogen into smaller sugars. Lipase is another enzyme secreted by the pancreas. Lipase digests triglycerides into two fatty acids and a monoglyceride (glycerol with a single fatty acid). The pancreas also secretes nucleases to digest the nucleic acids, RNA and DNA.

The pancreas plays such a significant role in digestion that a defect in pancreatic function can have dramatic effects on the animal. Exocrine pancreatic insufficiency is a condition found in dogs, most commonly German shepherds. Affected dogs do not produce adequate amounts of pancreatic enzymes, which results in incomplete digestion. These dogs are typically thin with a ravenous appetite, produce large amounts of feces, and often have diarrhea. The condition is managed by adding enzyme replacement in the dog's food to replace the natural pancreatic secretions.

The liver is constantly producing bile, although the rate may vary. The bile is transported to the gallbladder, where it is stored between meals or delivered directly to the duodenum. Horses have no gallbladder, so bile is transported directly to the duodenum through the bile duct. Bile acts to emulsify fat. Through this process very small particles are created from larger fat globules. These smaller fat globules are more easily digested because they have a greater surface area than one large globule. The larger surface area allows for the lipases secreted by the pancreas to digest the fat.

Bile contains bile acids, cholesterol, bilirubin, and water. Bilirubin, the primary bile pigment, is produced from the breakdown of hemoglobin, removed from aged red blood cells. The bilirubin gives bile its distinct green color and has no role in digestion. Its inclusion in bile is a means to excrete a metabolic waste product. The bile pigments are responsible for the coloration of feces. The bile acids are critical for proper digestion of fat and, as a result, for the absorption of fat and fat-soluble vitamins. Much of the bile acids are reabsorbed from the ileum. The bile acids enter the hepatic portal vein and are transported back to the liver where almost all are reabsorbed.

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The process of bile acid secretion and its reabsorption can be used to evaluate the function of the liver. The bile acid level in serum should remain low but can vary over the course of the day. To evaluate liver function, for example in a dog, serum bile acid levels would be measured when the dog's stomach was empty. The dog would then be fed canned food with a relatively high fat level, stimulating the release of bile from the gallbladder. Two hours later, bile acid levels in the blood would be measured again. When bile is released, the bile acids are reabsorbed and the liver removes the majority of the acids; thus, the bile acid levels do not increase dramatically. When there are liver function problems, however, the second sample will often be elevated significantly. This finding does not typically define the specific cause but localizes it and gives reason for further diagnostic testing.

Three hormones that control digestion are secreted by the duodenal mucosa. When the acidic contents of the stomach enter the duodenum, secretin is produced. Secretin stimulates the pancreas to release sodium bicarbonate and the liver to produce bile. As fats and proteins enter the duodenum, cholecystokinin (CCK) is released. CCK stimulates the pancreas to release its digestive enzymes and the gallbladder to empty. Gastric inhibitory peptide (GIP) is also released to decrease the activity of the stomach. All three of these hormones are released into the bloodstream. It is only when the hormone is returned to the target organ that its action occurs.

Just as in the esophagus, material in the small intestine is moved through via peristalsis. These organized contractions physically push the chyme along in the intestinal tract. In addition, segmentation contractions break up the chyme into small regions. These areas relax and contractions form in between the previous contractions. Much like the gastric contractions, this mechanism helps to break up the ingesta and mix it with the digestive enzymes.

The small intestines are lined with tiny fingerlike projections called villi (Figure 7–14). Every villus is

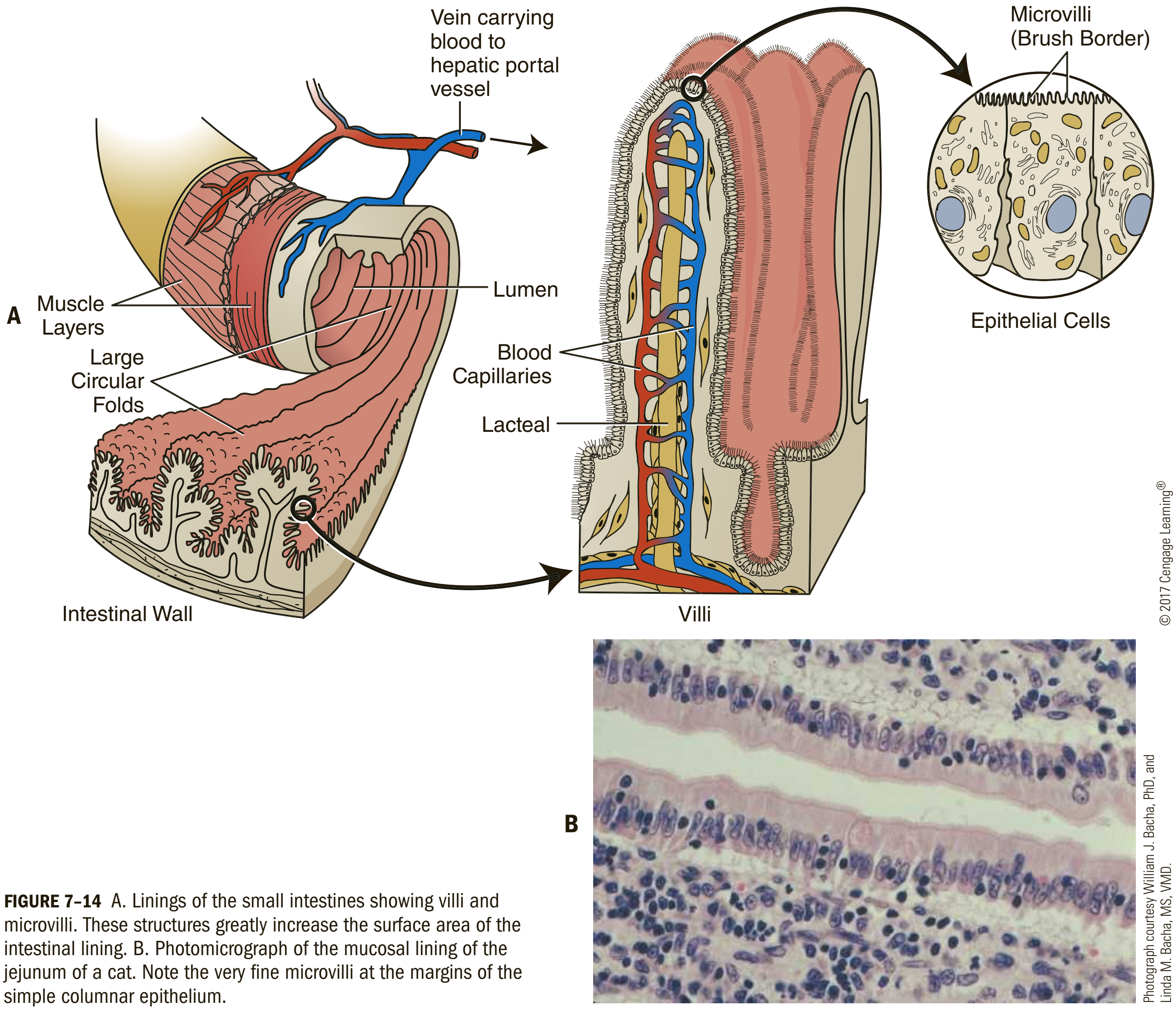

FIGURE 7–14 A. Linings of the small intestines showing villi and microvilli. These structures greatly increase the surface area of the intestinal lining. B. Photomicrograph of the mucosal lining of the jejunum of a cat. Note the very fine microvilli at the margins of the simple columnar epithelium.

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covered with even smaller microvilli. These villi and microvilli greatly increase the surface area of the intestinal lining. It is estimated that the villi increase the surface area of the small intestinal wall by 10 to 14 times. The villi are covered with a simple columnar epithelium. Within each villus is a rich blood supply to aid in the absorption of nutrients.

The partially digested food delivered into the small intestine is primarily in the form of short peptides, disaccharides, fatty acids, and monoglycerides. Many enzymes coat the microvilli that complete the digestion into individual amino acids and simple sugars. The amino acids, sugars (as well as many vitamins), electrolytes, and water are absorbed through the mucosal cells and delivered to the bloodstream. Active transport is needed when the blood level is higher than the concentration in the intestine.

The monoglycerides and fatty acids are absorbed into the lining cells. The cells reconstruct triglycerides within the smooth endoplasmic reticulum. The fats are then released into the center of the villus and enter a lacteal, rather than the capillaries. A lacteal is a duct associated with the lymphatic system. (A more complete discussion of the lymphatic system is presented in Chapter 11.) The lacteals join the much larger thoracic duct. The thoracic duct crosses the diaphragm into the thoracic cavity. The thoracic duct then empties into a major vein. If blood is collected from an animal shortly after a fatty meal, the serum will have a large concentration of fat. When separated from the blood cells, this type of serum has a cloudy white appearance, which is termed lipemia.

Blood from the villi collects into larger venules and veins, which then enter the liver. The liver processes much of the absorbed nutrients before they enter the systemic circulation. The vessels that carry blood from the intestinal tract to the liver make up the hepatic portal circulation. The liver has a wide variety of functions in the metabolism of the animal. The liver's production of bile salts to aid in fat digestion has already been discussed. The liver plays a major role in homeostasis. When excess nutrients are present, the liver removes them from the circulation. Likewise, when concentrations fall, the liver releases them back into the blood.

The liver helps to maintain a steady level of blood sugar. When excess glucose is present in the blood, the liver extracts and converts it into glycogen. The glycogen is basically used to store energy. When sugars other than glucose are present, the liver converts them to glucose and then into glycogen. When blood sugar levels decline, the glycogen is converted back to glucose. The glucose is then released into the bloodstream.

The liver is also involved in protein and lipid metabolism. Many of the proteins found in the blood, such as albumin, clotting factors, and lipoproteins, are manufactured in the liver. During the breakdown of amino acids, ammonia is created, which is toxic to the animal. The liver functions to convert the ammonia to urea, which is subsequently excreted by the kidney. Likewise, the liver is involved in maintaining lipid homeostasis. The liver can synthesize or break down plasma lipids, controlling the level of cholesterol, triglycerides, and phospholipids.

The pancreas helps to regulate this process of energy storage and release. In addition to being an exocrine gland, releasing digestive enzymes, it is also an endocrine gland. The pancreas has clusters of cells called islets of Langerhans. These islet cells produce the hormones glucagon and insulin, which are released into the bloodstream. Insulin causes the blood sugar to decline, whereas glucagon has the opposite effect, raising the blood sugar.

In addition to controlling blood sugar levels, the liver removes excess amino acids from the bloodstream. The excess amino acids have the ammonia group removed, which is then converted into urea. Urea is a waste product produced by the liver and then excreted by the kidney. The remainder of the amino acid is then burned to produce energy.

The liver also stores certain vitamins and iron, acting as a reserve for when levels decline. The liver cells have many enzymes that help to break down toxins and drugs. If the liver is exposed to the same medication for long periods, the specific enzyme used to remove this drug increases. An example is **phenobarbital**, a drug used to help prevent seizures in dogs and cats. Many of these animals are given phenobarbital for many years. The liver becomes more and more efficient at eliminating the drug from the blood. When this occurs, the blood level declines and the seizures may increase in frequency. This may require that a higher dosage be given to the animal to maintain the same concentration.

The small intestines absorb the vast majority of all the nutritious components of the ingested food. The residue that passes into the large intestine is primarily composed of indigestible products and water. Much of this residue is made of indigestible plant fiber. This fiber provides nourishment to the enormous population of bacteria present in the large intestine. The bacterial population is so large that up to half of feces can be bacterial cells. Some of these bacteria produce vitamins, which are then absorbed by the animal.

The main function of the large intestine is to absorb water and electrolytes from the feces. This water absorption occurs during the 12- to 24-hour period that the fecal material spends in the colon. Any disease that alters this timing can result in digestive problems for the animal. Diarrhea occurs when this time is shortened. The large intestine has inadequate time to absorb enough water, and the feces liquefy. In the opposite manner, constipation occurs when the transport takes longer than normal and the resulting feces become very dry.

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As fecal material fills the rectum, stretch receptors in the anus stimulate the internal muscular ring of the anus to relax. This stimulates the animal with the urge to defecate. Defecation requires both voluntary and involuntary muscular contraction to complete the act. Under voluntary control the external muscular ring of the anus relaxes as the colon and rectum contract to force out the feces. Contraction of abdominal musculature and the diaphragm increase the force and help in defecation.

SPECIES VARIATION

Objectives

- Compare and Contrast the Specialization of Dentition and Digestive Tracts Found in the Various Domestic Species
- Define Symbiosis and Describe Its Significance in the Ruminant

In the discussion of monogastric digestion, it was mentioned that much of the fecal material that reaches the colon derives from indigestible plant fiber. Many of the domestic species, such as horses, cows, sheep, and goats, rely predominantly on plant fiber for their nutrition. Special adaptations are present in their digestive systems that allow these species to obtain their nutrients from plants.

As already mentioned the teeth of herbivores (plant eaters) are adapted for their diet. The large flat molars and premolars are designed specifically for grinding the plant material. This mechanical processing is necessary to allow further digestion. The incisors of horses are aligned in a tight row that allows the grasses to be sheared off during grazing. Cattle, on the other hand, have no upper incisors. The lower incisors press the grass against a specialized region of the upper palate called the dental pad. The grass is held tight and torn loose, rather than incised between sharp teeth.

Cattle and horses also eat loose feed such as grain, which does not require use of the incisors. Horses use their lips to gather the food and then the tongue to move it farther into the mouth. Cattle use their tongue much more to pull the loose food into the mouth.

Horses are monogastrics, like dogs and cats. The digestive process in the stomach and small intestines of the horse is identical to that discussed earlier. The large intestine is the region that distinguishes the horse's intestinal tract from other species.

Horses have a very well-developed large intestine (Figure 7–15). At the beginning of the horse's large intestine is a very long cecum. The cecum of an adult horse can be around 1.25 meters long and can hold 25 to 30 liters. The cecum leads into the beginning of the colon. The colon divides into four regions, each separated by a sharp bend or flexure. Table 7–3 shows a comparison among species of the relative sizes of the colon and cecum. Notice that the cecum and colon make up a much larger portion of the horse's intestinal tract compared with the dog.

Plant fiber is digested in the cecum and colon in a process called fermentation, in which the bacteria present in the cecum and colon digest the plant fiber. These bacteria then release valuable nutrients for the host animal to absorb and use. The bacteria are provided with nutrients, fluid, and warmth by the horse, and in return they supply essential nutrients to their host. A close relationship between two organisms that benefits both organisms is called **symbiosis**.

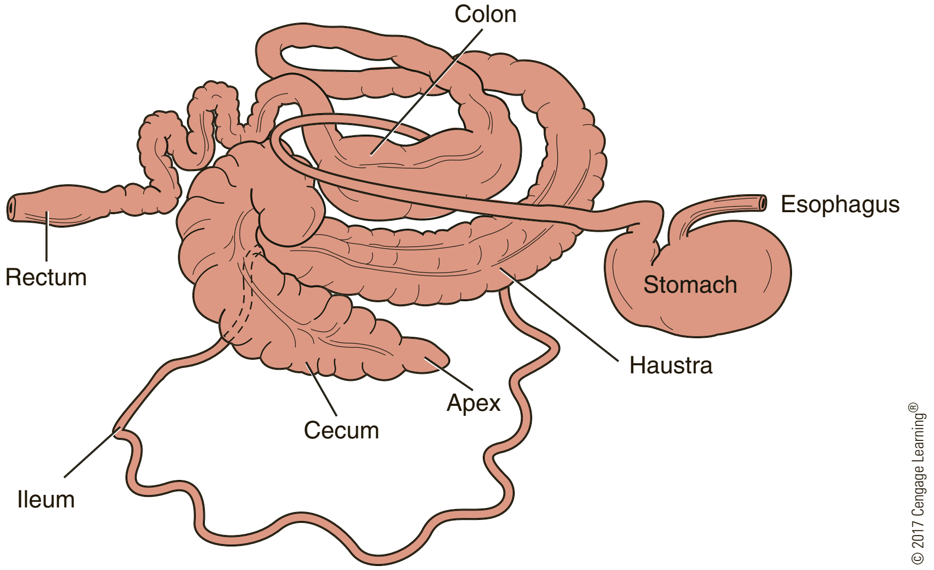

FIGURE 7–15 The anatomy of the horse's intestinal tract.

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Table 7–3 Comparison of Capacity within Digestive Systems*

Species	Cecum	Colon and Rectum	Reticulorumen
Dog	1	13	–
Horse	15	54	–
Rabbit†	43	8	–
Human	< 1	17	–
Cattle	5	5–8	64
Sheep	8	4	71

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Adapted from Van Soest, Peter, *Nutritional Ecology of the Ruminant, 2nd edition.*

*The numbers in the chart represent the percentage of the entire intestinal tract made up by the organ listed.

†Notice that the rabbit has a very large cecum in proportion to its intestinal tract.

In the horse, material is exchanged to some extent between the cecum and colon. A portion of the fermentation occurs within the cecum, but the majority of the fiber digestion occurs in the colon. Because this process occurs after the food has moved through the stomach, horses are described as postgastric fermenters.

Cattle, sheep, and goats are ruminants. Ruminants also rely on symbiosis and fermentation to digest plant material. In contrast to horses, the fermentation in ruminants occurs before food reaches the acid-secreting stomach and small intestines. It is generally said that ruminants have four stomachs (Figure 7–16), but technically these stomachs derive from the same region in the developing embryo and are four regions of one stomach. When observed during surgery or while studying anatomy, these four regions appear as distinct structures. In addition, these regions have different functions and each region is named. This text tries to illustrate the practical application of veterinary science. While veterinarians recognize that these structures are specialized compartments derived from the same embryologic region, they are often referred to as stomachs. In clinical application, diseases of a particular region of the stomach (e.g., rumen distension

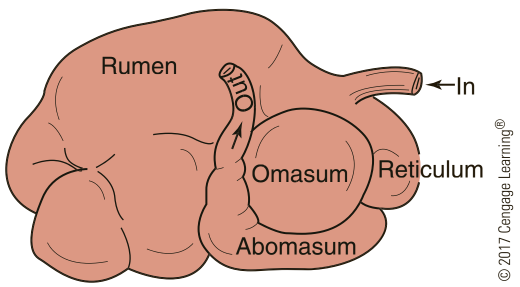

FIGURE 7–16 The four-compartment stomach of the cow.

in bloat) are treated specifically without consideration of the embryologic origin. Students are encouraged to keep this origin in mind; however, subsequently the regions will be described as stomachs.

The esophagus enters the stomachs at the junction between the rumen and reticulum. The rumen is considered the first stomach. The rumen is a large fermentation vat that occupies the majority of the left side of the abdomen in the cow. In adult cattle the rumen can hold 30 to 60 gallons of fluid and feed. The lining of the rumen is covered with tiny fingerlike projections called papillae (Figure 7–17A). These papillae increase the surface area that allows for absorption of nutrients.

The rumen is not one large sac but has structures that divide it into a dorsal and ventral sac. The rumen regularly undergoes an organized contraction that helps to stir the contents within it. When performing a physical examination on a cow, the stethoscope is used to listen to these contractions. These contractions are easily heard as a rumbling noise. A healthy animal should normally have two to three rumen contractions every minute.

In the rumen the contents separate to a certain degree. The most liquid portion is in the lowermost region. There are many small particles floating in this liquid, above which is a fiber mat of large particles basically floating on the liquid. Above this is a gas that is continuously produced by the bacteria and must be belched off regularly by the cow.

The second stomach, the reticulum, is only partially separated from the rumen. The reticulorumen is often considered to be one functional unit that is the site of fermentation. The reticulum has a lining that is divided into regions, giving it the appearance of a honeycomb (Figure 7–17B). The position of the reticulum and the type of lining make it the site that traps any heavy objects ingested. See Chapter 4 for a discussion of a cow suffering from hardware disease. The reticulum is the stomach first affected by hardware. The metal settles out of the liquid-like contents and into the low pouch of the reticulum, becoming entrapped in the honeycomb lining. As the stomach contracts and moves, a sharp piece of metal can puncture through the wall of the reticulum into the abdomen. The reticulum is located immediately behind the diaphragm and liver. Often the metal continues to penetrate into the liver or through the diaphragm and into the heart. Placing a magnet in this stomach can prevent hardware disease. The heavy magnet settles into the stomach for the same reasons as the metal does. The goal of the magnet is to hold the metal tight against it, preventing sharp ends from penetrating the wall.

The third stomach is the omasum. The omasum is lined with long, thin sheets that divide the stomach, preventing large particles from passing (Figure 7–17C). These sheets greatly increase the surface area of the

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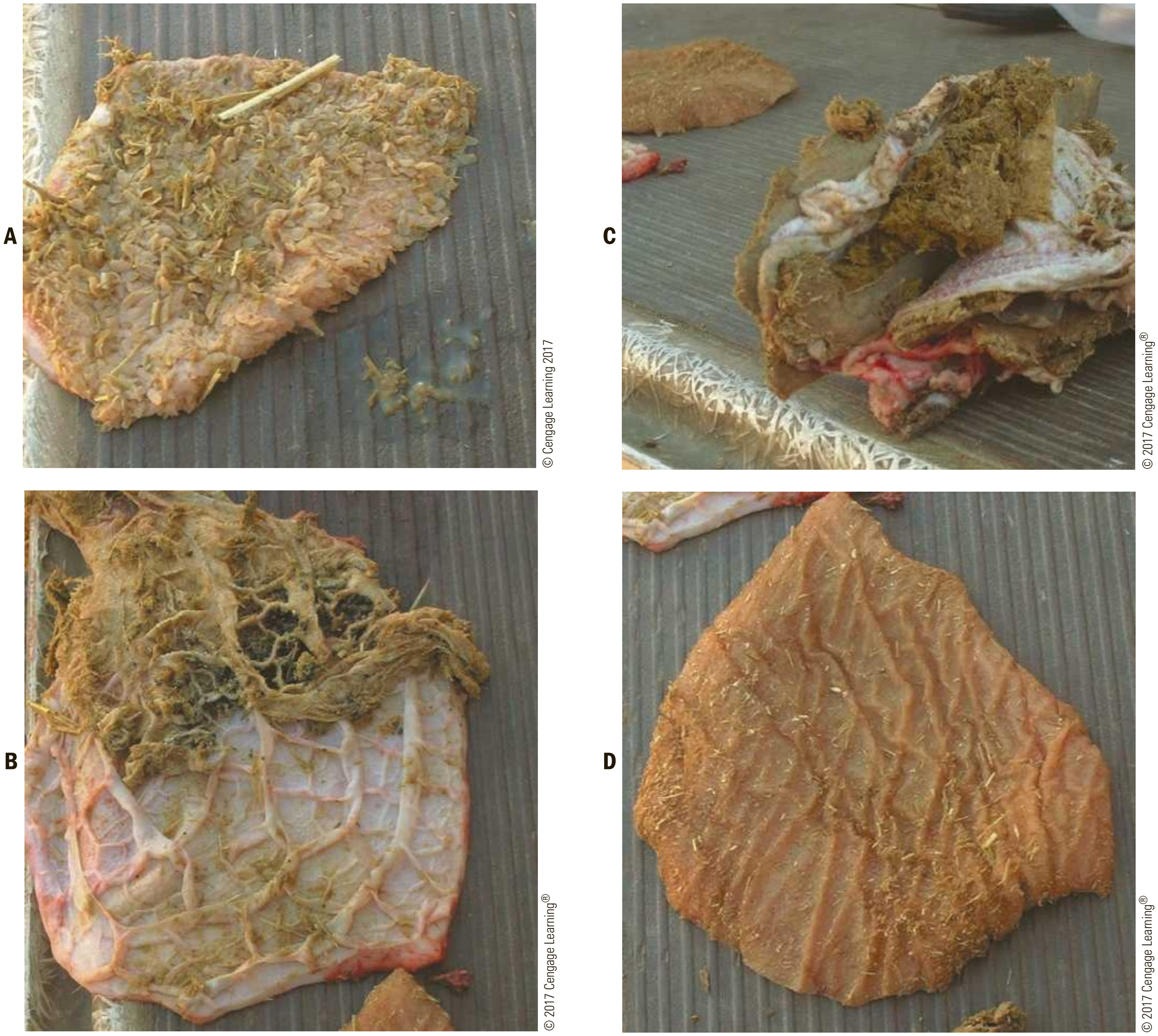

FIGURE 7–17 The linings of the four stomachs of a cow. A. Rumen. Note the small fingerlike projections, the rumen papillae, that increase the surface area for absorption. B. Reticulum. The distinct lining gives the reticulum its colloquial name, *honeycomb*. C. Omasum. The lining has large sheets with ingesta between the layers. D. Abomasum. This smooth glandular lining appears very similar to the monogastric stomach.

stomach and provide a location for the absorption of water, electrolytes, and nutrients. The omasum then passes the ingesta into the fourth stomach, the abomasum.

The abomasum is often called the true stomach, because it is functionally identical to that of the monogastrics (Figure 7–17D). The abomasum contains acid and enzyme secretions just like the monogastrics. This stomach begins the digestion of all the materials that are not bound in the indigestible plant fiber. (The introduction of Chapter 2 discusses a common problem associated with the abomasum. Review the discussion of displaced abomasum and the treatments available.)

Young calves have a poorly developed rumen and reticulum and as a result function as a monogastric. When a calf suckles, a reflex causes a region in the reticulum to contract. This region forms a groove that basically extends the length of the esophagus. This reticular or esophageal groove directs the milk to the abomasum, bypassing the rumen. Over the next several months, the rumen continues to develop and gradually the calf transitions from a monogastric to a ruminant.

Ruminants eat very quickly. Food is taken into the mouth, chewed briefly, and then swallowed. Later the animal begins the process of **rumination**. In rumination

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the rumen and reticulum contract in a manner that forces some of the ingesta back through the esophagus and into the mouth (regurgitation). At this point the animal takes the time to chew the ingesta into fine pieces—an activity that is colloquially called cud chewing. During cud chewing, even more saliva is combined with the food, and then it is swallowed again. Depending on the type of diet and amount of rumination, adult cattle can produce between 100 and 200 liters of saliva, including large amounts of bicarbonate. Cows at rest are often observed chewing their cud. During this time the rumen continues to contract, keeping the contents stirred. After swallowing, another cycle of rumination can occur.

The finely ground pieces of ingesta that result from cud chewing are able to be digested by the microorganisms within the rumen. The rumen houses a tremendous number of bacteria and protozoa that function to digest plant fiber. This is another example of symbiosis. These microorganisms ferment the plant material, releasing volatile fatty acids (VFAs; acetic, propionic, and butyric acid) into the rumen. The VFAs are basically a waste product of the microorganisms but are absorbed by the cattle for energy. Without absorption of these acids by the cow and buffering from the bicarbonate in the saliva, the pH of the rumen would drop to a level that would kill the bacteria. This further exemplifies the symbiotic relationship between the cow and the inhabitants of the rumen. These organisms also produce gas as a by-product of fermentation. As previously mentioned, this gas accumulates in the dorsal sac of the rumen and is periodically **eructated** or belched. Like rumination, this requires organized contractions of the rumen.

The microorganisms of the rumen flourish in the warm, wet, nutrient-rich environment. There is such a tremendous growth that many of them pass into the abomasum. The bacteria and protozoa are then digested as a source of nutrients for the cow because they can be digested normally in the acid-secreting abomasum. The need to feed the rumen organisms, which then feed the cow, must be kept in mind when developing rations for feeding cattle.

Once the ingesta reach the abomasum, digestion occurs in much the same way as in other monogastrics. Cattle have a relatively large cecum, but the rumen is the primary site of fermentation.

CLINICAL PRACTICE

Objective

- Discuss the Clinical Significance of the Academic Material Learned in This Chapter

In the exploratory surgery, I found that Toby did have an intussusception (Figure 7–18). At times the intestine can be pulled back into its normal structure. Unfortunately, I was unable to correct Toby's intussusception in that fashion. An intussusception eventually cuts off the normal blood supply to the intestine, and the tissue is no longer healthy. With Toby I had to remove a portion of his jejunum.

To accomplish this, I used a pair of clamps on each side of the intussusception. These clamps are gentle enough that they do not damage the tissue but firm enough to prevent any intestinal contents from leaking. Tying off the arteries and veins supplying that region stopped the blood supply to the damaged intestine, and I removed the diseased section. I then sutured the ends of the open intestine together until I was satisfied that I had a leak-proof connection.


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FIGURE 7–18 Intraoperative photograph of an intussusception, showing a region of intestine that has telescoped into another section.

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The important considerations in such an operation are similar to every surgery. The tissues that are sutured together are handled with care to prevent further damage. I removed a large enough section of intestine that I was sure I had healthy tissue at each end. I also had to ensure that there was a blood supply to the sutured tissues. When I was finished with intestinal surgery, I double checked to see that the contents did not leak from the incised intestine.

Not all foreign bodies are readily seen on a radiograph. Rocks in an intestine are easily detected on a radiograph, but materials such as a sock or underwear often are not so easily seen. To aid in diagnosis, I can give an animal oral barium, which shows up extremely well on a radiograph (Figure 7–19). By taking a radiograph immediately after administering barium, and then at regular intervals, the function of the gastrointestinal tract can be followed. When an obstruction is present, the barium stops progressing or at least slows down. This technique can be very helpful in deciding whether to perform exploratory surgery on an animal.

Vomiting is a complex process that is not always a direct result of gastrointestinal disease (e.g., it can occur with kidney failure). Vomiting begins with nausea. Nausea not only makes an animal feel sick but also slows motility in the stomach and esophagus. Nausea proceeds into **retching**, or strong, rapid abdominal contractions. Finally, vomiting occurs as the stomach's contents are forcefully driven by peristalsis in the opposite direction through the esophagus and out of the mouth. Even materials that have moved into the duodenum can be forced into the vomitus.

Vomiting can be induced by several mechanisms. A signal is sent from the vomiting center in the brain. The vomiting center can receive stimulation from receptors in the stomach and abdomen. Inflammation or disease in the stomach or abdomen stimulates the vomiting center. In addition, receptors that pick up stimuli in the blood (such as azotemia or certain drugs) can also induce vomiting. The balance center, called the **vestibular system**, also influences the vomiting center. You may have felt nauseated after an amusement park ride that made you dizzy. This is a firsthand demonstration of the effect of the vestibular system on the vomiting center.

Diarrhea occurs when feces pass through the intestinal tract too quickly. The resulting feces have high water content. Many causes of diarrhea exist, including problems in either the large or the small intestine. Diarrhea originating in the large intestine often results in frequent defecation, in small amounts, and with mucus, blood, or both. Small-intestine diarrhea usually causes an increased volume of very liquid feces without a tremendous increase in frequency.

The greatest risk associated with a sudden onset of vomiting and diarrhea is loss of water and electrolytes. Dehydration often kills animals that are experiencing severe vomiting and diarrhea. Vomiting prevents adequate intake of fluids. Diarrhea and vomiting both increase the loss of fluids. Animals with long-term or chronic vomiting and diarrhea usually present with severe weight loss. If these animals can maintain hydration, the problem that develops is a loss of nutrients.

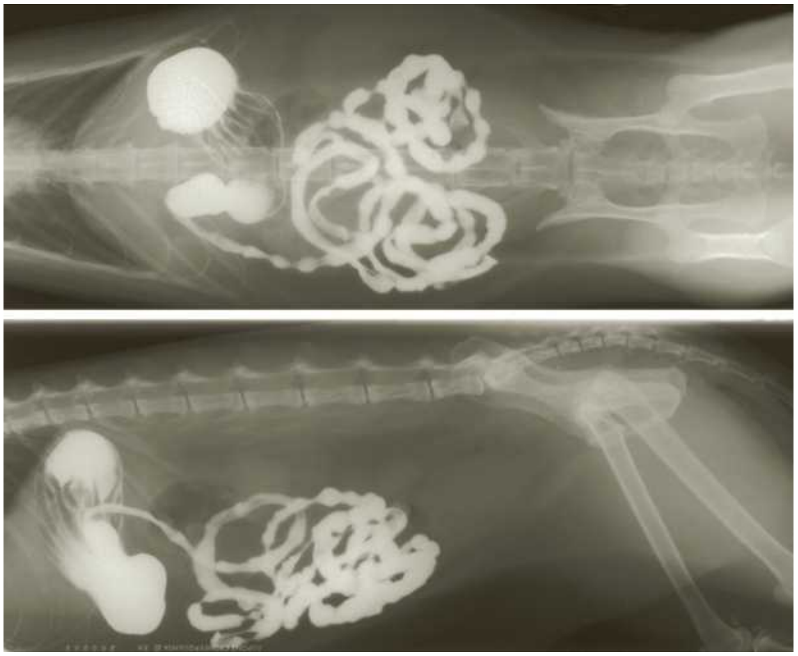

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FIGURE 7–19 Radiograph of a cat during a barium series. The bright white area is barium within the gastrointestinal tract.

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Many cases of vomiting, diarrhea, or both can be handled with symptomatic treatment. In cases of vomiting, the animal is taken off water and food for several hours (NPO). We often recommend up to 8 to 12 hours without food. However, very small pets or those with severe vomiting may lack the reserves to be kept off of fluids for that period. Each case must be evaluated individually and the animal monitored for dehydration. If the vomiting is under control when the animal is NPO, the pet is introduced to small amounts of water. If no vomiting occurs, the animal is then fed a bland diet. Bland diets, such as boiled chicken and rice, are very low in fat and high in fiber. Fiber in the diet helps to absorb water in the large intestine and slows down the transit of feces in the colon.

Animals that do not respond to such treatment must be treated for dehydration. (Refer to Chapter 6 to review the calculations used in fluid therapy.) Many medications are available to treat the symptoms of vomiting and diarrhea. It is also important to investigate the underlying cause and treat that condition if necessary.

In addition to diarrhea, animals can suffer from constipation. One common cause of constipation in dogs is the feeding of bones. The dog's powerful jaws crush the bones into pieces, which move into the colon and become tightly packed. The resulting feces can become extremely hard. Treatment in these cases is not fun for the animal or the veterinarian. These animals often require enemas (fluid is added into the rectum in attempt to soften the stool), manual removal, or even surgery to remove the firm feces.

Severe constipation is only one problem that veterinarians see as a result of dogs eating bones. Broken teeth, bones stuck in the roof of the mouth, bones stuck on the jaw, and vomiting can all result from dogs chewing bones. Many dogs eat bones without having problems; however, veterinarians see many of those that are not so fortunate. Because of all of the potential problems, it is strongly recommended that dogs should never be fed bones.

Horses show signs of colic when they have pain in the abdomen. These signs can occur with any problem that causes pain, but the most common causes are a direct result of intestinal pain. Often an affected horse has intestinal spasms with diarrhea, excess gas in the intestine, or severe constipation, but the complete list of possible causes is extremely long. Table 7–4 is a partial list of the common causes of colic in horses.

Diagnosing the underlying cause of colic can be difficult. A complete physical examination, including an examination of the feces and rectum, is important. At times a problem can be felt within the abdomen during a rectal examination. Response to treatment is also used to evaluate many patients if a specific cause is not determined. Pain-relieving medications and laxatives are often used in nonspecific colic. Many horses recover with a single treatment.

Table 7–4 Common Causes of Equine Colic

Accumulation of gas in intestines
Intestinal cramping or spasms
Impaction and constipation
Twisted intestine or colon
Abdominal tumors
Accumulation of sand in intestines
Parasitism
Intussusception
Peritonitis (inflammation of the peritoneum)
Stomach dilation
Hernia

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Further blood tests and radiographic or ultrasound examinations may help to define a colic problem. If a horse does not respond to treatment and the condition worsens, surgery may be required. Loops of the intestines can become twisted upon themselves, cutting off the blood supply (Figure 7–20). Surgery is required to correct such a condition. Such serious causes of colic can be life threatening for a horse. After surgery, these horses require intensive care, including antibiotics and intravenous fluids.

The condition of displaced abomasum has already been discussed in cattle. The rumen can also be a source of problems in cattle. The production of gas in the rumen is a natural event. The cows must periodically eructate or belch this gas to rid it from the rumen. If for some reason the gas cannot be eructated, the cow develops **bloat**. Bloat is a large gaseous distension of the rumen. This distension initially occurs high on the

Photograph courtesy Dr. Arthur Hattel, Pennsylvania State University.

FIGURE 7–20 A gangrenous (dark area) section of small intestine of a horse. The gangrene is due to lack of blood supply to the affected portion of the intestine and represents tissue damage at this site.

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FIGURE 7–21 A bloated cow. Note the distension high on the cow's left side.

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FIGURE 7–22 Metal and indwelling plastic trocars. Both trocars have a solid pointed spike in the center that is removed once the trocar is in place. With the spike removed, the tube portion of the trocar allows gas to escape.

left side of the abdomen, where the dorsal sac of the rumen is located (Figure 7–21). The rumen can become so distended that the entire abdomen takes on a distended appearance.

There are two classifications of bloat: free gas or frothy. In frothy bloat the gas is trapped in many small bubbles (much like the appearance of soap bubbles), which prevents the animal from belching a larger pocket of gas. Classically, this occurs after cattle are turned onto a lush pasture. The change in diet results in conditions in the rumen that create the small bubbles. Medications are available that break down the small bubbles, allowing the animal to eructate.

In free-gas bloat the gas accumulates in a large pocket in the dorsal sac of the rumen. The gas is in a form that could be eructated, but for some reason the cow cannot. One cause can be choke, in which the esophagus becomes obstructed with ingesta. The rumen is functioning normally, but the gas cannot physically pass out of the esophagus. Free-gas bloat may also result when the rumen is not functioning properly. The vagus nerve controls the normal contractions of the rumen. This nerve travels through the chest cavity to reach the rumen. In animals with pneumonia, this nerve can be damaged. The result is that the rumen stops contracting normally. Another common cause is low blood calcium (hypocalcemia or milk fever), which often occurs in older cows around the time of calving. Calcium plays a critical role in the function of muscles, including the smooth muscle in the walls of the rumen. Low calcium causes poor tone in the rumen wall and results in bloat.

Supplementing calcium corrects bloat associated with milk fever very quickly. In other forms of free-gas bloat, a stomach tube is passed through the mouth and esophagus into the stomach. When the tube reaches the gas pocket, the rumen deflates very quickly. Treating the underlying cause is then important to prevent recurrence. Bloat can be so severe that it is life threatening because of the pressure that it places on the diaphragm and blood vessels in the abdomen. Immediate treatment may be required, in which a trocar is driven into the rumen through the abdominal wall. The trocar is a large, sharp probe with a metal sleeve around it (Figure 7–22). Once into the rumen, the probe is removed, leaving the metal sleeve as an opening to drain the gas. A plastic trocar is also available that can be placed in the rumen for a longer term. This can be useful in cattle that have developed the bloat secondary to pneumonia. The stomach stays deflated while the animal is being treated for the pneumonia.

Morris, introduced at the beginning of the chapter, showed evidence of liver disease on his initial blood tests (Table 7–5). As discussed earlier, the liver is responsible for the metabolism of bilirubin, derived from the breakdown of hemoglobin from old red blood cells. An elevated bilirubin level can be evidence of excessive breakdown of hemoglobin, or a situation in which the liver is not functioning properly to clear it.

The liver cells are rich in enzymes used to perform a wide variety of metabolic functions. These enzymes are found in the bloodstream at normal levels in healthy animals. With disease conditions, the amount of these enzymes leaking into the bloodstream increases. Two examples are alanine transferase (ALT) and alkaline phosphatase (Alk Phos). ALT is found only in liver cells and elevations are an indication of recent or active liver damage. Alkaline phosphatase is found not only in liver but also in bone cells. Cells lining the biliary ducts are rich in alkaline phosphatase, so obstruction of the biliary ducts is a common cause of elevation.

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Table 7–5 Blood Results for Morris

		Date		
Test	**Reference Range**	**Dec. 12**	**Jan. 16**	**Mar. 9**
Glucose	70–120 mg/dl	93	94	93
Urea nitrogen	17–30 mg/dl	19	19	12
Creatinine	0.6–1.6 mg/dl	1.3	1.9	1.4
Sodium	143–153 mEq/dl	153	155	158
Chloride	108–128 mEq/dl	120	118	123
Bilirubin	0.1–0.3 mg/dl	1.5	2.1	15.4
Alkaline phosphatase	10–80 U/L	246	262	534
ALT	10–80 U/L	633	606	432
Total protein	5.3–7.2 g/dl	8	8.7	7.5
Calcium	7.8–11.2 mg/dl	10	11.2	10.1
Phosphorus	3.3–7.0 mg/dl	4.5	4.7	4.4

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ALT = alanine transferase.

On December 12, Morris had elevations in bilirubin, alkaline phosphatase, and ALT. The blood report defined the problem and traced it to the liver, but as usual the case did not specifically identify the underlying cause. At this point Morris was still doing well and a general treatment was started. Morris returned a month later for follow-up blood work. As Table 7–5 shows, no improvement was evident. Morris had also lost a little more weight, so we elected to refer him to a specialist.

The specialist detected an inflammation in the liver and also noted that the gallbladder was quite large and a portion of the common bile duct was distended. He was very concerned that there might be an obstruction in the duct. He prescribed a slightly different medical therapy and monitored Morris carefully. Unfortunately, Morris did not respond to this therapy. Blood results from March 9 show the progression. He was now referred to a surgical specialist.

The surgical specialist did an exploratory surgery and discovered that the bile duct was truly obstructed. Unfortunately, this structure is quite small and she was unable to relieve the obstruction. In an attempt to correct the problem, the surgeon created an opening in the gallbladder and in the duodenum. She then sutured these two openings together, creating an opening so that bile could be transferred directly to the duodenum without a duct. Fortunately, Morris responded very well to this surgery. He returned home, began to eat well, gained weight, and regained his enthusiasm toward life.

For six months Morris did quite well, but then began to decline. Unfortunately, liver disease progressed. A second surgery was performed and tissue samples were taken from the liver. The tissue samples showed that the liver cells were severely diseased and had deteriorated dramatically since the first surgery. The tissue samples showed why Morris had worsened, but nothing completely explained the underlying cause. Unfortunately, Morris did not respond to the second surgery. All of the veterinarians involved in this case truly appreciated what a great cat Morris was and were very disappointed at his passing. This case is a good example of using blood work to aid in diagnosing problems and the cooperation that occurs between general practitioners and specialists in the field of veterinary medicine.

SUMMARY

The basic process of digestion is the same for all animals. However, a variety of dentition and digestive tracts exists among differing species. Carnivores' teeth tend to be sharp to allow for tearing meat, whereas herbivores' teeth are smoother and more suited to grinding forage and grains. Swine, cats, and dogs are examples of animals possessing monogastric or simple stomachs. Cattle, sheep, and goats are all ruminants,

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which have multiple-compartment stomachs. Horses are monogastric animals with a specialized cecum that accommodates large volumes of forages. The differences among species challenge veterinarians to understand the disease conditions associated with each.

REVIEW QUESTIONS

1. Define any 10 of the following terms:

   intussusception
   colic
   carnivore
   herbivore
   deciduous teeth
   peristalsis
   monogastric
   phenobarbital
   symbiosis
   rumination
   eructate
   retching
   vestibular system
   bloat
2. True or False: The stomach is responsible for most of the absorption in the digestive tract.
3. What is the role of the pancreas?
4. Which organ absorbs a majority of digested nutrients?
5. Describe the role of the large intestine.
6. Compare and contrast papillae and villi.
7. True or False: Cows can produce 200 to 400 liters of saliva.
8. How does eructation aid in digestion?
9. What structure lines the entire abdominal cavity?
10. True or False: Horses and cattle conduct prehension in the same manner.
11. What substance can be provided to pets to aid in taking radiographs of the digestive tract?
12. Describe the three layers of the components in the rumen.
13. True or False: Ruminants have four stomach compartments that all have similar functions.
14. What is the role of bile in digestion? What would be the result if bile did not do its job?
15. The incisors of cattle, sheep, and goats push against what part of the ruminant's mouth?
16. What levels are checked to identify liver damage?
17. Describe why the stomach of animals is acidic.
18. Why are German shepherds often observed to be thin dogs with large appetites?
19. Which stomach compartment in ruminants is considered to be the true stomach?
20. True or False: Looking at the teeth of a horse can help to identify its age.
21. What structure covers the opening of the larynx?
22. NPO (veterinary lingo) means ________ .
23. Give two examples of how the digestive tract is protected from the high acid content of the stomach.
24. Name two monogastrics discussed in this text.
25. Describe the process of digestion in monogastrics.

ACTIVITIES

Materials needed for completion of activities:

rumen fluid
dropper
beaker
oil
slides
light microscope

1. After researching the digestive tracts of common domestic species, compare and contrast the structures and functions of at least four species of interest in chart form.
2. Search the Internet to find out how to examine horses' teeth to determine age.
3. Contact a butcher shop to obtain a sample of rumen fluid. If a fresh sample can be obtained, special care should be used to keep the organisms alive. Place the liquid rumen contents in a glass beaker. Cover the surface of the fluid with a layer

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of mineral oil. The organisms in the rumen do not survive when exposed to air; the layer of oil floating on top of the liquid helps keep air out of the sample. Place the beaker in a warm water bath (37°C). Place a drop of the liquid on a microscope slide, and cover with a cover slip. Examine the sample under the microscope. Numerous bacteria and protozoa should be observed. If a fresh sample can be obtained, there should be a large amount of movement from the organisms.

4. Use Table 7–1 to investigate the total number of teeth in the various species. Remember that the table lists the number of teeth for one side of the mouth. Research the number of teeth in the human mouth.

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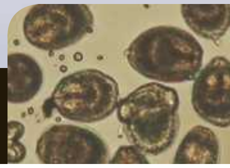
CHAPTER 8



The Reproductive System

Objectives

Upon completion of this chapter, you should be able to:

- Identify male anatomy and relate associated hormonal function.
- Discuss female anatomy and the estrous cycle.
- List the steps in establishing pregnancy and identify the stages of parturition.
- Discuss the clinical significance of the academic material learned in this chapter.

Key Terms

spay (ovariohysterectomy)	puberty	parturition	cesarean section
castration	polyestrous	gestation	ligated
prolapsed uterus	estrus	involution	pyometra
epidural	seasonal polyestrous	weaned	cryptorchidism
lidocaine	anestrus	obstetric	
estrous cycle	pheromone	whelping	

Introduction

The male produces sperm and delivers them into the female. The female then has the responsibility of providing the path and helping, through muscular contractions, to deliver the sperm to the location of the egg, which she produces. After the sperm and egg join, the female houses and nourishes the developing embryo until it is mature enough to survive on its own. At that point, the female delivers the newborn. Appropriately functioning reproductive systems in livestock largely determine the economic success of the producer. Veterinarians assist farmers in caring for the reproductive health of pets.

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A Day in the Life
Reproduction . . .

Preparing this chapter made me think about how much of my career revolves around the reproductive systems of animals. I had just finished my morning surgeries and had a break until my afternoon office appointments. My morning surgeries included a cat **spay** and front declaw, a dog spay, and two dog **castrations**.

In a spay, technically called an **ovariohysterectomy**, the ovaries and uterus are removed. In castration the testes are removed. Both spaying and castration prevent any unwanted pregnancies. In addition, the neutering procedure provides other health benefits.

Earlier in the text I mentioned that herd checks comprise a large portion of my job. Dairy cattle begin producing milk after their first calves are born. Subsequently, producers attempt to have the cattle calve every 12 to 13 months. At herd checks, I help facilitate this process, which includes checking for pregnancy. I perform more herd checks than any other dairy-related task.

Yesterday afternoon I received a call from one of our farm clients. He had a down cow, which means the cow was lying down and could not stand. The cow had begun to calve and did not have the strength to rise. She had developed hypocalcemia, or milk fever. (Review the role of calcium in the function of muscles in Chapter 2.) I gave her two bottles of calcium intravenously. Afterward the farmer and I examined another cow that was not eating well. When we returned to the down cow, the calcium had entered the muscles and the cow was able to rise.

I then thoroughly cleaned her vulva and reached into the uterus to find that the calf was ready to be born. Many cows with milk fever do not deliver normally because they lack muscle strength. Having been treated, this cow may have calved normally, but I could not be positive. I placed calving chains around the legs of the calf and, along with the farmer (and with the help of the cow pushing), pulled the calf. Fortunately, the calf was born alive and the mother was standing (Figure 8–1). To this day, cases such as this continue to be the most rewarding in my profession. The results are immediate and dramatic. I still enjoy helping to bring a newborn into this world.

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FIGURE 8–1 Newborn calf and dam.

I received an emergency call as I was writing this chapter. The receptionist at the office called to tell me that one of our Amish clients had a cow that had thrown her calf bed, or in other words had a **prolapsed uterus**. This heifer had just delivered her first calf two hours earlier. The calf was quite large, and following the delivery, the cow continued to strain. Consequently, the uterus turned inside out and was pushed through the vulva.

When I arrived, the cow was down and her uterus protruded behind her. Because our Amish clients have no electricity on their farms, the farmer lit a lantern for me to see. I felt like an old timer, working in the barn by lantern light.

I gave the cow an **epidural**, in which I inject a local anesthetic (**lidocaine**) into the fluid around the spinal cord. The epidural relieves pain in the region around the vulva and rectum. Because the cow felt no pain, she resisted my efforts less. I then pushed her large, swollen uterus back through the vulva. Fortunately, this case went very well. The farmer and I hoped for a positive outcome.

I am always looking for cases to illustrate both the material and the type of work that veterinarians perform. One morning this week, my first case sounded like it was going to be difficult. The farmer called to report that a cow was trying to calve, but the only things showing were the intestines of the calf (Figure 8–2). I've

continues

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A Day in the Life continued

FIGURE 8–2 This cow was in labor. The only portion of the calf showing was the small intestines.

FIGURE 8–3 Schistosoma reflexus—an “inside out” calf.

seen similar presentations before and knew that this calf was malformed. The scientific terminology, schistosoma reflexus, describes an “inside out” calf. My assumptions were correct, and there was no way that I could deliver the calf naturally. With the cow standing, I performed a cesarean section and removed the calf surgically. The legs of the calf were folded over the back, the inside of the skin showed, and the organs were on the outside (Figure 8–3). Fortunately, this problem is rare.

MALE ANATOMY AND HORMONAL FUNCTION

Objective

- Identify Male Anatomy and Relate Associated Hormonal Function

In mammals, the male produces sperm cells and has the means to deliver them to the reproductive tract of the female. The male anatomy provides the organs and structures to accomplish both.

In the male, the testes (singular is testis) lie external to the abdomen, housed in a skin-covered sac called the scrotum (Figure 8–4). The scrotum is lined by peritoneum, which stretches from within the abdomen. The cremaster muscle within the wall of the scrotum allows the testes to be pulled closer to the abdomen. For sperm production to occur optimally, scrotal temperature must be lower than body temperature. In warmer temperatures the muscle relaxes, allowing the testes to stay farther away from the heat of the body. As external temperatures decline, the muscle contracts, pulling the testes close to the body. This action helps to maintain a consistent temperature within the testes.

In the embryo, the testes develop within the abdomen. As development progresses, the testes descend into the scrotum. In most species a testis is oval with flattened sides. The testes produce sperm cells in a process called spermatogenesis. A large number of seminiferous tubules fill the testes. Sperm production occurs within the seminiferous tubules (Figure 8–5). In addition to being a reproductive organ, the testis is also an endocrine gland. Interstitial cells found between the seminiferous tubules produce a hormone called testosterone.

The testes closely adhere to the epididymis, a long, convoluted (highly folded) tube attached to the outer surface of the testes. The epididymis acts as a storage area for the sperm produced within the testes. In addition, the sperm go through their final maturation within the epididymis. This final development is necessary before the sperm become capable of fertilizing an egg.

On physical examination of a male, such as a bull, the testes and epididymis can be palpated.

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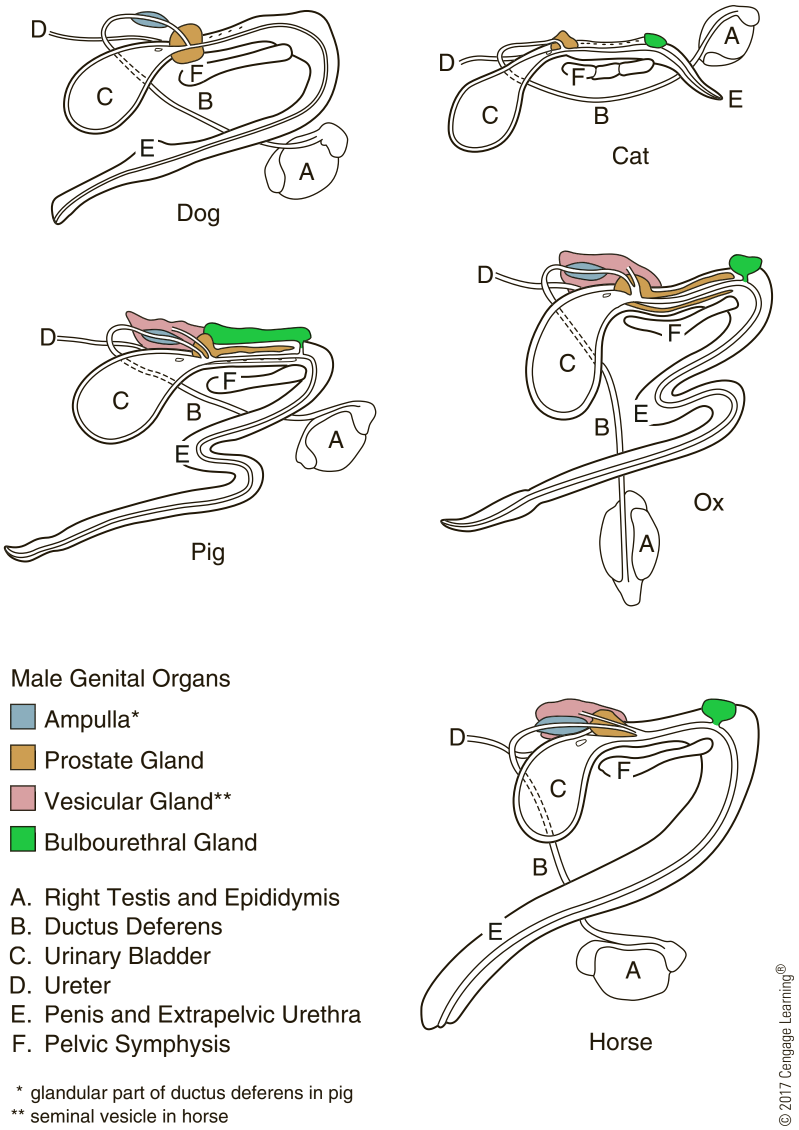

FIGURE 8–4 Male reproductive tracts.

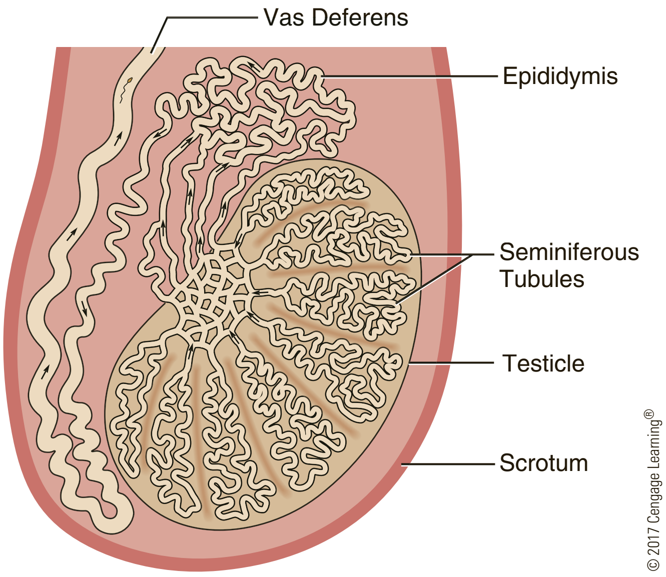

FIGURE 8–5 The structure of a testis.

The spermatic cord leads from the testis toward the abdomen. The spermatic cord contains the testicular artery, vein, and nerve. The arterial blood supply originates from the descending aorta in the abdomen. In addition to the blood vessels, the spermatic cord also contains the ductus deferens. The spermatic cord enters the abdomen through a small slit called the inguinal canal, which is located in the abdominal muscles. The tissues on each side of the inguinal canal lie in close apposition and provide a potential space through which other structures can protrude. If this region is weakened or does not develop properly, structures from within the abdomen (e.g., a loop of intestine or the uterus) may herniate through this canal. This condition is called an inguinal hernia. It can often be diagnosed by palpating the region and reducing the contents of the hernia (i.e., pushing them back into the abdomen). The defect can then be surgically repaired

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by suturing the edges of the inguinal canal together to reduce the size of the opening.

The ductus deferens carries the sperm from the epididymis to the prostate gland. Like many other tubular structures the ductus deferens has a wall with smooth muscle that allows for peristalsis to physically transport the sperm cells. The prostate gland is located at the base of the urinary bladder, surrounding the urethra. The prostate produces an accessory secretion, which adds to the sperm to produce semen. The prostate is the only accessory sex gland present in the dog. The secretions produced by the prostate are necessary for the survival and motility of the sperm. Cattle and horses have two additional accessory sex glands. They are the vesicular glands (previously called the seminal vesicles) and bulbourethral glands. Both these paired glands closely associate with the urethra. They too contribute to the fluid portion of the semen.

Within the prostate, the ductus deferens joins the urethra. The urethra, therefore, plays the dual role of carrying urine for excretion and semen for reproduction. The urethra then leads through the penis. The penis lies within a tubular, skin-covered sheath. This protective sheath, the prepuce, is lined with mucous membrane.

The penis has numerous blood vessels and sensory nerves within its structure. Larger open areas called sinuses connect the veins. This highly vascular tissue is housed in two paired corpora cavernosa on each side of the penis. In addition there is a smaller region, the corpus spongiosum, which is more closely associated with the urethra. As sexual excitement occurs, the flow of blood out of the penis is restricted. As blood continues to flow into the penis through the arteries, the sinuses become filled with blood. As the pressure increases, the penis becomes erect, protruding from the prepuce. Through this mechanism, the penis is able to penetrate the vagina of the female and deliver the semen. Ruminants and swine have a more fibroelastic penis that is firm when not erect. The penis extends by a straightening of the sigmoid flexure (**S** curve) near the base of the penis.

The penis divides into three regions. The two roots of the penis provide the attachment to the pelvis. The roots join into the body of the penis, which is a region rich in sinuses. The tip of the penis is called the glans. In horses, the glans is quite large whereas in the cat, it is covered with small spines.

The penis of the dog has several unique features. One noticeable feature is a small bone, the os penis, within the structure of the penis. This can be seen on a radiograph of a male dog (Figure 6-8). The os penis has a groove open ventrally through which the urethra passes. Occasionally, this structure is of clinical significance because it can be fractured with trauma, and it can be the site of obstruction if a bladder stone is passed through the urethra. At the base of the glans penis is the bulb of the glans, which contains erectile tissue. During breeding this tissue swells, resulting in the male and female dog being "tied." During this phase, the two dogs are facing in opposite directions and the penis cannot be removed. This normally lasts 10 to 20 minutes and ends in due course when the bulb of the glans shrinks. Do not attempt to separate dogs during this stage.

Precursor cells that line the seminiferous tubules produce sperm cells. Throughout the male's life, cells undergo mitosis, providing an unlimited supply of precursor cells. To produce sperm cells, the precursor cells undergo meiosis. The divisions of meiosis produce sperm cells with half the normal number of chromosomes. Review the process of meiosis in Chapter 1.

The spermatids produced through meiosis undergo changes to become functional sperm cells. Sperm cells have flagella that provide motility but have very little cytoplasm. Rather, chromosomes are densely packed in the head of the sperm. In addition, mitochondria at the base of the flagellum provide the energy necessary for motion. Also at the head of the sperm cell is the acrosome, a membrane-bounded sac containing hydrolytic enzymes. These enzymes are released when the sperm cell comes in contact with the egg cell at fertilization.

As mentioned earlier, the testes act as an endocrine gland, producing the hormone testosterone. Testosterone stimulates the development of the male genitals. Testosterone also produces a male's distinguishing features. The powerful musculature of the bull and the associated deep bellow are both a result of the hormone testosterone. Testosterone is also essential for the production of sperm.

Two hormones released from the pituitary gland help control the function of the testes. Both males and females produce these two hormones. They are named based on the function that they perform in females: luteinizing hormone (LH) stimulates the production of testosterone by the testes, and follicle-stimulating hormone (FSH) facilitates actual sperm production.

FEMALE ANATOMY AND HORMONAL FUNCTION

Objective

- Discuss Female Anatomy and the Estrous Cycle

The vulva, the external opening to the urogenital tract in the female, leads into the vagina. The opening of the urethra lies on the floor of the vagina. Urine exits through the urethra into the caudal portion of the vagina and then through the vulva. The vagina

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also leads into the cervix. The cervix, a portion of the uterus, is a firm structure that protects the opening of the uterus.

The uterus has a short body that joins the two horns of the uterus. The uterus takes on the shape of a **Y**, with the two horns leading from a common body and cervix (Figure 8–6). The proportion of body and horns varies between species. The uterus, a hollow muscular wall organ, is lined with a simple columnar epithelium and has the ability to expand dramatically to support the developing fetus.

The uterus tapers into a small oviduct or uterine tube that leads to the ovary. The ovary, the female gonad, produces eggs. The oviduct carries the egg from the ovary to the uterus. At the end of the oviduct lies a thin membranous infundibulum. The infundibulum wraps around the ovary to catch the egg after it is released from the ovary during ovulation. The ovaries are located caudal to the kidneys.

Branches from the descending aorta supply blood to the ovary and uterus. A separate ovarian artery sends blood to each ovary and oviduct and to the cranial portion of the uterine horn. Caudally, a uterine artery delivers blood to the cervix, uterine body, and each horn. The blood from the uterine and ovarian arteries then returns to the caudal vena cava by the uterine and ovarian veins. Knowledge of the reproductive tract's blood supply is critical during spays and castrations.

Ovaries produce eggs through meiosis. As the ovaries develop in the embryo, the precursor cells undergo the first step of meiosis and then stop. The number of eggs that can be produced is established at this point. This differs from the male, where the sperm precursor cells continue to undergo mitosis. The male basically has an unlimited supply of sperm cells. The number of eggs is established early in development but allows for a supply larger than the female would naturally use during her reproductive lifetime.

Females undergo an **estrous cycle**. This process begins at a point in the animal's development called **puberty**. Puberty represents the beginning of the animal's reproductive life and typically begins only after the animal reaches a certain percentage of its adult body weight. Nutritional deficiencies or diseases that slow growth will delay the onset of puberty. The estrous cycle prepares the female to become pregnant. Hormones control the cycle. Specific details associated with the estrous cycle vary among species. The bovine estrous cycle serves as an example and a species comparison follows.

The average estrous cycle in the cow is 21 days, although it may normally range from 17 to 25 days. The estrous cycle in cattle is described as **polyestrous**, meaning that cycling continues until the cow becomes pregnant. **Estrus** describes the animal when in a state of sexual excitement. In lay terms, the animal is said to be in heat. In the animal kingdom, estrus tells the male of the species that the female is receptive.

An estrous cycle has four phases. The events of each phase are distinct. However, the cycle flows without pause. Proestrus in cattle describes the 3 days prior to heat. The ovary contains a corpus luteum (CL), which produces the hormone progesterone (Figure 8–7). At the beginning of proestrus, the hormone prostaglandin releases into the bloodstream from the uterus. The prostaglandin causes the CL to regress, lowering the level of progesterone (Figure 8–8).

The declining progesterone results in increased activity of the pituitary gland and release of the hormones FSH and LH. The rising level of FSH results in the development of a follicle in the ovary. The follicle, a fluid-filled structure, surrounds the egg. The cells lining the follicle secrete the hormone estrogen in response to the FSH. Estrogen is responsible for the behavioral changes that occur in the female during estrus. The day before estrus there is also a sharp increase or pulse in the release of LH.

The actual estrus in cattle lasts 8 to 30 hours, although most animals cycle toward the shorter end of that range. The most definitive sign of heat occurs when a cow stands when mounted (Figure 8–9). Other secondary signs of heat include increased excitability, restlessness, bellowing, and mounting of other cows. (Cows not in heat usually try to run when mounted by another cow.) Cows in estrus may also show a clear mucus discharge from the vagina and a reddened vulva.

The developing follicle usually releases the egg 10 to 14 hours after estrus, which is the ideal time to artificially inseminate cattle. Release of the egg, or ovulation, occurs as a result of the surges in LH and FSH that occurred the prior day. Ovulation marks day 1 of the estrous cycle. The infundibulum captures the egg and transports it into the oviduct. If the cow was inseminated or bred, sperm is present in the oviduct to fertilize the egg.

After ovulation, the blisterlike follicle collapses, leaving a depression in the surface of the ovary (ovulation depression). Metestrus follows ovulation. At this point the level of estrogen begins to decline. A surge in LH stimulates the cells of the follicular wall to develop into a CL. *Corpus luteum* translates from Latin as "yellow body." The cells lining the CL begin to produce progesterone. The progesterone stimulates the uterus to prepare to nourish the embryo. Metestrus lasts three to four days, during which time the egg or embryo resides in the oviduct.

During diestrus the embryo moves into the uterus to establish a pregnancy; the CL produces a large amount of progesterone at this time. Progesterone stimulates the growth of the lining of the uterus and provides the necessary environment for the embryo to survive.

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A

B

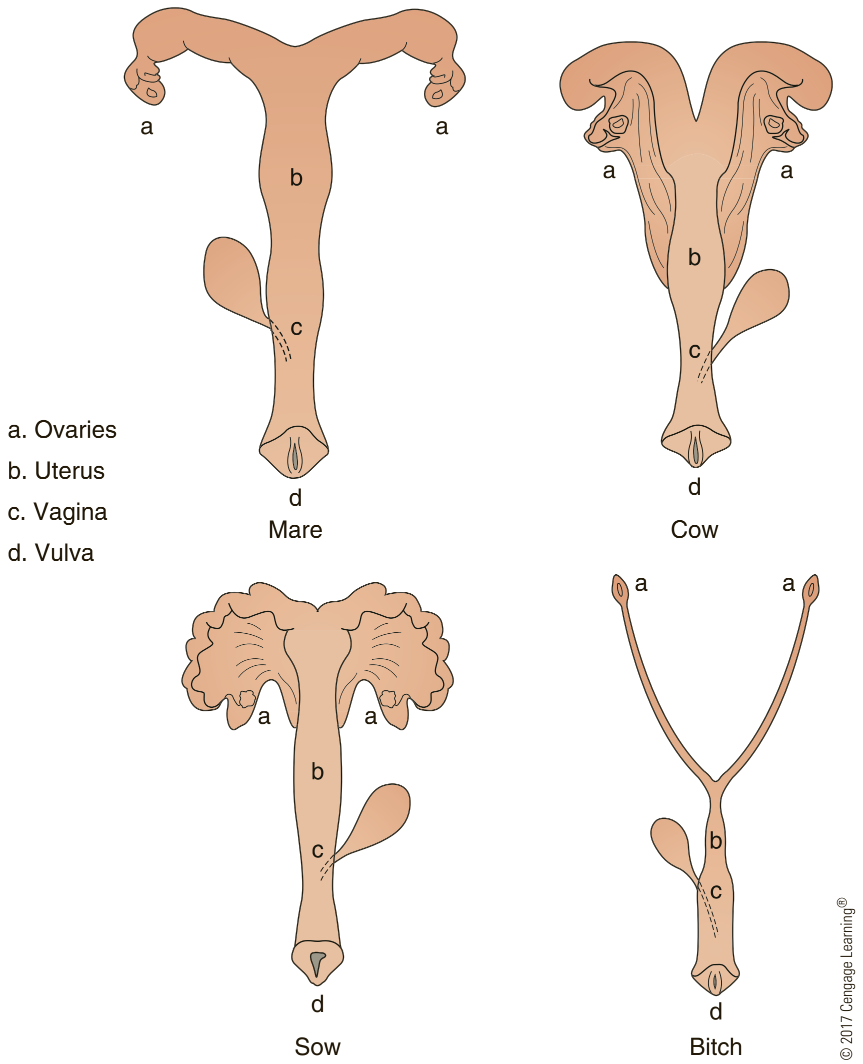

FIGURE 8–6 A. Bovine reproductive tract. The ovaries in this animal were unusually large, likely a result of a tumor. B. Illustration of the female reproductive tracts of several species.

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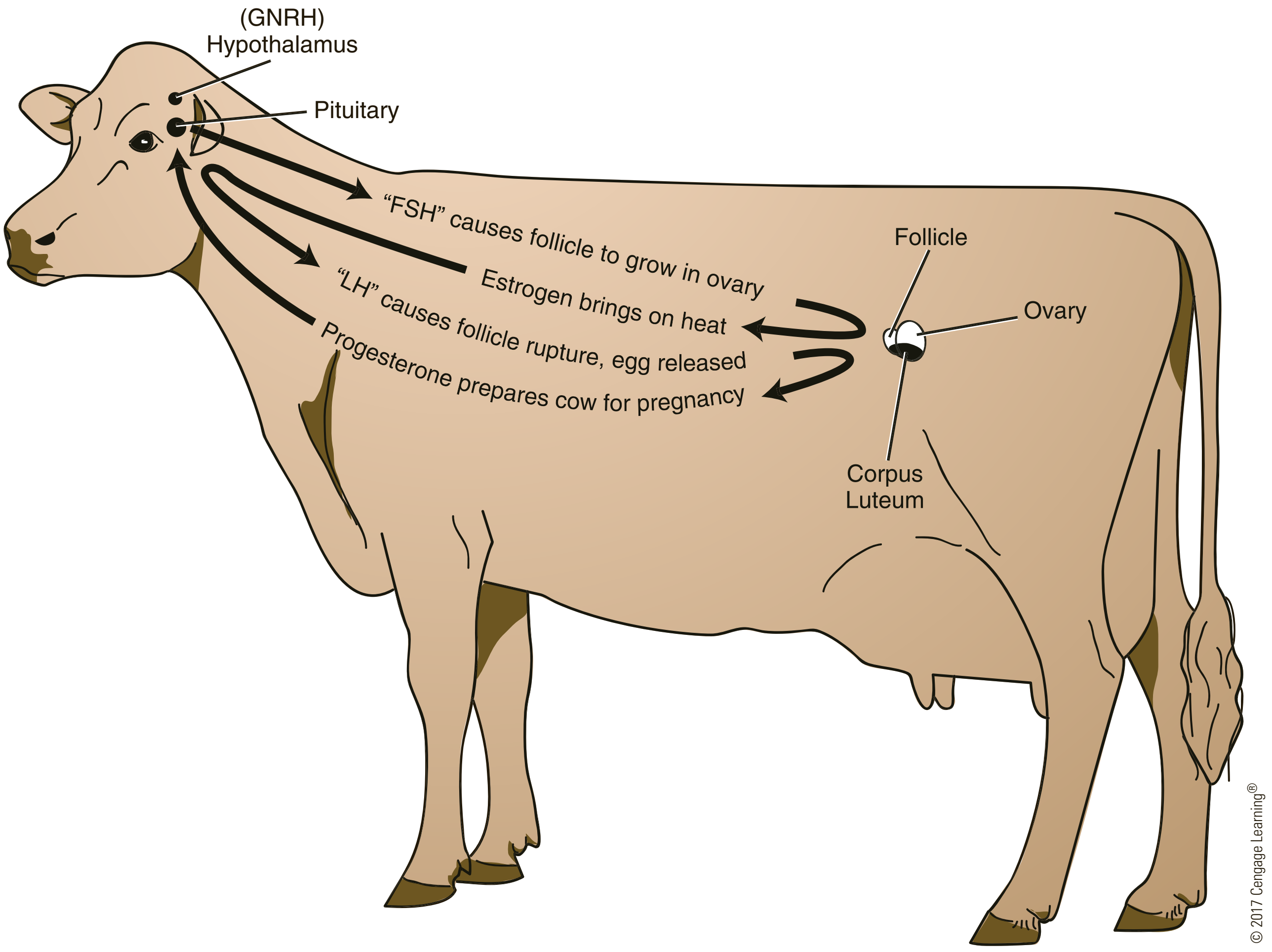

FIGURE 8–7 The hormones of the bovine estrous cycle. GNRH = gonadotropin-releasing hormone.

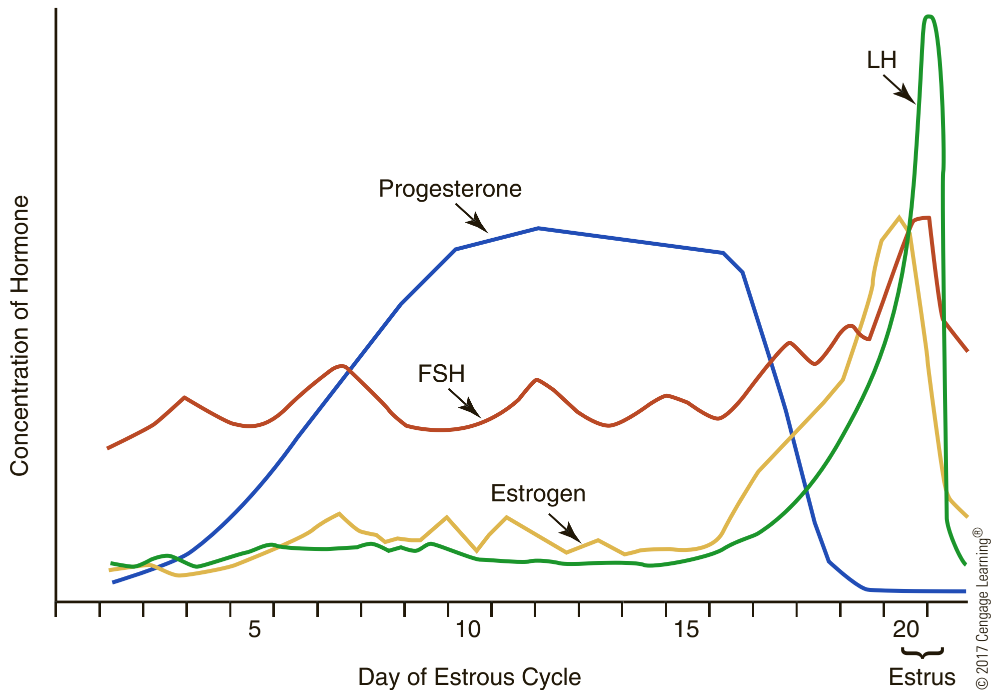

FIGURE 8–8 Levels of hormones in the bovine estrous cycle. FSH = follicle-stimulating hormone; LH = luteinizing hormone.

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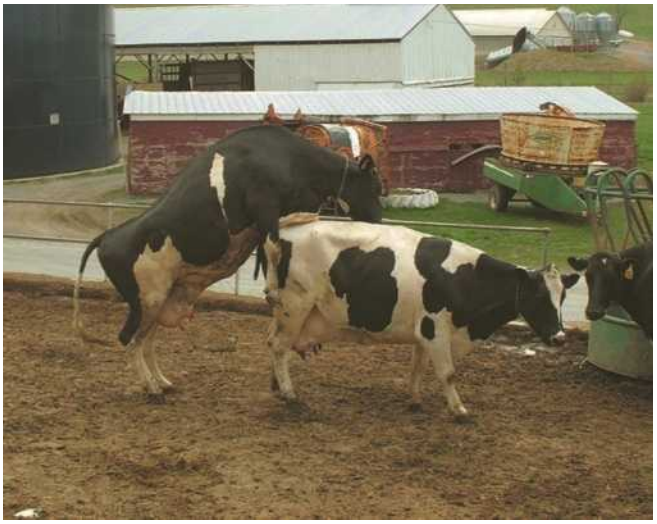

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FIGURE 8–9 A cow showing estrus. The lower cow was in standing heat. She stood still, accepting the heat mount by the other cow.

Diestrus lasts 12 to 15 days in an animal that does not become pregnant. Without a pregnancy, the uterus releases prostaglandin and the cow enters into the cycle at proestrus. Following the prostaglandin release, the entire cycle begins again, providing the cow another opportunity to become pregnant. If the cow is pregnant, the uterus does not release prostaglandin and the CL does not regress. Progesterone is essential to maintaining pregnancy. The CL must be maintained long enough to allow the pregnancy to be established. Without a pregnancy it is critical for the CL to regress for the animal to return to estrus.

Table 8–1 shows the variation that exists among the estrous cycles of the various species. Cattle and swine are both polyestrous, meaning that in animals that are not pregnant, the cycles continue throughout the year. Sheep, goats, and horses are also polyestrous, but the cycles occur only during certain times of the year (**seasonal polyestrous**). **Anestrus** describes the periods when an animal is not going through estrous cycles.

PREGNANCY AND PARTURITION

Objective

- List the Steps in Establishing Pregnancy and Identify the Stages of Parturition

The length of daylight, or photoperiod, affects many seasonal breeders. Horses, for example, are long-day breeders. Horses naturally enter the breeding season in the spring and summer as the days lengthen. For certain breeds, foals born earlier in the year are of more value. Therefore, techniques have been developed to use artificial lighting to initiate an earlier start to the breeding season.

Although there is variation among breeds, sheep are classified as short-day breeders. Sheep tend to have a breeding season in the fall as the days shorten. After gestating for five months, lambs are born at a time that maximizes their ability to survive, because pasture is usually plentiful in the spring.

Goats are also short-day breeders, with a breeding season that can extend from October to March. Cycling in goats can also be influenced by the introduction of a male. If female goats are housed separately from a buck, his reintroduction can initiate the breeding season several weeks early.

Cats are also seasonally polyestrous; however, the season can be quite long. The breeding season often begins in January as the days begin to lengthen and often continues until September. Cats are induced ovulators. The act of mating stimulates ovulation and a quicker end to estrus. The duration of the cycle varies depending on the timing and occurrence of breeding. Following breeding, a CL is formed, and the cycle may last up to three weeks. Without breeding, the cat may return to heat in a much shorter period.

Cats also enter anestrus when they are nursing kittens. The body's natural design allows support of an existing litter before entering into another pregnancy.

Table 8–1 Comparison of Reproductive Cycles

Species	Age of Puberty	Cycle Description	Cycle Duration	Estrus Duration	Timing of Ovulation
Cattle	12–15 months	Polyestrous	21 days	8–30 hours	10–14 hours after estrus
Sheep	7–12 months	Seasonal polyestrous	17 days	1 day	End of estrus
Goats	6–8 months	Seasonal polyestrous	21 days	12–24 hours	End of estrus
Horse	10–24 months	Seasonal polyestrous	21 days	6 days	Day 5 of estrus
Swine	4–9 months	Polyestrous	21 days	2–3 days	Day 2 or 3 of estrus
Dog	5–24 months*	Monestrous	6–8 months	3–21 days	Day 2 or 3 of estrus
Cat	4–12 months	Seasonal polyestrous	15–21 days	10–14 days†	Induced following breeding

*Larger-breed dogs tend to reach puberty at an older age than smaller breeds.
†Duration of estrus can be shortened, depending on the time of mating.

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If the kittens are removed from nursing, the cat enters breeding season again. Male cats may kill a litter of kittens if the female leaves them unprotected. It is presumed that the male does this to stimulate the female back into estrus.

Dogs are unique in being monestrous. Typically, a delay of six to eight months exists between heat periods. In dogs, proestrus lasts an average of 9 days but can continue up to 17 days. During this time the female attracts males but is not receptive to them. During proestrus the female typically has a bloody discharge from a swollen vulva. The blood passes through the wall of the uterus and vagina.

Estrus follows, during which the female accepts the male. The duration of estrus in the dog is quite variable, ranging from 3 to 21 days (the average is approximately 9 days). Diestrus, the first day that the female will not accept the male, follows. The CL is maintained for the same length of time in the pregnant and nonpregnant animal. Pregnancy typically lasts 63 days from the onset of diestrus. The CL regresses at the end of pregnancy and at the same point in time in the nonpregnant female.

The dog then enters anestrus. The next cycle does not occur for another six to eight months. Some dogs may have up to one year between cycles. The entire cycle does not vary between pregnant and nonpregnant dogs.

There is a tendency to compare the bloody vaginal discharge in dogs with the menstrual period in human females. In dogs, the discharge occurs prior to estrus and ovulation. The human menstrual cycle differs. Following menstruation, the uterine lining in women thickens. This thickening continues to increase following ovulation as the uterus prepares to accept a pregnancy. If no pregnancy occurs and the CL regresses, the lining of the uterus is sloughed or shed. Without a pregnancy, the uterine lining prepares for the next cycle.

All male domestic animals detect a distinctive chemical emitted by the female in estrus. This chemical is called a **pheromone**. Pheromones serve as a means of chemical communication between the sexes. Pheromones stimulate males to become sexually excited. A nervous reflex, controlled by the parasympathetic nervous system, constricts the vessels within the penis, resulting in an erection.

For all domestic animals, the female in heat then stands to accept the male, and the male's penis penetrates the vagina of the female. The male's excitement builds until ejaculation occurs. During ejaculation the ducts in the epididymis and ductus deferens contract, propelling the sperm forward. Immediately before ejaculation, the accessory sex glands contribute fluid to create semen. Urethral contractions help to propel the semen forward, depositing it in the cranial vagina. The sperm then propel themselves forward with their flagella. More importantly contraction of the walls of the vagina and uterus helps to move the sperm into the oviduct. Once in the oviduct, the sperm undergo further maturation. This process, called capacitation, prepares the sperm to be able to fertilize the egg.

The sperm meets the egg within the oviduct. The sperm attach to the cell membrane of the egg. The first sperm attaching then penetrates the membrane upon release of enzymes from the acrosome. Once one sperm enters the egg, the membrane changes to prevent any other sperm from penetrating. The nuclei of the egg and sperm combine, providing the fertilized egg with a complete number of chromosomes. The fertilized egg then undergoes a series of mitotic divisions, creating an embryo.

The embryo (using the cow as an example; specific details vary with species) stays within the oviduct for three to four days. Following this, the embryo moves into the uterus. Mitosis continues, increasing the number of cells within the embryo. As the cell number increases within the embryo, the major organs and systems develop in a process called differentiation. The presence of the embryo in the uterus inhibits the release of prostaglandin and prevents the cow from entering estrus again. The CL remains intact, secreting progesterone, which is necessary to maintain the pregnancy.

Beginning at day 28 and completing by day 45, the embryo attaches to the uterus. This process is called implantation. The points of attachment provide sites for transfer of nutrients and waste between the mother and embryo. In the cow, 80 to 100 of these sites, called placentomes, exist. A placentome has highly folded vessels of the mother closely associated with vessels of the embryo. Separating these layers gives the impression of dividing two layers of Velcro™ (Figure 8–10).

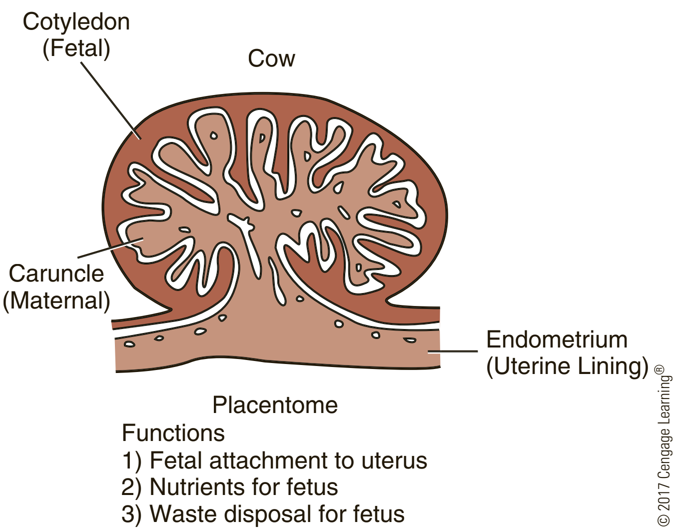

FIGURE 8–10 A placentome, the site of attachment between the fetal placenta and the maternal uterus in the cow. The actual blood supply of the two animals does not mix.

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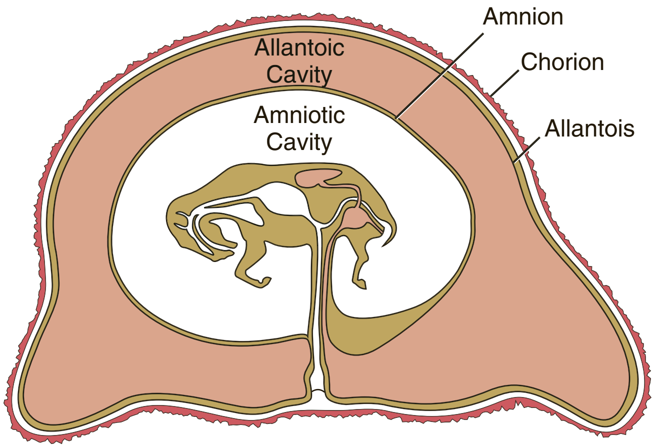

FIGURE 8–11 A developing fetus and the relationship to the placenta.

The intertwined vessels provide a large surface area that allows transfer of nutrients, oxygen, and wastes in a mechanism similar to that which occurs in the alveoli of the lungs. The blood of the embryo and mother do not mix. The principle of placentation is similar between species, but the site and appearance of the attachment varies between species.

The vessels from the embryo's circulation are contained within a set of membranes that surround the embryo (Figure 8–11). The embryo is bathed in a fluid-filled sac called the amnion. In addition, the surrounding membranes form the placenta, which contains the vessels that contact the uterus at the placentome (Figure 8–12). The vessels of the placenta combine into one large set that enters the embryo (the umbilical cord).

As the embryo undergoes differentiation, it develops the normal appearance and structures of a newborn. At this point the embryo becomes a fetus. The fetus grows relatively slowly early in the pregnancy as differentiation occurs. The most rapid growth of the fetus occurs in the last third, or trimester, of the pregnancy.

Table 8–2 Average Length of Pregnancy

Species	Length of Pregnancy (days)	Months*
Cattle	279–292	9
Goats	145–155	5
Sheep	144–151	5
Swine	112–115	3m3w3d†
Horses	330–342	11
Dogs	58–70	2
Cats	58–65	2
Rabbits	30–35	1
Elephants	600–660	20–22

*The length of pregnancy varies significantly with animals and breeds. The pregnancy length is therefore often averaged in months.
†The average length of pregnancy in swine is often considered as 3 months, 3 weeks, and 3 days.

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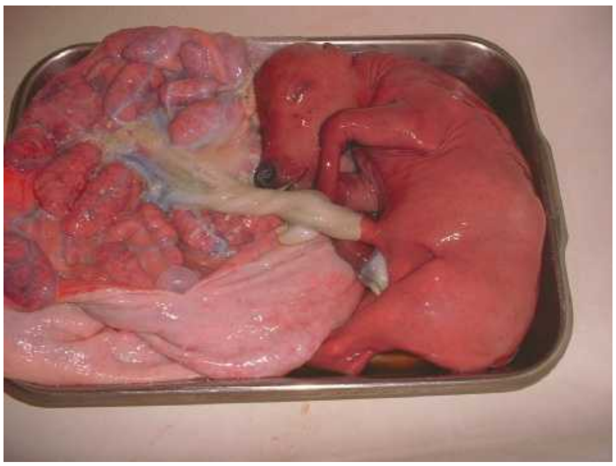
To maintain pregnancy, the CL must continue to produce progesterone. As the fetus develops, the placenta takes over production of progesterone. Eventually, the placenta produces enough progesterone that the CL is no longer necessary to maintain the pregnancy.

As the fetus approaches full term, hormone levels change in preparation for **parturition**. Table 8–2 summarizes the normal **gestation** period for all domestic animals. Parturition, or delivery of the newborn, occurs normally at a point when the fetus is capable of surviving on its own. As the pregnancy ends, progesterone levels begin to decline, and estrogen levels increase. The estrogen prepares the uterus for delivery. The fetus then increases its release of the hormone cortisone, which stimulates parturition to begin.

A



B

FIGURE 8–12 A. This photograph shows the relationship of a fetus with the umbilical cord leading to the placenta and uterine attachments. B. A close-up view of the placentomes.

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As parturition approaches a protein hormone, relaxin, is released to prepare the animal for the impending delivery. Relaxin helps to relax the muscles and ligaments in the pelvis to ease the passage of the fetus. In addition, relaxin is important in softening the cervix, allowing it to open.

Parturition develops in three stages. The initial stage prepares for the impending delivery. The animal becomes restless and uncomfortable, and the uterus goes through periodic contractions. The pressure from the fluids and placental membranes stimulates the cervix to dilate, or open. The cervix becomes much softer, and the opening increases.

As the cervix opens and the fetus begins to enter the pelvic canal, the animal enters the second stage of parturition. During this stage of active labor, the uterus undergoes much stronger contractions and abdominal contractions begin. These strong contractions force the cervix to completely open, and the fetus enters the pelvis. The contractions then continue until the newborn animal is delivered.

Following delivery, the mother often licks the newborn to stimulate breath. Any fetal membranes that might still be over the nose and mouth are also removed with stimulation from the mother. The sudden stop in delivery of blood through the umbilicus signals the newborn to breath.

In the final stage of parturition, the placental membranes are expelled from the uterus. Once the membranes have separated, the uterus begins to shrink back to its normal size. This process is called **involution**. Uterine size dramatically reduces after delivery. In the Holstein cow an average calf often weighs 40 to 45 kg. The uterus must stretch to accommodate the calf and an equal volume of fluid. Within three weeks after delivery, the uterus in a normal cow will have shrunk to only 35 to 40 cm in length and 3 to 4 cm in diameter. Horses also realize a drastic uterine change after birth. Usually, within one week of delivering a foal, a horse comes into heat and the uterus is ready to carry another pregnancy.

At delivery the fetus has to become independent; it no longer relies on the mother for nutrients and waste elimination. Several important changes occur once the blood supply stops at the umbilical cord. In the uterus, the blood supplied through the umbilical vein is rich in oxygen and nutrients, which were transferred from the mother to the fetus's circulation in the placenta. Because of this maternal supply, the fetus does not rely on adult-type circulation.

In the fetus, an opening called the foramen ovale lies between the left and right atria (Figure 8–13). In addition, a connection called the ductus arteriosus exists between the pulmonary artery and aorta. Much of the blood delivered to the right atrium bypasses the pulmonary circulation through the foramen ovale and the ductus arteriosus. The fetus does not rely on the lungs to oxygenate the blood; therefore, little is delivered there. The highly oxygenated blood delivered by the umbilical vein then directs quickly into the systemic circulation. Blood returns to the placenta through the umbilical arteries to eliminate the wastes and replenish the nutrients and oxygen.

The blood supplied to the fetus is rich in nutrients that have already been processed by the mother's liver. In addition, the liver of the fetus does not fully function. A ductus venosus shunts blood around the fetal liver. About half the blood entering through the umbilical vein is directed around the liver and directly into the caudal vena cava. Note that the blood delivered to the fetus in the umbilical vein is rich in oxygen and nutrients. The vessel delivers blood toward the heart and is therefore a vein, not an artery.

At birth a dramatic transition occurs. The newborn must take a first breath and expand the lungs. This process reduces the pressure in the vessels, allowing blood to flow more freely into them. As the pressure changes within the vessels, the foramen ovale closes with a small valve. With time, this closure becomes permanent. Similarly, the ductus arteriosus constricts, thus stopping the flow of blood. This closure becomes permanent with time. As you might expect, the ductus venosus undergoes a similar constriction followed by a permanent closure. These three changes are necessary for the conversion of the fetal circulatory system to the adult-type system.

In mammals, the mother supplies nutrition to the infant in the form of milk. The mammary glands, a collection of epithelial-lined ducts, are housed within connective tissue. The secretory cells are arranged in alveoli with a duct that takes away the milk. The ducts join into larger ducts until they meet in a gland cistern, a collecting area. The gland cistern then flows into the teat cistern, the open area within the teat. The streak, or teat canal, is the sphincter that allows milk to pass to the outside. In cattle the udder is supported by a well-developed suspensory ligament in the center and lateral edges of the udder. It is common for high-producing dairy cattle to produce more than 100 lb of milk in a day and this weight needs to be supported.

There is considerable variation among the domestic species in the number and location of the mammary glands. Horses, goats, and sheep have two mammary glands, while cows have four. In all these species, the mammary glands are located inguinally (i.e., between the rear legs). Cats, dogs, and pigs have 10 to 14 glands that run the entire length of the ventral abdomen and thorax. The ducts empty into a teat cistern at the base of the teat. The milk can then flow through the teat canal and teat orifice.

Initial development of the mammary system begins at puberty. Development is stimulated by the presence of estrogen and progesterone. The mammary system undergoes dramatic development during pregnancy. The high levels of estrogen stimulate significant growth in the epithelial cells that will eventually secrete milk.

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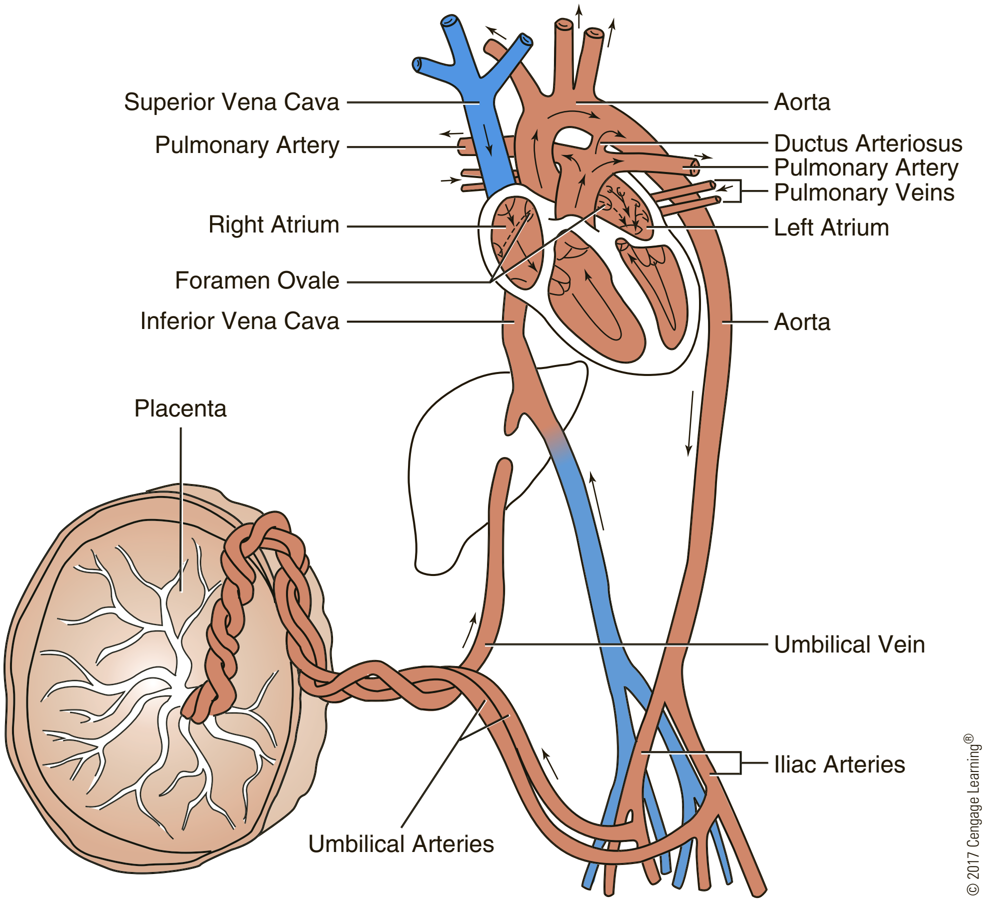

FIGURE 8–13 Fetal circulation. Important differences exist as nutrient- and oxygen-rich blood is supplied from the placenta in the umbilical vein. The fetus does not rely on its own lungs for the supply of oxygen. The foramen ovale and ductus arteriosus lessen the flow of blood to the fetal lungs.

High progesterone levels during pregnancy stimulate even further development of the secretory cells. The hormone prolactin increases as parturition approaches. Prolactin stimulates the production of the enzymes in the secretory cells that are essential for the production of milk. Oxytocin, a hormone released by the posterior pituitary, actually causes the release of milk from the ducts into the teat cistern (Figure 8–14). The secretory cells and ducts are surrounded by myoepithelial cells, which contract under the influence of oxytocin. Before the release of oxytocin the majority of the milk is stored in the alveoli and ducts, not in the gland cistern. This allows the newborn access to the milk as it suckles on the teat. Suckling by the calf or udder preparation at milking time stimulates the release of oxytocin.

Following parturition, milk production increases as the newborn grows. Dairy cows have been selected and fed for higher production. Typically, these animals produce much more milk than is needed by the calf. Dairy cattle reach peak milk production almost 2 months into their lactation. Production then slowly declines over the next 8 to 12 months.

In most other species, the mother continues to produce milk until the nursing animal can consume a normal adult diet. When the infant is **weaned** (stops nursing), the milk production continues initially. However, pressure begins to increase in the alveoli of the mammary gland, which signals the mother to cease milk production. Likewise in dairy cattle, at the end of lactation the cattle are given a dry period when they are not milked. Once milking has stopped, the pressure builds in the udder signaling the cow to stop producing milk. The mammary gland undergoes involution where the cells of the alveoli regress. These cells are then regenerated as the next parturition approaches.

Newborn and Orphan Patients

The care of newborns is the same whether assisting a natural delivery or resuscitating pups or kittens delivered via cesarian section. The first priority is to establish a clear airway. Any fetal membranes should be cleared from the nose and mouth and the mouth suctioned to remove any excess fluid or mucus. The animal is then rubbed with a warm towel to stimulate respiration, dry it, and keep it warm. Healthy natural-born animals should respond quickly. Following a cesarean section, newborns are often more sedated and require more

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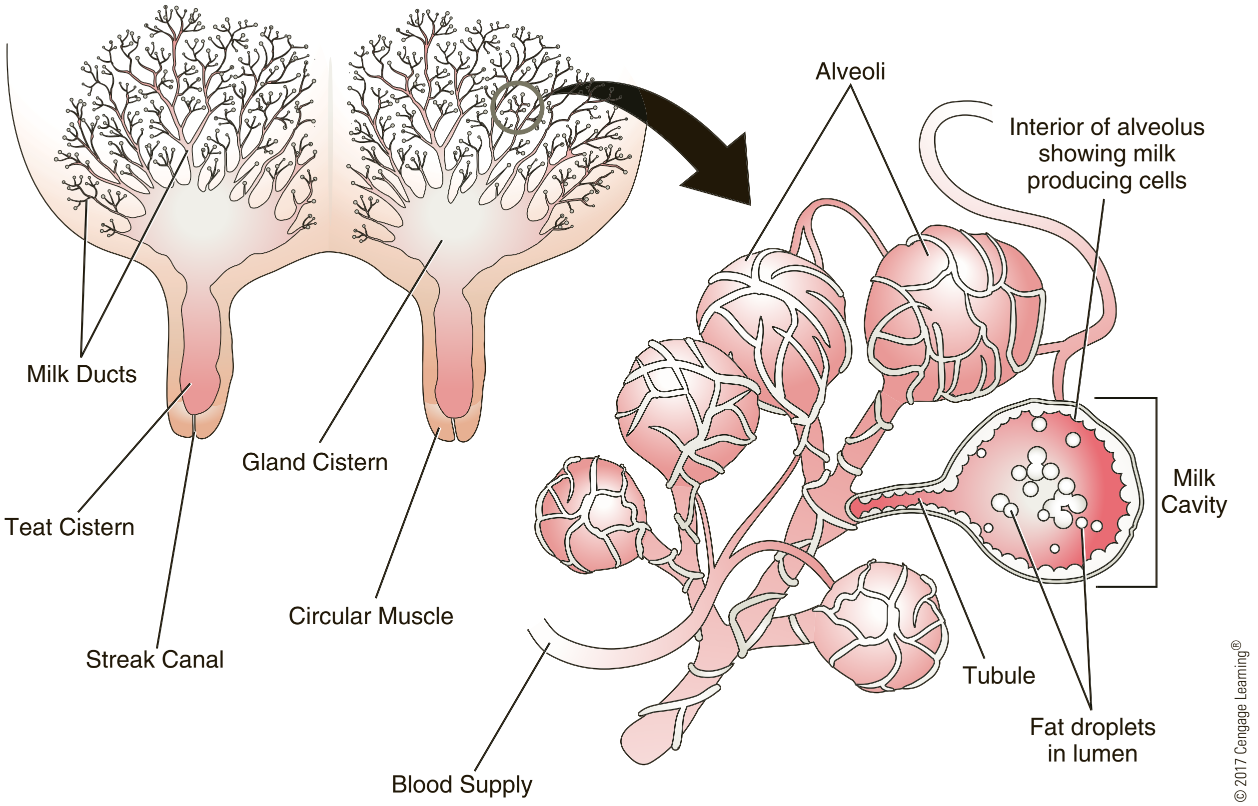

FIGURE 8–14 The udder of a cow.

effort to establish regular breathing. It is an excellent sign when the newborns vocalize.

Orphaned animals require the caretaker to provide nutrition. Although it is ideal to provide the animals with colostrum from the mother, it is not always possible. Milk replacer formulations are specifically developed for newborns. Healthy, aggressive animals can be nursed with a properly sized nipple bottle. Weaker animals may need to be fed with a feeder tube inserted into the esophagus, and the milk replacer injected with a syringe.

CLINICAL PRACTICE

Objective

- Discuss the Clinical Significance of the Academic Material Learned in This Chapter

Only after the first breath is the newborn no longer dependent on the placental blood supply. In a difficult delivery, the umbilical vessels may become obstructed by pressure against the bones of the mother's pelvis. If this restriction occurs for too long, the fetus will die. The changes in the fetal circulation at birth are not always successful either.

As a fetus prepares to be delivered, the ideal positioning for the animal is to be coming head first, with the two front feet pointing forward (Figure 8–15).

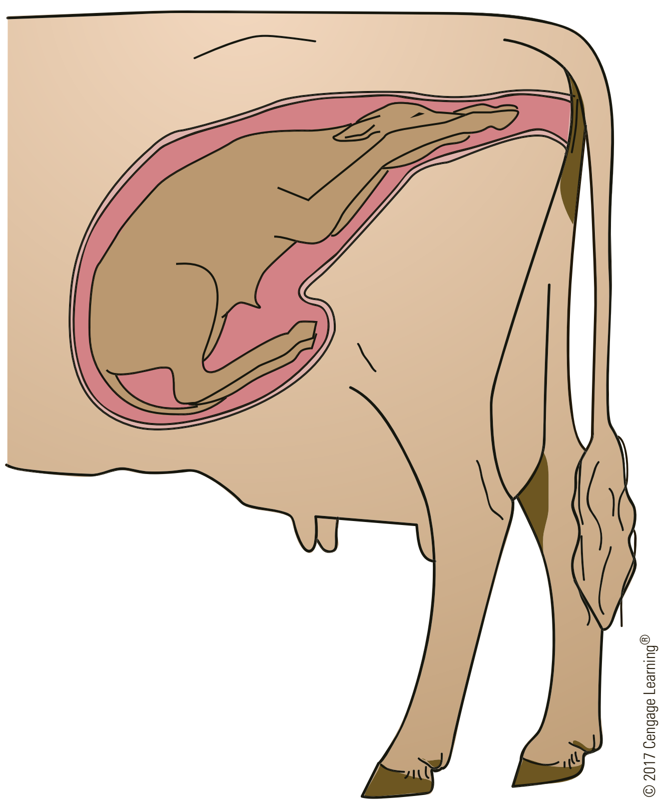

FIGURE 8–15 Normal presentation of a calf at birth.

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Using a cow and calf as an example, the calf's head works to dilate or open the cervix as it pushes through the pelvic canal. As the calf is further delivered, the head becomes exposed by the time the umbilical vessels are pinched over the pelvis. In this presentation, the calf is not at risk of inhaling amniotic fluid as it tries to take its first breath.

Calves are often born with both hind legs coming first. Cows usually have more difficulty delivering calves in this position. However, a calf can be removed in this position, even if it takes additional force. In dogs and cats, front and rear presentations occur equally and are both considered normal.

Not all calves are born with a normal presentation. Figure 8–16 shows illustrations of several abnormal calf presentations. In these positions, a calf usually cannot be delivered without assistance. In these situations, the farmer or veterinarian must correct the positioning of the calf. Cleaning the vulva is the first step. This prevents contamination of the uterus with bacteria. Then, using plastic gloves that reach up to the shoulder, the farmer or vet must reach into the vagina and uterus and assess the positioning of the calf. Knowledge of anatomy is very important in this task. The person delivering must rely on the feel of various structures to identify the positioning of the calf. The head is quite obvious, but it is important to distinguish front legs from back legs.

To reposition the calf, it is pushed deeper into the cow. This provides room to allow a leg or head to be moved. This can be physically challenging, because the cow's natural reaction is to push. Correcting the position of the calf is usually a multistep process. It is unusual to be able to make the correction on the first attempt. Usually, the calf is forced in deeper and a small correction is made in the position of a leg until the cow forces the calf back. The process is repeated until the calf is moved to a normal forward presentation or with both hind legs coming first.

Once the calf is properly positioned, the cow may still need assistance to deliver. In cattle, **obstetric**

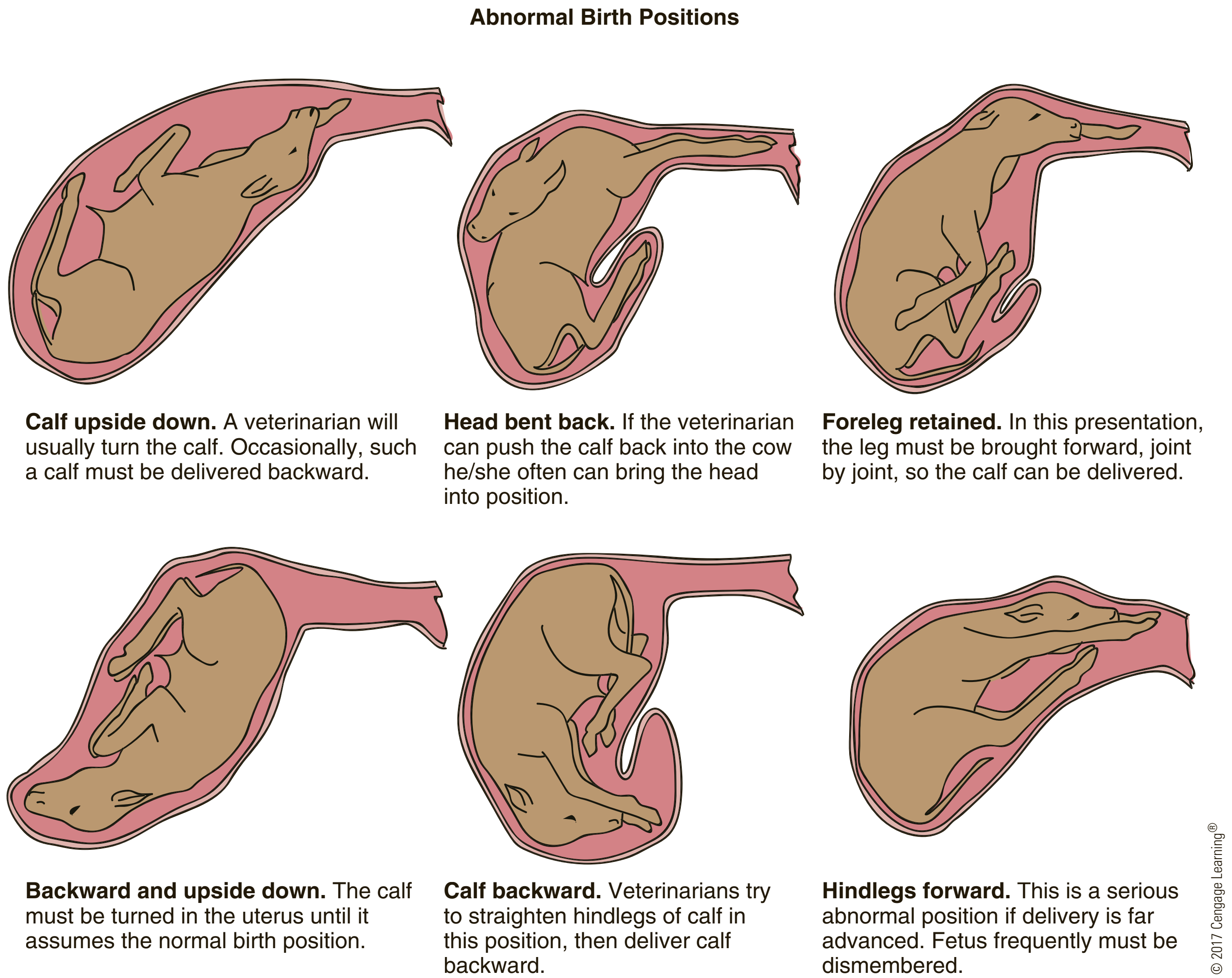

FIGURE 8–16 Abnormal presentations of calves. The presentation must be corrected before delivery is possible.

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FIGURE 8–17 A fetal extractor (calf jack) in action. The extractor applies pressure to the hind limbs of the cow as traction is applied to the calf.

chains or straps are placed around the calf's legs, and then force is applied to aid the cow (*obstetrics* relates to pregnancy and birthing). This force may come in the form of human power, a come-along, a block and tackle, or a calf jack. A calf jack presses against the cow's hindquarters and has a bar with a winch system to provide tension on the calf (Figure 8–17).

Obviously, dogs and cats do not have the size to allow for such intervention. Often just prior to delivery, the pet makes a nest in a secluded location (such as a cat nesting in the sock drawer). A dog's rectal temperature drops below 100ºF within 24 hours of **whelping** (normal temperature being 101ºF to 102ºF). As the dog reaches full term, daily rectal temperatures can accurately predict the date for the delivery.

As a dog enters the first stage of labor, she becomes restless and nervous. True labor develops when the dog begins to actively strain. When a dog is in labor more than five hours, or more than two hours between pups, a problem might exist. It is important for owners to understand that labor may not progress if their dog is upset. Frequent visits and interaction by the owner and family can cause a dog to stop progressing when in early labor. The dog's natural instinct is to find a secluded spot and avoid outside interference.

Dogs often show signs of a false pregnancy. Hormone changes in dogs are the same whether pregnant or not. The life of the CL is the same in both conditions. As the CL regresses and the progesterone declines rapidly, a dog that is not pregnant may show many signs of being pregnant. The dog may also become restless and nervous and begin nesting. Stories of dogs taking stuffed animals to mother are common. This condition is temporary, and the animals return to normal without treatment.

Whenever any animal reaches a point where the veterinarian is unable to complete the delivery, a **cesarean section** (c-section) is required. The c-section is a surgical procedure in which the body wall and uterus are incised and the fetus is extracted. In dogs and cats a ventral midline incision is commonly used. In this surgery the pet lies on its back and an incision is made down the centerline of the abdomen. The uterus is brought outside the body, and an incision is made into it (Figure 8–18). A puppy or kitten is then removed from within the uterus. The umbilical cord is clamped and cut and the puppy or kitten is quickly handed to an assistant. The assistant then stimulates the newborn and suctions any liquid from its mouth and nose. The incision in the uterus is then sutured, followed by the body wall. Often the dog or cat is spayed following the c-section. In cattle, one method is to do the surgery with the cow standing. The abdomen is entered with an incision in the abdominal wall on the left side.

As mentioned in the beginning of this chapter, spays and neuters, or castrations, are common surgical procedures in small animal practice. In the spay, the female's abdomen must be opened surgically, and the ovaries and uterus are removed (ovariohysterectomy). The ovarian and uterine arteries and veins must be **ligated**, or tied, before the organs are removed.

Spaying is extremely valuable in controlling pet populations. In addition, the procedure has some distinct health benefits for the pet. Obviously, spaying prevents an unwanted pregnancy and the risks that may occur at delivery. In addition, spayed animals no

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FIGURE 8–18 Intraoperative photograph of a c-section in a dog. The distended uterus has been exteriorized. The next step is to incise the uterus to remove the pups.

longer come into heat, which eliminates the behavioral challenges associated with estrus. For example, cats become very vocal during estrus. Both dogs and cats are much more likely to roam when in heat, increasing the risk of other problems, such as being hit by a car.

In addition, removing the uterus prevents a very serious disease called **pyometra**, an infection within the uterus, which often occurs in elderly dogs and cats (Figure 8–19). This disease can be life threatening if left untreated. The standard treatment is to spay the animal. Unfortunately, instead of spaying a healthy young animal, the veterinarian must perform the surgery on an elderly sick animal with an infected organ to remove. The risks are much higher in this type of surgery. Spaying pets before their first estrous cycle dramatically also decreases the risk of mammary tumors.

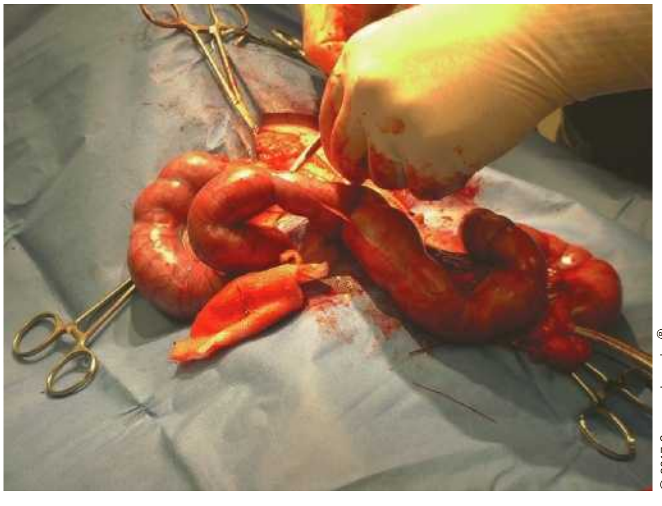

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FIGURE 8–19 Intraoperative photograph showing a pyometra. Note that while the uterus may have a similar appearance to a pregnancy, this uterus is filled with pus.

Castration in pets is an easier surgical procedure. In dogs, a skin incision is made in front of the scrotum on the midline. The testis is pushed into the incision, and the connective tissue is incised until the testis can be removed. The spermatic cord, which includes the testicular artery and vein and the ductus deferens, is ligated and the testis removed. The second testis is then removed through the same incision.

Castration also provides distinct health benefits. Neutering a male at an early age greatly decreases the risk of tumors and enlargement of the prostate gland. Many male dogs develop such problems as they age. Castration also has behavioral benefits. Neutered males are much less likely to roam and are often less aggressive.

Remember that the testes originate within the abdomen of the fetus and then descend into the scrotum. One or both of the testes may fail to enter the scrotum, a condition called **cryptorchidism** (today's gravy-splasher!). The retained testis may be in the abdomen, in the inguinal canal, or under the skin in front of the scrotum. This testis is much smaller than a descended testis. The higher temperature surrounding this testis prevents its full development. These testicles will not produce viable sperm cells, but will secrete testosterone. Cryptorchid dogs have a higher rate of tumors in the retained testicle. Surgery to castrate a cryptorchid dog is a little more difficult. The retained testis must be located, which may mean opening the abdomen. The small size of the testis can make it difficult to find.

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Cows that have a very large calf are more likely to have a prolapsed uterus. Following a difficult delivery, all the tissues in the vagina and vulva are stretched and irritated. The cow may continue to strain, causing the uterus to begin to turn inside out (Figure 8–20). When the tip of the uterus enters the pelvic canal, even more straining occurs. Eventually, the entire uterus is exposed outside the body.

This can be a life-threatening situation. The uterine arteries must stretch to travel that far. These vessels can tear, and the cow can bleed to death. In extreme temperatures the exposed uterus, rich in blood vessels,

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B

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FIGURE 8–20 A. Cow with prolapsed uterus. B. Close-up view of prolapsed uterus showing placentomes.

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causes the animal to lose or gain tremendous amounts of heat, and the animal can die. One of our clients had a beef cow that began running as he tried to catch her. The cow's entire uterus tore. She rapidly bled to death.

A cow with a prolapsed uterus may first be given epidural anesthesia. A local anesthetic is injected in the space surrounding the spinal cord. This decreases the sensation in the entire pelvic region, minimizing straining as the uterus is replaced.

After being cleaned, the uterus is held close to the body at the level of the vulva, so that the weight of the uterus does not keep pulling it outward. Then, using the back of the fist or the flat portion of the hand, the uterus is pushed back into the cow. This can be a difficult task, because the uterus can be very fragile and the points of the fingers can puncture it. The longer the uterus has been prolapsed, the more swollen it becomes. The swelling makes it more difficult to push it through the vulva. Once the entire uterus has been replaced, it is important to completely correct the positioning. If a portion of the horn is left turned inside out, the condition could recur.

At herd checks, rectal examinations are performed when palpating cows' reproductive tracts. The cervix, uterus, and ovaries are felt through the thin rectal wall. The size of the uterus is judged to evaluate if the cow is ready to be bred, and the ovaries are checked for structures. Ovarian structures include the CL, a follicle, or a cyst. A follicle feels much like a blister and can be up to 2.5 cm (1 inch) in diameter. The CL is a firm structure that often has a bump at one margin where the follicle had released its egg. A follicular cyst is a follicle more than an inch in diameter. This abnormal condition occurs when a follicle does not release its egg normally. While an animal is cystic, it will not become pregnant. Some follicular cysts produce excess estrogen. Cows with this type of cyst show estrus very frequently and irregularly.

The changes in the circulation after birth are quite dramatic, although there are times where the process is not completed. For example, if the ductus arteriosus does not close, a heart murmur will be present. The pressure in the aorta is higher than in the pulmonary circulation, so blood is shunted from the aorta. This murmur exists throughout the entire cardiac cycle and is called a machinery murmur. When the ductus partially closes, the leakage is less severe. Affected animals do not have normal circulation, and as they grow, the signs worsen. Many of these animals do not grow well and are inactive. Surgery can be performed to ligate the ductus arteriosus, and a complete cure can be expected. The surgery is quite delicate and is usually performed by a surgical specialist. The cost of the surgery can be quite high. The last puppy that I can remember having this type of repair was being raised as a seeing-eye dog. The surgery was a success, and the puppy recovered nicely.

The portocaval shunt can remain open, again to varying degrees. Animals with this condition show signs as they grow in size. (Review the circulation to the liver and the function of the liver.) Normally, the blood from the intestinal tract goes through the liver for processing. With a portocaval shunt, much of this blood goes into the systemic circulation. Certain nutrients absorbed from the intestines, such as ammonia, become toxic at high levels. The blood flows through the body, including the brain, instead of into the liver, where the ammonia could be removed. Seizures can occur, usually a short time after a meal. One of the keys to diagnosing this disease is a history of the signs worsening after eating. This condition too can be repaired by surgically ligating the vessel, redirecting blood into the liver.

In nature, the act of breeding occurs naturally. With the management of domestic species, human intervention is often required. For example, a dog in heat may need to be transported to another location to be bred by the male. Because the length of proestrus is quite variable, choosing the correct time for breeding is not easy. As the dog progresses from proestrus to estrus, the epithelial cells lining the vagina undergo distinct changes in response to estrogen levels. A veterinarian can use a sterile swab to collect some of the vaginal epithelial cells and observe them under the microscope.

During anestrus, the epithelial cells are small and cuboidal. As proestrus develops the cells develop into larger stratified squamous epithelial cells. As the cycle progresses toward estrus, these squamous cells have more keratin deposited within the cytoplasm and the nucleus becomes much smaller. Eventually, the nucleus is completely lost from these cells. By doing vaginal smears every few days, the veterinarian can follow the progression of changes in these cells. Once nearly 100% of the cells are keratinized and without a nucleus, the dog is in estrus and can be introduced to the male. Typically, the female is bred every other day for several breedings. This improves the odds of proper timing relative to ovulation and therefore of getting a pregnancy.

The dog is the only one of the domestic species that typically develops prostate disease. With age, an intact male dog may develop an enlarged prostate. The prostatic hyperplasia (*hyper-*, prefix meaning excessive or above; *-plasia*, suffix meaning formation) is under the influence of testosterone. The most common sign in dogs with prostatic hyperplasia is constipation. This is in contrast to human males, who develop urination difficulty. The prostate is located at the pelvic brim under the rectum. With enlargement, the opening of the pelvic canal narrows and during straining the enlarged prostate moves deeper into the canal. Castration in any male greatly lowers the level of testosterone. Castrating young dogs prevents prostatic hyperplasia. If the condition has developed, castration is also helpful in reversing the enlargement.

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SUMMARY

The male reproductive system and the associated hormones allow production and delivery of sperm cells. Likewise, the female reproductive system and the associated hormones aid in the production of eggs. The joining of the egg and sperm results in pregnancy and, it is hoped, a successful parturition.

REVIEW QUESTIONS

1. Define any 10 of the following terms:

   spay (ovariohysterectomy)
   castration
   prolapsed uterus
   epidural
   lidocaine
   estrous cycle
   puberty
   polyestrous
   estrus
   seasonal polyestrous
   anestrus
   pheromone
   parturition
   gestation
   involution
   weaned
   obstetric
   whelping
   cesarean section
   ligated
   pyometra
   cryptorchidism

2. True or False: Luteinizing and follicle-stimulating hormones function in both the female and male.
3. The ________ produces sperm.
4. The ________ is the only accessory sex gland present in the dog.
5. Parturition divides into ________ stages.
6. Cystic ovaries can interfere with ________.
7. What organ becomes infected in pyometra?
8. Name one species that exhibits induced ovulation.
9. In which trimester does the fetus experience the most rapid growth?
10. Which hormone released by the fetus stimulates parturition?
11. When does the peak of lactation occur in dairy cattle?
12. Does a dog's temperature rise or fall prior to whelping?
13. Can females continue to produce additional numbers of eggs throughout life?
14. List the four stages of the estrous cycle.
15. Describe a normal presentation in delivery of calves.
16. What is the first priority in caring for a newborn?

ACTIVITIES

Materials needed for completion of activities:

   sample of frozen bull semen
   light microscope
   slides
   cover slips
   beaker with water
   thermometer
   conversion equation for changing kilograms to pounds

1. Contact an artificial inseminator or farmer and obtain a sample of frozen semen. Thaw the semen at 95°F, and place a small drop on a warm glass slide. Cover the drop with a cover slip and examine under a microscope. Healthy sperm should progress forward. If the slide cools, this will slow quickly. Examine the sperm for normal structure. The sperm cell should have a head with a straight and moving tail, or flagella. Examine the slide for defective sperm cells (such as missing or coiled tails).
2. Search the Internet for images of ovarian structures in various stages, as well as ovarian abnormalities such as cysts.

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3. You are called by Farmer Nitecaller at 2 AM to help deliver a calf. Mr. Nitecaller had reached in and found two hooves but no head. He figures it must be coming backward but could not pull the calf. You arrive on the farm and need to determine the calf's position. When reaching into the cow, the calf's entire leg can be felt. What structures or joints must be felt to distinguish a front leg from a back leg? Examine a photograph of a cow, calf, or skeleton to answer this question.
4. Convert 40 kg and 45 kg to pounds to see how much a typical Holstein calf might weigh.
5. Contact several dairy and beef farmers to inquire how they manage heat checking and subsequent breeding in their herds. Compare and contrast the differences between the dairy and beef producers' answers. Submit a report with the findings.
6. Search the Web for milk replacer formulas for various animal species.

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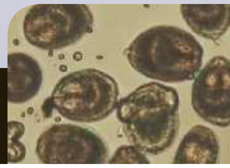

CHAPTER 9

The Nervous System

Objectives

Upon completion of this chapter, you should be able to:

- Describe the neuron, the nerve impulse, and the synapse, and explain the components of a reflex arc.
- Identify the major structures of the brain and name associated functions.
- Discuss the anatomy and function of the spinal cord.
- Compare and contrast the function of the sensory somatic system to the autonomic nervous system and differentiate between the two branches of the autonomic system.
- Discuss the clinical significance of the academic material learned in this chapter.

Key Terms

circling disease (listeriosis)
epilepsy
cervical disk disease
equine protozoal myeloencephalitis
volt
polarization
myelinated nerves
coma
myelogram
sensory somatic system
autonomic system
plexus
sympathetic system
parasympathetic system
dilate
constrict
nystagmus
ataxia
atrophy

Introduction

The discussion of tissues in Chapter 2 introduced basic information about nervous cells and tissues. This chapter reviews these facts and goes into further detail on the structure and function of the nervous system, which allows animals to interact with and react to their environments.

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A Day in the Life

Circling, Seizing, and Stumbling…

One Sunday morning, the phone started ringing early. It was 6:20 am and I was in the middle of breakfast when I got a call from an upset goat owner. The day before, one of his goats had begun to hold its head funny and walking in circles. That morning she was lying down on her side, unable to rise. The signs were classic—this goat likely had **circling disease**, or **listeriosis**. What caused this infectious disease in the brain to begin?

One seemingly typical day, I went to the office and was told that an emergency case was coming in. A dog had begun to have seizures overnight and the owners were quite concerned. Sandy, a 3-year-old golden retriever, had been quite healthy until the seizures occurred. Upon arrival, the dog began to have a seizure in the office. The dog was lying on her side as her legs began to thrash wildly and her jaws chomped quickly (Figure 9–1). Seizures seem to last a long time but usually are only a couple of minutes in length. Even so, seizures are always frightening events to watch. Sandy's seizure lasted only about 30 seconds. It stopped as I was administering medication, but I could not take credit for stopping it. At least the medication would be available to help prevent any further seizures. I submitted a blood chemistry profile and did not find any underlying problems. I had to conclude that this dog had **epilepsy**.

Jack, a 9-year-old yellow Labrador retriever, came to the office with a limp, which had developed yesterday. It was much worse this morning, and he was in obvious pain. I felt Jack's leg. He did not seem to mind all the bending and poking. It was only when I bent his neck that he reacted. Jack would hold his neck to the right but yelped in pain if I brought it to the left. I concluded that Jack had **cervical disk disease**. One of his intervertebral disks pressed on the nerves or spinal cord in that region. As a result, he felt intense pain in his neck and leg. I started Jack on high levels of a medication that would help relieve the swelling and pain associated with his condition.

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FIGURE 9–1 A seizing dog. During a seizure, dogs typically are unresponsive, lying on their sides, paddling their legs, and chomping their jaws.

In preparing to write this chapter, I remembered a case I had seen in veterinary school. It is one thing to help a staggering dog, but it was quite intimidating to lead a 1,000-lb horse that stumbled. This particular horse had lost its coordination and would often trip as it walked. The clinicians on the case suspected **equine protozoal myeloencephalitis** (EPM). In this disease, protozoa invade the brain and cause a variety of neurologic signs. The outcome was not favorable, and this horse was eventually euthanized.

Because I am a veterinarian in a multi-vet practice, I only have to work every other Saturday. Weekend days can range from very quiet to extremely busy. During one of the more hectic days, I was working with my newest associate. We left for farm calls feeling like things were generally under control. Unfortunately, the calls kept coming. The pressure builds on these kinds of days, but veterinarians just have to handle one call at a time, work efficiently, and then get to the next call as soon as possible.

We each made it through our calls, where we assisted in the delivery of calves. Then I headed to another farm that had reported they had heifers dying. This was a small farm, and the farmer was upset at having lost three heifers in the last two days. Another heifer was unable to stand. I examined her and found a normal body temperature, no evidence of trauma, and no obvious pneumonia. My next step was to evaluate her muscle strength. On a normal cow it is very difficult to hold onto her tongue, due to the strong tongue muscles and the wet saliva. Unfortunately for this animal, she had very poor tone to her tongue—I could hold it easily.

I suspected botulism and did one more test. I placed a bucket of water in front of the cow, and she placed her nose into the water. The sound and motion of her throat made it look as if she was drinking. However, when we took the bucket of water away, we could see she had not been able to drink. The botulism toxin had affected the function of her muscles, making her so weak that she could not stand or drink.

Diseases affecting the nervous system often produce dramatic symptoms. The clinical signs are usually explainable with an understanding of the structure, anatomy, and function of the nervous system.

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NEURON FUNCTION

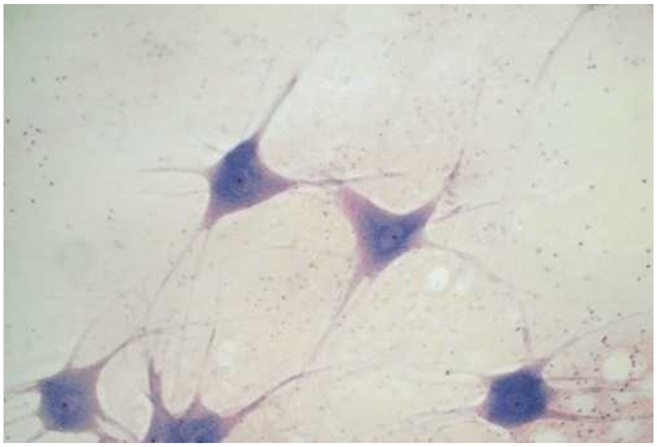
Objective

- Describe the Neuron, the Nerve Impulse, and the Synapse, and Explain the Components of a Reflex Arc

The neuron, as discussed in Chapter 2, is a specialized cell that lies within the nervous system. Neurons conduct electrochemical signals along their length. The neuron has a larger region called the body and a long, thin extension called the axon. The axon, a membrane-bound extension of the cytoplasm, transmits the signal long distances to other structures. The axon ends in the presynaptic terminal, a slight enlargement that contains vesicles full of neurotransmitter. This structure is important in the communication between the neuron and the target cell. Groups of axons run together in visible structures called nerves. Neurons may also have shorter extensions, dendrites, which receive signals from other neurons. The dendrites are modified receptors, which are sensitive to neurotransmitters released by other neurons.

Other accessory cells may be closely associated with the neuron. Schwann cells in the peripheral nervous system (PNS) have extensions of the cytoplasm and cell membrane that wrap around the axons of neurons. The multiple wraps from the Schwann cell increase the diameter of that region (Figure 9–2). Schwann cells create the myelin sheath, which increases the speed of the nerve signal. The points where the Schwann cells meet are called nodes of Ranvier. Oligodendrocytes serve the same function within the central nervous system (CNS). Myelin produces the typical white appearance of nerves. This is the reason that regions of myelinated axons within the central nervous system are called white matter. Not all nerves have a myelin sheath.

Neurons divide into three classifications. The first are sensory neurons, which deliver a signal from a specialized receptor to CNS. The receptor may detect some mechanical force, light, sound, or chemical. Interneurons are responsible for delivering a signal from one neuron to another. Interneurons provide the complex pathways present in the brain and spinal cord. Motor neurons then deliver the signal from the CNS to the muscle or gland being stimulated for a response (Figure 9–3).



Photograph courtesy William J. Bacha, PhD, and Linda M. Bacha, MS, VMD.

FIGURE 9–2 Photomicrograph of multiple motor neurons from the spinal cord of a cow.

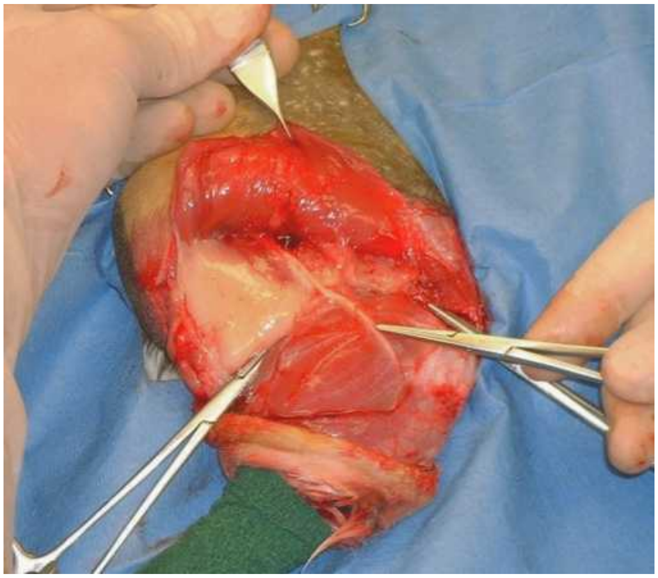


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FIGURE 9–3 Intraoperative photograph of a sciatic nerve exposed during an amputation procedure. The cat's leg had been severely damaged by trauma from being struck by a car.

The nerve impulse is the electrochemical signal that transmits along the length of the neuron. This very complex process requires an input of energy by the cell. When voltage or electrical potential is measured across the membrane of the neuron, the interior is noted to be more negatively charged. This resting potential is normally in the range of −70 millivolts (mV). A **volt** is the unit of measure in electricity describing the force associated with a difference in charge across a region. **Polarization** is also used to describe the condition in which one region of a cell has a different charge than an adjacent region. This potential difference develops because of the distribution of negative and positive ions close to the cell membrane.

Located within the cell membrane is the sodium–potassium pump. The cell remains polarized as the pump actively transfers sodium (Na^+) ions to the extracellular fluid. The concentration of Na^+ is approximately 10 times higher in the extracellular fluid than in the cytoplasm. Potassium (K^+) ions are distributed in the opposite manner, with the higher concentration within the cytoplasm. The total concentration of K^+, however, is much less than that of Na^+, resulting in the interior of the cell being more negatively charged.

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The natural tendency is for the Na^+ to diffuse inward and the K^+ to diffuse outward. The neuron must continuously pump the ions to maintain the concentrations. Mitochondria provide the energy for this active transport by the sodium–potassium pump. Stimuli to the nerve cell increase the permeability of the cell membrane to Na^+. With enough stimulation, the resting potential will approach −50 mV, which is called the threshold potential.

When this threshold is reached, an action potential is triggered. The permeability of the membrane dramatically increases and Na^+ rushes into the cell. The interior of the cell actually takes on a positive charge for a short time (Figure 9–4). This sudden change in electrical charge is called depolarization. The changes occurring at one point on the membrane stimulate adjacent membranes to change as well. In this manner the signal is sent along the length of the axon. The depolarization sweeps down the neuron making up the nerve impulse or action potential. Not every input will create a depolarization. However, once the threshold is reached, depolarization is complete; it is an all-or-nothing event.

It is tempting to compare the axon to an electrical wire, but this is not correct. Electricity flows at the speed of light. Nerve impulses are much slower. Nerve impulses flow in the range of 10 to 500 m/sec. (The speed of light is approximately 300,000 km/sec.) The nerve impulse is more accurately compared to lighting a fuse or a line of gunpowder.

Myelinated nerves (those with a myelin sheath) transport a signal much faster than nonmyelinated nerves. In myelinated axons the action potential occurs only at the nodes of Ranvier. The impulse occurs at one node and then jumps across the Schwann cell's membrane to depolarize at the next node of Ranvier. This salutatory conduction may transmit an impulse up to 50 times faster than in those axons lacking a myelin sheath.

The instant the nerve impulse has left a region, the process of repolarization begins. Potassium ions rapidly diffuse out of the cell, reestablishing the normal polarity of the cell. During this time, called the refractory period, the nerve cell cannot transmit another signal. For most neurons the refractory period is in the range of 1 to 2 milliseconds. The neuron must reach its normal resting potential before it can transmit another impulse. To accomplish this, the sodium–potassium pump must reestablish the appropriate concentrations. When nerve cells fire, it is all or none. For a greater response to occur, a greater number of nerve cells must be recruited.

The nerve impulse must then be transmitted to another neuron or cell, such as a muscle or gland. The junction where this occurs is called the synapse (Figure 9–5). The cell carrying the nerve impulse is the presynaptic (*pre-* is a prefix meaning "before") neuron. This axon widens as it ends in a synaptic knob, or presynaptic terminal. Once a nerve impulse reaches the synaptic knob, a neurotransmitter, such as acetylcholine (ACH), is released into the synaptic cleft. Many more neurotransmitters exist in the CNS. Transmission from one cell to the next with neurotransmitters maintains the flow of signal in only one direction.

A neuron may have hundreds of synapses on its dendrites and cell body. ACH, released at the synapse, is bound onto receptors of the postsynaptic cell membrane. This causes the membrane to become more permeable to Na^+. When enough ACH is released from

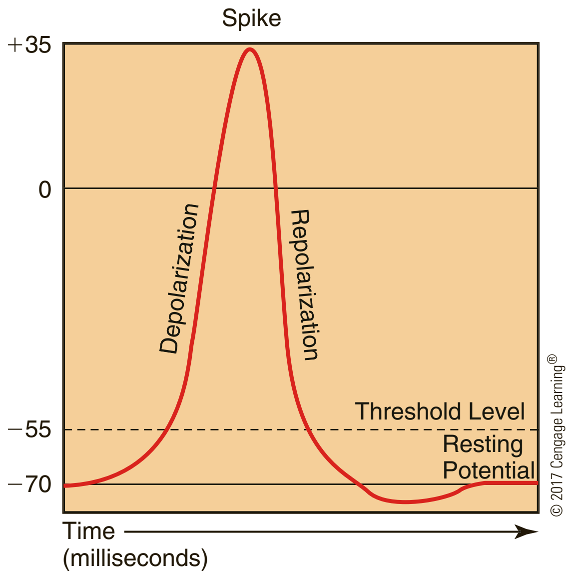

FIGURE 9–4 Voltages in an action potential.

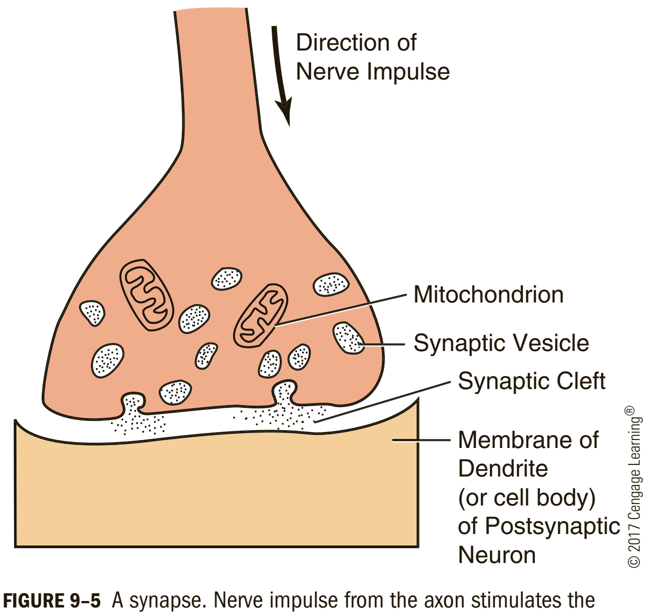

FIGURE 9–5 A synapse. Nerve impulse from the axon stimulates the release of a neurotransmitter.

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multiple synapses, the neuron reaches the threshold potential and another nerve impulse begins. ACH is a chemical transmitter, allowing the signal to flow from one cell to the next. ACH is then broken down by an enzyme, acetylcholinesterase, into acetic acid and choline. The ACH must be removed to prevent repeated stimulation from one incoming signal. The breakdown products of acetylcholine are reabsorbed into the presynaptic neuron and reassembled in preparation for the next event.

Some synapses may actually be inhibitory. These synapses release a transmitter that allows K^+ to diffuse out of the cell. This results in the neuron becoming more polarized, further from the threshold potential (hyperpolarization). The neuron may still fire, but it would require a higher number of excitatory synapses to reach its threshold potential. These inhibitory synapses are very important in allowing coordinated movement. The discussion of muscles showed that when one muscle group contracts, another antagonist group must relax. These inhibitory synapses allow for the smooth motion of muscle contractions, as one group contracts while another relaxes.

The reflex arc is the simplest unit of function within the nervous system. In a reflex the body reacts without requiring conscious thought. A withdrawal reflex is a commonly encountered example. As an illustration, picture a cat that has jumped onto a kitchen counter and walks toward the stove. The cat takes a step and places its foot onto a hot burner. The cat quickly pulls back its paw to prevent further injury. How did this occur?

The reflex arc begins with a stimulus, a hot stove in our example. Sensors in the foot detect heat, which then triggers a nerve impulse in the sensory nerve (Figure 9–6). The sensory nerve synapses onto an interneuron within the spinal cord. The interneuron is stimulated and, depending on the particular reflex, stimulates other interneurons or goes directly to a motor neuron. The motor neuron then stimulates a muscle to pull back the leg, preventing further damage.

This describes the pathway in a very simplistic reflex arc. The order of events is correct, but in the animal the number of pathways is actually much larger. There are numerous sensory inputs, large numbers of interconnections between interneurons, and multiple motor neurons that must be stimulated. For example, when one large group of muscles contracts, the antagonistic muscle group must relax, all of which are controlled by neurons. The significant features in a reflex arc, though, are illustrated. The large number of connections allows for the response in a reflex to have variation, depending on the severity of the event.

Notice that no signal is sent to the brain to cause the motion. The entire reflex occurs at the level of the spinal cord. The brain, however, can influence a reflex arc. The brain typically sends signals through the spinal cord to keep reflexes in control. To some degree, conscious thought can be used to overcome the events in a reflex. Many people are able to overcome a natural reflex of blinking when placing contacts in their eyes. It is a reflex to blink when an object is coming toward the eye. The contact wearer consciously keeps the eye open, knowing that no damage will occur. During a reflex the brain does receive signals of the events. The cat in our example required no input from the brain to pull its foot away. However, the brain was sent signals telling the animal that the stove was hot. As a result, the cat changed its course, and the reflex prevented a severe burn.

The response to the hot stove is called a withdrawal reflex and is one type of a somatic reflex. Somatic reflexes involve skeletal muscles. A withdrawal reflex

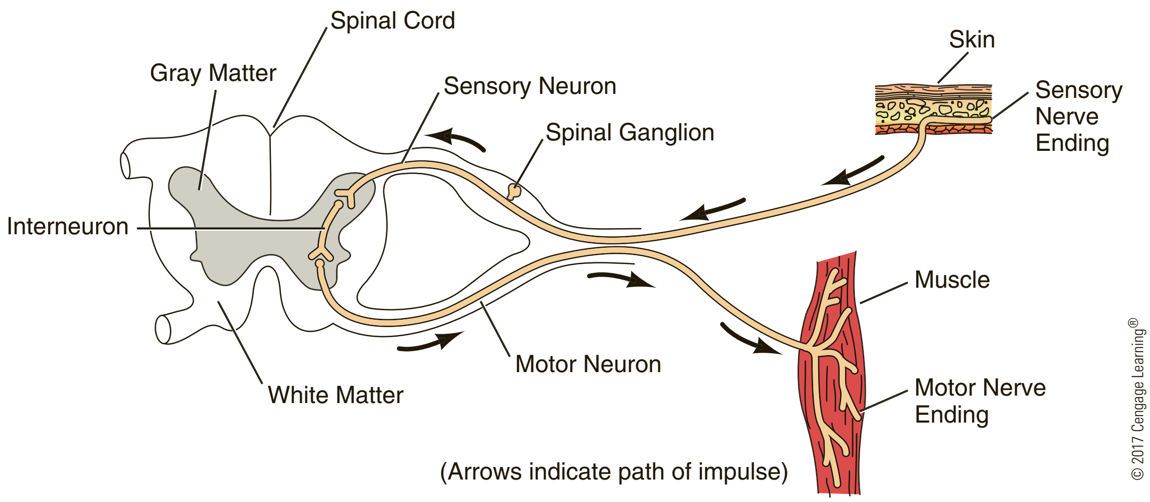

FIGURE 9–6 The pathway for a reflex. Painful stimuli are detected by sensory nerve endings in the skin. The signal is transmitted by a sensory neuron to an interneuron. The interneuron then stimulates a motor neuron. The result is a muscle contraction, pulling the leg away from the painful stimuli.

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FIGURE 9–7 A veterinarian tests the patellar reflex (knee jerk reflex) of a dog. By striking the patellar tendon, receptors sense the sudden lengthening and quickly contract the muscle in response.

is typically combined with a cross extensor reflex. As one leg is withdrawn, the opposite leg is extended in attempt to keep the animal from falling. Another type, the stretch reflex, involves a special receptor called a muscle spindle. A sudden stretch of the muscle spindle results in a reflex in which the affected muscle is contracted and the opposing muscle group is relaxed (Figure 9–7 shows the classic knee jerk reflex). While a reflex can be described in very simple terms it is important to recognize that there may be a large number of interactions. Autonomic reflexes also exist in the body and are used to control smooth and cardiac muscles as well as some endocrine functions.

BRAIN STRUCTURE AND FUNCTION

Objective

- Identify the Major Structures of the Brain and Name Associated Functions

The nervous system divides into the central (CNS) and peripheral (PNS) nervous systems. The PNS detects stimuli and informs the CNS through afferent nerves. The PNS also carries the signal through efferent nerves to cause a response at the level of the muscles and glands. The CNS receives all the signals from the peripheral system and coordinates all the activity. The spinal cord and brain comprise the CNS.

The skull and vertebrae provide protection for the CNS. Within the bony casing, the meninges, a group of three membranes wrap around the brain and spinal cord. In addition, the CNS is bathed in cerebrospinal fluid (CSF), which provides additional protection. The brain has nearly the same density as the CSF and therefore floats in the fluid. The CSF cushions the CNS when trauma occurs to the head or backbone. Openings within the brain itself, called ventricles, also contain CSF.

CSF is produced within the ventricles of the brain from a complex group of capillaries called the choroid plexus. The CSF flows from within the ventricles in the brain to the space between the brain and meninges. With activity from the animal, the CSF flows around the brain and spinal cord. Another complex of capillaries absorbs the fluid and returns it to the bloodstream. CSF is constantly being produced and then absorbed. In the average dog this amounts to about 3 ml every hour.

Visually, the brain divides into four regions: the cerebrum, the cerebellum, the diencephalon, and the brain stem (Figure 9–8). The brain stem controls most of the functions necessary to maintain life. The cerebellum provides coordination in the animal's movement. The cerebrum, the largest and most prominent region of the brain, controls the remainder of voluntary movement and thought.

Within the brain stem lie the medulla oblongata and the pons, which appear as a swollen end to the spinal cord. This region of the brain stem controls respiration and circulation. All the nervous control of functions such as heart rate, blood pressure, and respiration rate originates from this region of the brain. In addition much of the control of the entire digestive system is controlled by this region. Damage to this region of the brain causes instant death.

In front of the medulla and pons sits a region called the midbrain. The midbrain provides communication between regions of the brain and also from sensory organs, such as the eyes and ears, to the brain. This region of the brain controls balance and many reflexes of the eye. Also within this region lies the reticular activating system, which is involved in the animal's awareness and consciousness. When the system is actively firing, the animal is quite aware of its surroundings and is focused. This region basically stimulates the cerebrum. Damage to this region can result in **coma**, a prolonged state of unconsciousness.

The diencephalon is composed of the thalamus and hypothalamus. The thalamus sits at the top of the brain stem. The thalamus works to process all the incoming sensory signals (except smell) before transferring the signal to the appropriate regions of the cerebrum. The thalamus works to coordinate the signals between the spinal cord and the cerebrum.

Immediately below the thalamus are the hypothalamus and the pituitary gland. This region helps to control water balance, thirst, hunger, and temperature regulation. The hypothalamus also acts as an endocrine gland. Hormones such as oxytocin and antidiuretic hormone are produced by the hypothalamus. They are then stored in and released by the pituitary gland.

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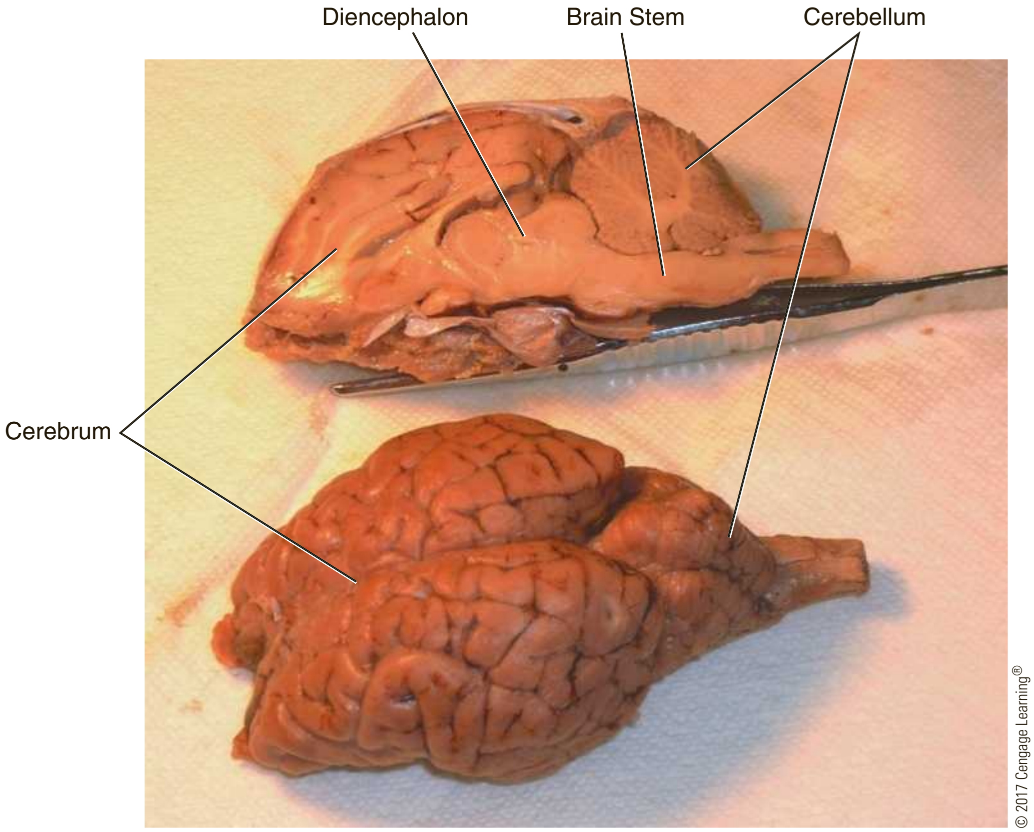

FIGURE 9–8 The external structure and midline section of the brain.

Many of the hormones of the pituitary gland have been discussed in previous chapters and are further detailed in Chapter 10.

Toward the back of the brain is the cerebellum. The cerebellum's main role is to control the coordination of movement. The cerebrum initiates most movement, but the signal passes through the cerebellum to provide controlled, coordinated motion. The cerebellum also monitors signals from the eyes and the balance center to aid in coordination.

The largest and most cranial structure of the brain is the cerebrum. The cerebrum divides into two halves, or hemispheres. The hemispheres are joined by white matter in the center of the brain, a structure called the corpus callosum. The white matter is made of the myelinated axons. The outer region, or cerebral cortex, consists of cell bodies, or gray matter, which have elevations and grooves that increase the surface area within the brain (Figure 9–9).

The cerebrum is the site of most voluntary and conscious processing. Voluntary movement begins in this region, and much of the sensory input is processed there as well. The cerebrum controls all thought, learning, memory, judgment, language, and personality. The cerebrum is quite large to allow for all the pathways and connections necessary to process this information.

FIGURE 9–9 The brain in cross-section. Note the arrangement of gray matter (cell bodies) in the outer regions and the internal white matter (myelinated axons).

The cerebrum divides into several lobes. Different regions within the cerebrum control different functions. There are regions that process the different sensory information, movement, and thought. These regions are well mapped in humans. With this knowledge it

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is possible to predict the effects of damage to a certain region. For example, a patient requiring surgery on a brain tumor can be told what defects might exist following the procedure.

ANATOMY AND FUNCTION OF THE SPINAL CORD

Objective

- Discuss the Anatomy and Function of the Spinal Cord

The spinal cord is the second component of the CNS and functions as the link between the PNS and the brain. In addition, the cord functions in many aspects of coordination through the reflex arcs. It extends from the base of the brain through the canal formed by the vertebrae. The actual cord reaches the level of the sixth or seventh lumbar vertebra in the dog. From that point, nerves pass through the spinal canal until they exit between the lower vertebrae.

The white matter's location on the outer region of the spinal cord is opposite to that of the brain (Figure 9–10). As in the brain, the white matter is composed of the myelinated nerves. The gray matter, the cell bodies, is housed in the inner portion of the cord. The meninges and cerebrospinal fluid surround the spinal cord, just as they do the brain.

At each vertebral segment, two nerve branches exit the spinal cord. The dorsal root carries sensory nerves. The ventral root has motor function. In each root, a collection of nerve cell bodies creates an enlargement in that region. A collection of nerve cell bodies outside the CNS is called a ganglion. The two branches join to create a mixed nerve, and then mixed branches divide in the periphery.

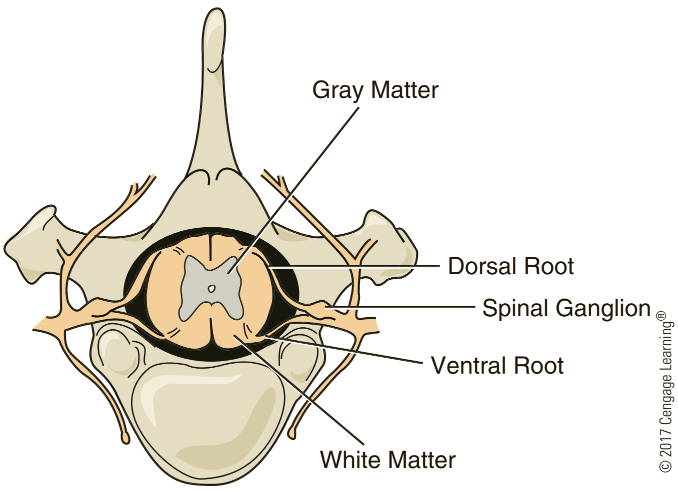

FIGURE 9–10 The spinal cord and spinal column. Note that the orientation of the gray and white matter is the opposite of that in the brain.

Nerves of similar function run together within the spinal cord. These collections are called tracts. Many nerve tracts cross somewhere within the brain or spinal cord. This is important in localizing the site of a disease process. Damage to a region in the right side of the brain may result in a weakness in the left side of the body.

In Chapter 3, intervertebral disk disease was discussed. In review, a portion of the intervertebral disk protrudes and puts pressure on the spinal cord or nerves. This information can now be interpreted with the knowledge of the structure of the spinal cord and nerves. Depending on the direction of the disk protrusion, the clinical signs vary. The disk may bulge to the side and put pressure on the spinal nerves exiting the cord. This can result in pain and motor deficits at the sight of the defect.

The disk may also bulge dorsally into the spinal cord. The signs are dependent on the degree of damage that occurs. The disk may just put pressure on the cord or may cause significant swelling and bleeding. The extent of the damage defines how severe the signs are. Complete paralysis can occur in the legs behind the damage.

One means of testing for damage is to evaluate the reflexes in the legs. If damage has occurred at the level where the spinal nerve for that reflex joins the cord, the reflex is depressed. The neurons in this region are termed lower motor neurons. When damaged, they may show clinical signs of weakness (paresis) or complete paralysis. With time, the muscle lacking innervation atrophy or shrink.

If the damage occurs above the level of the reflex, the signs are often exaggerated due to the lack of control by upper motor neurons. This shows the effect of inhibitory neurons. Clinically these animals have inappropriate movement of the affected limbs. Muscle atrophy will not occur as in the lower motor neuron example. The brain is not necessary for the reflex, but it does help to control it and keep it coordinated. As a result, if the cord is unable to transmit the inhibition, the signs of the reflex can be greater than normal.

One diagnostic test that is extremely useful in identifying the site of the problem is a **myelogram**. In the myelogram, a dye is injected into the epidural space (i.e., into the CSF). Because the CSF moves, it carries the dye along with it. The dye is unable to flow around an area where the disk has compressed the cord (Figure 9–11). A radiograph is taken to trace the flow of the dye. The dye is visible on a radiograph and helps to show the location of the problem. In severe cases, surgery is necessary to remove the pressure from the spinal cord. The myelogram identifies the location where surgery is required. In recent years the availability of magnetic resonance imaging (MRI) technology in veterinary medicine has made myelograms much less common.

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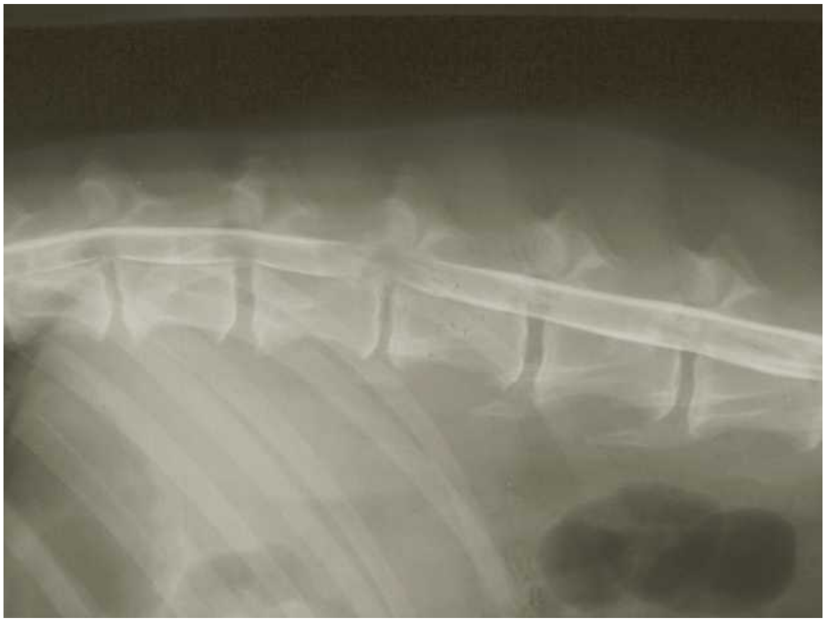

Photograph courtesy David Sweet, VMD.

FIGURE 9–11 Myelogram showing intervertebral disk disease. Dye injected into the spinal column shows the compression of the spinal cord.

SENSORY SOMATIC AND AUTONOMIC NERVOUS SYSTEMS

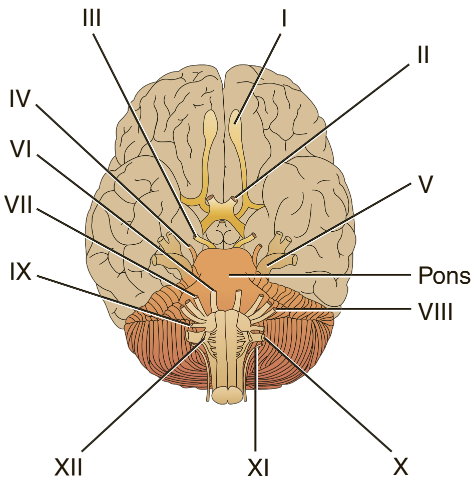
Objective

- Compare and Contrast the Function of the Sensory Somatic System to the Autonomic Nervous System and Differentiate Between the Two Branches of the Autonomic System

The PNS consists of all the nerves and neurons outside the brain and spinal cord. The PNS divides into two systems: the **sensory somatic system** and the **autonomic system**. The sensory somatic system operates all the motor activity of the body and includes all the receptors and neurons associated with detecting changes in the environment.

The sensory somatic system includes 12 pairs of cranial nerves. These nerves enter the brain directly, not the spinal cord (Figure 9–12). Several of these nerves are sensory only and therefore have no motor function. These include the nerves for sight, smell, and sound. Table 9–1 lists the 12 cranial nerves and describes their functions. These nerves are responsible for controlling the functions of structures within the head. In addition, some of the nerves control functions in regions outside the head. For example, the vagus nerve controls many functions in the organs in the chest and abdomen.

The spinal nerves enter the spinal cord at each intervertebral opening. As mentioned earlier, the nerves enter the cord in dorsal (sensory) and ventral



I. Olfactory Nerve
II. Optic Nerve
III. Oculomotor Nerve
IV. Trochlear Nerve
V. Trigeminal Nerve
VI. Abducens Nerve
VII. Facial Nerve
VIII. Vestibulocochlear Nerve
IX. Glossopharyngeal Nerve
X. Vagus Nerve
XI. Spinal Accessory Nerve
XII. Hypoglossal Nerve

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FIGURE 9–12 Cranial nerves and ventral surface of the brain. Table 9–1 lists the cranial nerves and their functions.

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Table 9–1 The Cranial Nerves

Number	Nerve	Sensory Function	Motor Function
I	Olfactory	Smell	None
II	Optic	Vision	None
III	Oculomotor	Position of eye	Move eye, constrict pupil, focus lens
IV	Trochlear	Position of eye	Move eye
V	Trigeminal	Sense in face and teeth	Muscles of chewing
VI	Abducens	Position of eye	Move eye
VII	Facial	Taste buds	Blinking, facial expression
VIII	Vestibulocochlear	Hearing, balance	None
IX	Glossopharyngeal	Taste buds	Muscles in swallowing
X	Vagus	Sensory in internal organs	Parasympathetic to internal organs
XI	Spinal accessory	Muscles of shoulder	Muscles of neck and shoulders
XII	Hypoglossal	Muscles of tongue	Muscles of tongue

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(motor) branches. In the dog, typically 36 pairs of spinal nerves exist. The dorsal and ventral branches join to create a mixed nerve. In many regions the spinal nerves combine and then further branch into smaller divisions. This extensive network of nerves is called a **plexus**. An example is the brachial plexus, which is the origin of the nerves to the front leg (Figure 9–13). The nerves in this region are derived from the last three cervical and first two thoracic vertebrae regions. The nerves join within the brachial plexus and then reorganize as nerves to the muscles of the front leg.

The other component of the PNS is the autonomic system. The autonomic nervous system has two divisions: the **sympathetic system** and the **parasympathetic system**. The autonomic system is an involuntary system that controls the internal environment of the animal, including blood pressure, heart rate, and intestinal motility. Special sensors within the

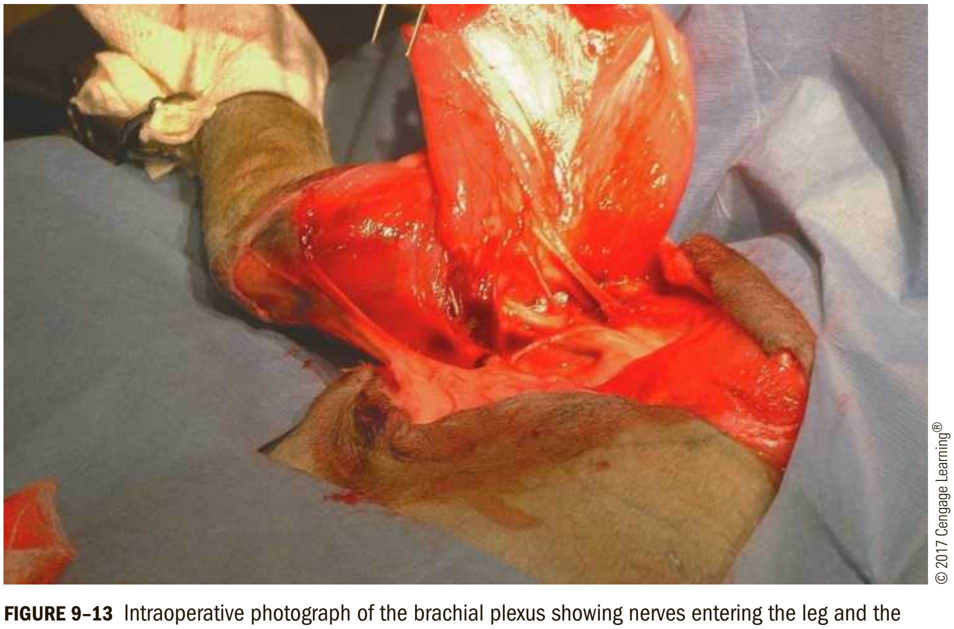

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FIGURE 9–13 Intraoperative photograph of the brachial plexus showing nerves entering the leg and the underside of the scapula. This cat was undergoing an amputation because of severe injuries suffered from a gunshot.

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Table 9–2 Summary of Autonomic Nervous System

Sympathetic	Parasympathetic
Dilates pupil	Constricts pupil
Dilates bronchi	Constricts bronchi
Increases heart rate	Decreases heart rate
Slows gut activity	Increases gut activity
Decreases saliva	Increases saliva

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internal organs and the CNS (especially the hypothalamus) monitor the internal conditions. In response to changes in conditions detected by the sensors, motor nerves send signals to endocrine glands and smooth and cardiac muscles. The system then adapts to any changes and influences any corrections. Table 9–2 compares the two systems, describing many of the functions under its control.

The autonomic system has two groups of motor neurons. The first, or preganglionic, neuron is in the CNS. Its axon exits through the ventral root of the spinal nerve and synapses in a ganglion. In the sympathetic system this ganglion lies on either side of the spinal column. In the parasympathetic system the ganglia are much closer to the organ being stimulated. The preganglionic neurons use acetylcholine as the neurotransmitter.

The second neuron in the system is called the postganglionic neuron, which sends an axon to the affected organ. In the sympathetic system, the axon releases the neurotransmitter norepinephrine at the synapse. The parasympathetic system uses acetylcholine in the second neuron, as well as the first.

In general terms, the sympathetic system stimulates organs in preparation for fight or flight. Consider the reaction of your body when you have been suddenly startled. With sympathetic stimulation, the heart rate and blood pressure increase. Blood shifts away from the skin and abdominal organs to the muscles, brain, and heart. The bronchioles are stimulated to open, allowing more air to enter the lungs. The pupils also dilate (open), allowing more light into the eyes. All these changes prepare the animal for an increase in physical activity, such as running from a predator.

Certain drugs and medications stimulate the sympathetic system. Caffeine, nicotine, and amphetamines are all examples of chemicals that stimulate this system. The clinical effects of this are all related to the signs associated with the sympathetic system.

The parasympathetic system basically has the opposite effect of the sympathetic system. The main nerve of this system is the vagus, or tenth cranial nerve. Other nerves exit from the lower spinal cord. Activation of the parasympathetic system slows the heart rate and lowers the blood pressure. The pupils constrict and blood is shifted back to the skin and abdominal organs. Peristalsis is also increased under the stimulation of the parasympathetic nervous system.

Receptors are the means by which the nervous system is able to detect changes in the environment. The environment can be outside the animal's body or within it. Heat receptors are present in the skin and are sensitive to the gain or loss of heat. These receptors are most sensitive to changes in temperature. There are also temperature receptors within the hypothalamus that detect changes in the body's internal temperature. As temperature rises, vessels dilate in the skin and sweating begins. If the body's core temperature declines, blood vessels in the skin constrict and shivering occurs.

The body also has mechanoreceptors, including those of pain and pressure. The skin has receptors sensitive to light touch. These receptors are close to the surface of the skin and are closely associated with hair follicles. These receptors are stimulated by light touch to the skin or even movement of the hair.

The skin has deeper receptors sensitive to pressure. These receptors, pacinian corpuscles, are deformed with pressure on the skin (Figure 9–14). Each pacinian corpuscle is attached to a sensory neuron. Once adequate pressure is reached, the neuron sends a nerve impulse to the CNS. Differences in the amount of pressure are signaled by the frequency at which the nerve impulse is sent. In addition, increased pressure activates more pacinian corpuscles, sending more signals to the brain. Conscious awareness of these sensations typically occurs when changes are taking place. When touch and pressure are consistent, the animal does not typically think of the sensations. For example, consider that people do not constantly think about the feel of clothes on their bodies.

The body has no particular receptors to detect pain. Pain results when the neurons receive such a deep stimulus that a nerve impulse is created. Lacking a receptor, these neurons require a stronger stimulus to signal the brain, and this is interpreted as pain.

Mammals also have important internal mechanoreceptors within the tendons and skeletal muscles. These proprioceptors detect stretching or contraction of the muscles and tendons. Proprioception is the body's ability to recognize the position of the body and limbs without having to visually observe it. These receptors are critical in maintaining the body's posture and allowing movement.

Several chemoreceptors have already been discussed in previous chapters. For example, the hypothalamus is able to detect changes in water or salt concentrations. Chemoreceptors are also used in the taste buds of the tongue. Four types of taste buds are

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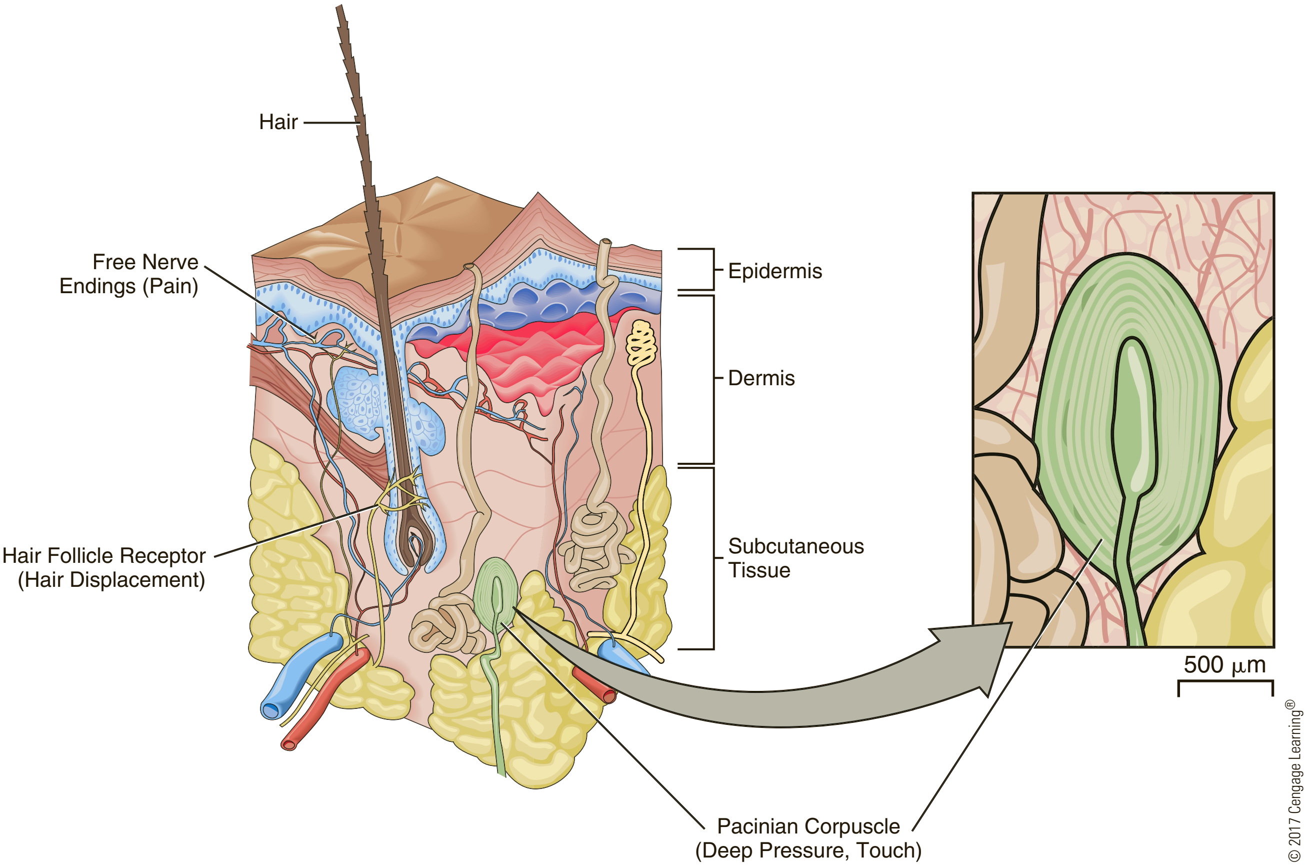

FIGURE 9–14 A pacinian corpuscle. This receptor is sensitive to pressure on the skin surface.

distributed in certain regions on the tongue. These receptors detect the tastes of sweet, sour, salty, and bitter. Special chemoreceptors within the nasal cavity detect different smells. There is a close relationship between smell and taste.

Sound waves are a series of increases and decreases in air pressure. The loose part of the ear, the pinna (which is located outside of the body), is designed to funnel the sound waves into the ear canal. The eardrum, or tympanic membrane, is a thin membrane at the base of the ear canal separating it from the air-filled middle ear. The middle ear also connects to the nasopharynx through the auditory (eustachian) tube. Changes in pressure can be balanced through the auditory tube. Within the middle ear are three ossicles (malleus, incus and stapes); these are three small bones that efficiently transfer the vibration of the eardrum to the fluid-filled inner ear.

The inner ear shares receptors for the auditory and vestibular systems. Within the inner ear are a series of bony labyrinths lined with a specialized membranous system. The cochlea, containing the organ of Corti, is the receptor region for the auditory system. The membranous lining contains hair cells with cilia that protrude into the fluid-filled opening. The vibrations from the sound cause the cilia to bend. This mechanical change is converted by the hair cells into a nervous signal that is transported by the eighth cranial nerve to the brain. The louder the sound, the more hair cells are recruited.

The vestibular system is responsible for maintaining balance and monitoring the orientation and acceleration of the head. The sensors for the vestibular system are also housed within the inner ear. There are three semicircular ducts oriented in 90-degree planes from each other. As in the auditory system, hair cells with cilia line the membranous labyrinth. Tilting of the head or acceleration causes the cilia to be bent and, as in the auditory system, the cells convert this change to a nervous signal to be sent to the brain. The direction of the bend of the cilia and the degree of severity are interpreted to give the animal signals to interpret the position and movement of the head. Having the sensors within each ear provides varied information. If the animal is rotating, the cilia in one ear will be bent in the opposite direction from the opposing ear. All of this information is sent to the brain for interpretation.

During rotation, a repeated fast and slow eye movement occurs that is termed physiologic nystagmus. The eye movement exhibited in physiologic nystagmus is an exhibition of the vestibulo-ocular reflex. Following

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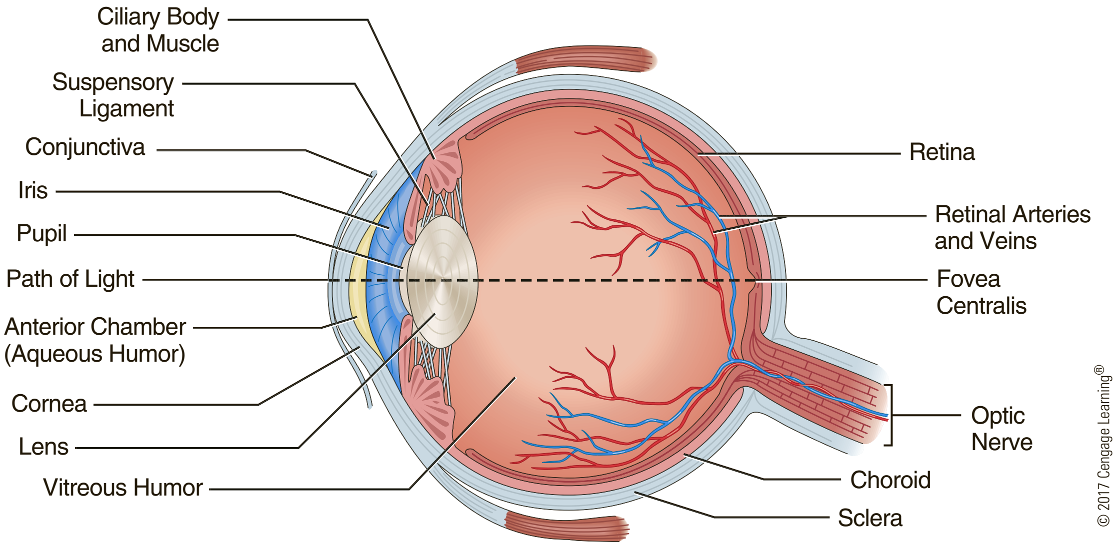

FIGURE 9–15 The structures of the eye.

rapid spinning such as on a carnival ride, the eyes will continue to show nystagmus for a short time because the fluid within the inner ear is keeping the hair cells stimulated. Nystagmus is a sign that can be detected with diseases of the vestibular system and is discussed later in this chapter.

The eye houses specialized receptors sensitive to light. The eye works on the same principle as a camera. In the eye, a single lens focuses the image onto a layer of light-sensitive cells. The eyeball, a roughly spherical structure, consists of three layers (Figure 9–15). The outermost layer is the sclera, the white portion of the outer eye. The very front of the sclera is specially adapted to be transparent or clear. This clear portion of the eye is called the cornea (Figure 9–16).

The middle layer, the choroid, is pigmented and contains the blood vessels of the eye. The iris, the portion of the eye that gives color, is located at the front of the eye. In the center of the iris is an opening, called the pupil. The pupil **dilates** (opens) and **constricts** (closes) in response to changes in the amount of light entering the eye. The lens sits immediately behind the iris and focuses the incoming light onto the back of the eye. The lens is suspended by ligaments and has muscles that can alter its shape. The shape of the lens changes to maintain focus on the back of the eye.

The iris and lens divide the eye into two chambers. The anterior chamber, in front of the iris, is filled with the liquidlike aqueous humor. The aqueous humor is constantly produced within the eye and then drains into the bloodstream. If the ability to drain the aqueous humor decreases, the pressure within the eyeball increases. This increase in pressure is called glaucoma. Initially, glaucoma can cause discomfort and redness of

A

B

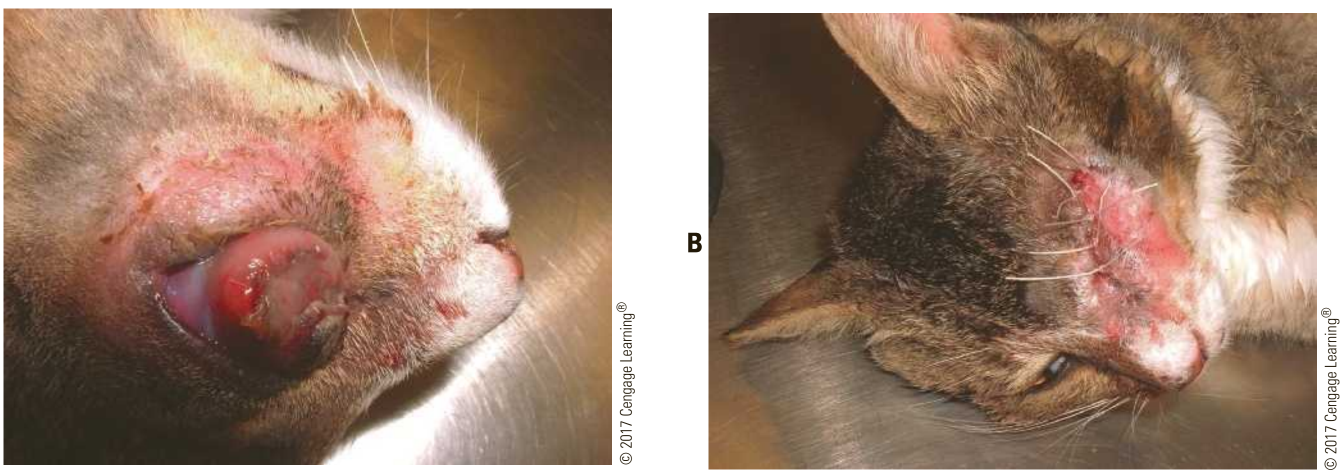

FIGURE 9–16 A. This cat suffered an injury to its cornea, which caused the eye to collapse. This injury was several days old. B. The eye was surgically removed and the eyelids sutured.

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the eye. If left untreated, the animal will develop blindness as the light-sensitive cells are damaged.

The vitreous chamber is behind the iris and lens. This chamber is filled with a thick jellylike material called vitreous humor. Both the aqueous and vitreous humors are transparent to allow light to be transmitted to the back of the eye.

The innermost layer, the retina, contains specialized light receptors. Two cell types, rods and cones, adapt to detect changes in light. The rods are very receptive to light and can detect objects in very dim light. Many rods attach to one neuron. The rods contain a special pigment that absorbs light, triggering the signal to be sent through the neuron. The rods provide a very coarse, colorless image. Rods make up about 95% of the receptors in dogs.

The cones work in bright light and are receptive to colors. The human eye has three different cones, each sensitive to a different wavelength of light or color (blue, red, and green). The sensitivity results from the type of pigment present within the cell. It is the relative response of the three cell types that allows humans to interpret color. Dogs on the other hand only have two types of cones, which also make up a smaller percentage of the retinal cells. As a result dogs, and many other animals, are not as perceptive of colors as humans.

CLINICAL PRACTICE

Objective

- Discuss the Clinical Significance of the Academic Material Learned in This Chapter

A thorough physical examination aids in determining the location of a defect in the nervous system. A complete neurologic examination can be very extensive, testing the function of both the cranial and spinal nerves. A description of all the possible steps in a neurologic examination is beyond the scope of this text. A few of the common tests performed are discussed here.

Table 9–3 General Observations of the Patient and the Region Involved

Region Evaluated	Normal	Abnormal
Cerebrum	Alert	Depression or coma
Reticular activating system	Alert	Depression or coma
Cerebellar	Balanced	Loss of balance
Vestibular/ Cerebellar	Normal head position	Head tilt
Proprioceptive system	Normal posture/gait	Ataxia, limbs knuckling

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The neurologic examination begins with general observation of the patient. The animal is evaluated for its mental status, determining alertness or depression. In addition, posture, head position, standing, and walking are all checked. Any defects in these signs can help to localize a problem. Table 9–3 summarizes these signs and the region of the nervous system being evaluated.

Many specific reflexes can also be evaluated. Table 9–4 summarizes several of the reflex tests available to check the cranial nerves. The menace response is an easy reflex to test—just bring the hand rapidly toward the eye. Take care not to touch the skin or hairs around the eye. In a normal animal, the hand is seen and recognized as a threat, and then a signal is sent to close the eyelids. If the reflex is intact, it shows that the optic nerve (cranial nerve II), the pathways within the brain, and the facial nerve (cranial nerve VII) are all

Table 9–4 Cranial Nerve Testing

Test	Nerve Tested
Menace (rapid movement toward eye)	Optic (II) and Facial (VII)
Pupillary light	Optic (II) and Oculomotor (III)
Blink when skin near eye is touched	Trigeminal (V) and Facial (VII)
Normal jaw tone	Trigeminal (V)
Hearing (response to loud noise)	Vestibulocochlear (VIII)
Head in normal position	Vestibulocochlear (VIII)
Gag reflex (response to finger deep in mouth)	Glossopharyngeal (IX) and Vagus (X)
Normal tongue strength	Hypoglossal (XII)

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functioning. The animal can therefore see the threat, react to it, and signal the muscles to blink.

Another test is called the pupillary light reflex. During this test, a light is shined into one eye. Normally the pupil will constrict or shrink, preventing too much light from damaging the retina. This test requires not only that the optic nerve be intact, but also that the oculomotor nerve (cranial nerve III) be functioning to constrict the pupil. Due to the communication between the optic nerves, the opposite pupil will constrict equally. When both pupils react, the interconnection is intact.

Observing the eyeballs for normal positioning and movement helps to evaluate cranial nerves III, IV, and VI. In addition, a normal animal with its head held still should have no rhythmic jerking to the eye. In **nystagmus** the eyes jerk back and forth in a rhythmic manner. The eye jerks one direction in a quick fashion and then returns more slowly. Nystagmus can result from damage in the inner ear, cranial nerve VIII, the brain stem, or the cerebellum. This condition can be created in people riding a spinning-type ride at the amusement park. When the ride stops (and the rider feels dizzy), the eyes will show nystagmus.

Reflexes are also used to evaluate the spinal nerves. Proprioceptive reflexes occur when tendons or muscles are stretched. One simple test is done with the pet standing. The foot is turned so that the top of the foot is touching the ground. In a normal animal, the foot is placed into the correct position almost immediately. Even without observing the foot, the animal recognizes the incorrect position and corrects it. In animals with nerve damage, the foot's position may not be corrected, or is corrected only after a prolonged period.

A classic reflex is the knee jerk. In this test, the patellar ligament is struck with a reflex hammer (Figure 9–7). This ligament stretches from the patella to the top of the tibia. The signal is sent to the spinal cord as if the knee is flexing. In response, the reflex signal is sent through the motor nerve to quickly extend the knee joint. A lack of this response signals nerve damage in the lower lumbar region.

Local anesthetics block the flow of sodium ions across the nerve cell membrane. Without the ion flow, an action potential cannot take place. As a result, sensory input from the anesthetized region does not occur. Local anesthetics are extremely useful in veterinary and human medicine. The anesthetic may be injected directly into the site where an incision is about to be made. This technique is commonly used in the surgery to correct a displaced abomasum, described in the introduction to Chapter 2.

Larger regions may be anesthetized as well. A needle may be passed between the caudal vertebrae of cattle and the anesthetic injected into the epidural space. This location will provide a regional anesthesia for surgical procedures involving the anus, vulva, and vagina. Motor nerves are also affected, which is evident with a limp tail. Too much anesthetic would cause a temporary paralysis of the hind legs.

Local anesthetics can also be used diagnostically. Lameness in horses can be quite subtle and difficult to localize. The anatomy of the nerves in a horse's lower leg is well defined. Using this knowledge, a local anesthetic can be injected in a specific location to block the sensation provided by an individual nerve. If the lameness improves after the region is anesthetized, the location of the pain has been established. This confirmation allows for a more focused attention at defining the underlying cause.

An animal experiencing a seizure often begins seizing by falling and losing consciousness. The animal may also show violent uncontrolled motor activity. A pet will paddle the legs and open and close the jaws as in chewing gum. Many muscle groups also seem to twitch. During the seizure, the animal may also drool, urinate, or defecate. Seizures result from excessive firing of neurons in the gray matter of the cerebrum.

Following a seizure, the animal may show abnormal behavior, such as disorientation. Some pets even appear blind for a time following a seizure. The severity of these signs usually depends on the severity and duration of the seizure. Many of these animals have an elevated body temperature due to the heat given off during the extensive muscle activity.

Clients with pets that have seizures are advised to be very careful around the animal's mouth. The seizing pet is unaware of its action during the seizure, and the owner could potentially be bitten. The pet should be protected from falling off furniture or down stairs during the seizure.

The majority of seizures last only a few minutes or less. The duration of seizures often seems much longer, because seizures are so stressful to watch. Short seizures are, in general, not life threatening. Occasionally, an animal's seizure lasts for more than 30 minutes. This can become life threatening.

There are many causes of seizures, including trauma, tumors, toxins, and certain infectious diseases. The most common seizure diagnosis in private practice is epilepsy. In epilepsy, no underlying cause can be determined. The seizures usually begin in pets from 6 months to 5 years of age. Often the seizures are infrequent, occurring several months apart. As the pet ages, the seizures often increase in frequency.

Several medications are used to control epilepsy, including phenobarbital. Usually, the pet requires treatment for its entire life. The medication does not cure the disease but merely controls the frequency and severity of the seizures. With long-term treatment, the dosage often requires adjustment when the seizures increase in frequency. The liver adapts to medication exposure. With time, the liver increases the amount of enzyme present that breaks down the drug. As this

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FIGURE 9–17 A cow suffering from listeriosis. The cow is unable to rise. Note the obvious drooped ear.

occurs, the same dosage to the pet results in lower levels in the bloodstream. To compensate, the dosage must be increased.

Certain insecticides (called organophosphates or carbamates) are toxic to the animal's nervous system. As a review, certain neurons (motor neurons and parasympathetic neurons) release acetylcholine (ACH) at the synapse. The ACH is rapidly broken down by an enzyme, cholinesterase. The ACH is broken down to prevent repeated overexcitation at the synapse. These insecticides block the action of the cholinesterase.

The signs are therefore predictable, knowing where the ACH will accumulate. At the muscle level, the increased ACH results in excessive stimulation with muscle twitching, tremors, and stiffness. Due to the effect on the parasympathetic system, the animal will drool, have constricted pupils, experience diarrhea, and show a slow heart rate. The brain can also be involved, resulting in signs of nervousness and even seizures. Medications are available that help to block the effects of the ACH or to reverse the effect of the insecticide on the cholinesterase.

Listeriosis (circling disease) is an infection that affects the brain. It is most commonly seen in cattle, sheep, and goats. Humans are susceptible as well, with cases usually resulting from consumption of unpasteurized dairy products. The organism is often found in soil and can therefore contaminate feed. The bacteria enter through the mucosa in the roof of the mouth and track along the branches of the trigeminal nerve (cranial nerve V) to enter the brain. The clinical signs then result from the location where the infection becomes established.

The signs of listeriosis may include difficulty chewing and swallowing. The muscles of the face can become paralyzed, producing a drooped ear or eyelid (Figure 9–17). The vestibular system can be infected, resulting in the circling, lack of coordination, and head tilt. As the disease progresses, the animal is unable to rise. Death occurs as a result of the infection in the brain or from dehydration, because these animals are often unable to drink.

If caught early, animals are treated with high levels of antibiotics. The medication can stop the infection and allow the damaged tissue to heal. Unfortunately, many animals do not survive, even with medication. I am pessimistic about the chances of success for the goat that I introduced at the beginning of this chapter. It has been my experience that treating down animals is usually unsuccessful.

Equine protozoal myeloencephalitis (EPM) is caused by a protozoan (*Sarcocystis neurona*) that invades the brain and spinal cord of the horse. Protozoa are a class of single-celled microscopic organisms. The clinical signs of the disease vary tremendously, because the organism can attack any region of the CNS. The disease is usually progressive, starting with mild signs and then worsening. The signs include **ataxia**, an uncoordinated movement. These horses may stagger and stumble. In some instances, certain muscles may begin to shrink, or **atrophy**. Muscles that lose nerve stimulation shrink because they are not being used.

Regions of the brain can also be involved, resulting in signs similar to those seen in listeriosis of cattle, sheep, and goats. The signs can vary among animals

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but include head tilt, circling, paralysis of facial muscles, and difficulty chewing and swallowing.

Treatment of horses with EPM has had relatively poor and inconsistent results. A positive diagnosis is possible only with an autopsy. Blood tests are available to show exposure to the organism but not disease confirmation. However, the clinical signs and the positive blood test do help support a diagnosis. Recently, a new medication has gained approval and offers hope in treating these horses.

The cow mentioned in the introduction was diagnosed with botulism. Botulism is caused by a toxin released by the bacteria *Clostridium botulinum*. This organism is commonly found in decomposing plants or animals. In cattle exposure may occur when a dead animal is inadvertently gathered into a hay bale during harvest. The organism is able to grow in conditions without oxygen (anaerobic). The bacteria release a toxin that is then ingested as the animal eats the hay. The toxin enters the bloodstream and penetrates into nerve cells. The toxin is able to block the release of ACH from the synaptic bulb. The result is a flaccid paralysis, in which skeletal muscles are not signaled to contract. Death typically occurs because of paralysis to the muscles of respiration.

SUMMARY

Understanding of the nervous system begins with the ability to describe the neuron, nerve impulse, synapse, and components of a reflex arc. An ability to explain brain structures and their associated functions is also important.

The brain and the spinal column comprise the central nervous system, whereas the nerves in the limbs constitute the peripheral nervous system. Conversely, the nervous system can also be divided into the sensory somatic and autonomic nervous systems, and between the two branches of the autonomic system. The nervous system in its entirety controls many body functions.

Companion animals, exotic pets, and large animals are susceptible to neurologic disorders that can be identified through clinical signs.

REVIEW QUESTIONS

1. Define any 10 of the following terms:

   circling disease (listeriosis)
   epilepsy
   cervical disk disease
   equine protozoal myeloencephalitis
   volt
   polarization
   myelinated nerves
   coma
   myelogram
   sensory somatic system
   autonomic system
   plexus
   sympathetic system
   parasympathetic system
   dilate
   constrict
   nystagmus
   ataxia
   atrophy

2. True or False: All nerves have a myelin sheath.
3. True or False: Damage to the right side of the brain causes weakness in the left side of the body.
4. The long, thin extension of a neuron is called the ________.
5. Gray matter is housed in the ________ region of the spinal cord.
6. The dorsal root, which exits the spinal cord, carries ________ nerves.
7. Sympathetic stimulation causes the heart rate to ________.
8. Does a reflex occur with conscious thought?
9. Are the rod or cone cells of the eyes receptive to colors?
10. Can an underlying cause of epilepsy seizures be found?
11. How can humans contract listeriosis?
12. Name the two systems of the peripheral nervous system.
13. Name the junctions where nerve impulses are transmitted.
14. List the regions of the brain.
15. List the four types of taste buds found on the tongue.
16. List the common behavioral indications of or clinical signs of listeriosis in cattle, sheep, and goats.
17. Describe possible behavioral changes in a horse with equine protozoal myeloencephalitis.

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ACTIVITIES

Materials needed for completion of activities:

flashlight
reflex hammer
six small paper bags
six small scoops of mini jelly beans in three different flavors (lemon, grape, cherry)
six marking pens
yardstick
graph paper

1. To evaluate the reflexes of the eye, have a subject seated in a dimly lit room. The dim light allows the pupil to dilate, but it should be bright enough to observe the size of the pupil.
   a. Gently and carefully touch the skin at the corner of the eye closest to the nose. What happened? Did the subject blink? It is possible for the subject to consciously overcome this reflex. In a normal person this should result in blinking.
   b. Observe the size of the pupil in the eye. Describe the size, estimating in millimeters the diameter of the opening.
   c. Take a small flashlight and shine it toward the eye from the side. Do not use an extremely bright flashlight. Shine the flashlight into the eye from the side for a short period. What happened to the size of the pupil? Repeat on the opposite side. Were the results the same?
   d. Once again, shine the flashlight into one eye. This time watch the opposite eye. Does this pupil show the same response? This pupil should react the same as the pupil with the light. This is called a consensual response and proves that the nervous connection between the eyes is functional.
2. Evaluate the knee jerk reflex. The subject should be seated with legs dangling and should try to relax. Identify the subject's patella and tibia. The patellar ligament runs from the patella to the front and top of the tibia. Physicians use a small rubber hammer to strike this tendon. (A reflex hammer is available from Carolina Supply, CE-69-6435.) Use the tips of the fingers held together or the side of the hand (as in a karate chop). Strike the ligament firmly and quickly. This causes a stretching of the ligament that is detected by the spinal cord. The cord then signals the muscles to contract, resulting in the knee being quickly extended. There is only a small amount of movement as the reflex compensates for the stretching. It is very possible for the subject to overcome this reflex if the muscles are not relaxed. It is also possible for the reflex to be exaggerated when the subject anticipates the result.
3. The senses of taste and smell are closely associated. Anyone who has had a severely congested nose can relate to the fact that food just does not taste as good. Perform quick and easy classroom tests by sampling food while both breathing freely and holding the nose shut. Note the differences in taste. This would also be an appropriate time to locate the regions of the tongue that sense sweet, salty, bitter, and sour tastes in foods.
4. Test the speed of nerve conduction and reaction time by having a subject sit with hand ready to grasp the end of a yardstick being held by the evaluator. Signal the subject to grab the yardstick at the same moment that the evaluator drops it. Perform each step of the following steps three times and average the results.
   a. The evaluator simply drops the yardstick. The subject will see the drop and try to quickly catch it. Record the point on the yardstick where it was caught.
   b. Have the subject keeps his or her eyes closed. Tap the shoulder of the subject at the moment the stick is dropped.
   c. Tap the foot of the subject as the stick is dropped. Again the subject should not observe the drop.

   Average the three trials in each step. Estimate the length of the nerve conduction in each step (e.g., foot to brain to hand in the third test). Plot the results with length of nerve conduction on the x-axis and distance on the yardstick on the y-axis. The y-axis is basically a measure of time required for the signal to be conducted through the nerves and synapses necessary to process each step. A stick is available that converts the distance to an estimate of time. Using the graph, is it possible to show that the longer the pathway, the longer the time required?
5. Students can evaluate the vestibulo-ocular reflex in the classroom. If a person is slowly rotated on a chair the eyes will focus on a point for as long as possible and then quickly shift in the direction of the spin.
6. Use the Internet to research neurologic disorders in two of the following exotic pets: ferrets, hamsters, hedgehogs, rabbits, chinchillas, gerbils, sugar gliders, and domestic pigs. List behavioral problems or clinical signs for each disorder.

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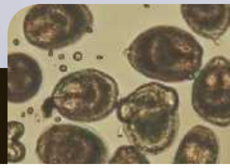
CHAPTER 10



The Endocrine System

Objectives

Upon completion of this chapter, you should be able to:

- Describe the endocrine system.
- Name the major endocrine glands, list the hormones secreted by each gland, and describe the functions of these hormones.
- Discuss the clinical significance of excesses or deficiencies of endocrine-related hormones.

Key Terms

Addison's disease	polydipsia	shunting	Cushing's disease
diabetes insipidus	polyuria	rickets	iatrogenic
diabetes mellitus	hypoglycemia	alopecia	

Introduction

You have now seen how the nervous system provides electrochemical communication among regions of the body. The endocrine system provides a chemical means of controlling distant regions of the body. Numerous ductless endocrine glands are present to help control many aspects of the body's metabolism and regulation.

Much of this chapter involves review of the many hormones already covered in the discussion of other organ systems. This chapter helps to summarize this information and provides further detail on the control and regulation of the endocrine system.

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A Day in the Life

Between a Rock and a Hard Place...

There are times when medicine and physiology hit a little too close to home. I was examining a heifer for pregnancy today. With the farmer's help we had run her behind a gate for examination. This usually works quite well, but occasionally the animal decides that it does not want to stay. This heifer elected to turn around. I waved my hand in front of her eyes, a technique that often works to discourage the movement. She was not about to change her mind, and lunged toward me. Unfortunately, my finger was between her head and the metal gate latch.

A reflex was immediately called into action. My finger sensed the pain, sent the signal to my spinal cord, and the motor signal quickly pulled back my hand. Unfortunately, the reflex was not quick enough to prevent some damage. My sympathetic nervous system then went into action as my heart rate increased and my pupils dilated. In addition, the excitement of the fray stimulated my endocrine system (adrenal glands) to release hormones to adapt to the stress of the event.

Some cases just stick in your mind for years. It was many years ago, in veterinary school, when I saw a pony that was almost 30 years old. It was June, but this pony had a very thick, long hair coat. Also, the temperature was warm, but this horse was sweating quite abnormally. The veterinarians on the case finally diagnosed the problem as a tumor in the pituitary gland. This particular gland was producing too much hormone, which was stimulating the adrenal gland in turn to produce too much of its hormone.

It was only three months ago when Sebastian, a nine-year-old Rottweiler mix, presented for severe weakness, poor appetite, and vomiting. Sebastian and his owners had just recently moved to the area. The owner informed me that Sebastian had been under treatment for low production by the adrenal gland for several years. This condition is called **Addison's disease**. Table 10–1 shows the results of numerous blood tests. Sebastian had several electrolytes in the abnormal range. His medication was no longer keeping his condition under control. The subsequent test results show how these values changed after his medication dosage was increased.

I've been asked the question many times in many ways: "So Doc, what do you think about this rBST-free milk?" Currently, this is a hot topic of discussion in the dairy industry. Posilac, manufactured by Monsanto, is an FDA-approved hormone for injection into dairy cows. It is used as a management tool to increase milk production. Posilac is a recombinant form of bovine somatotropin (rBST), or growth hormone. A segment of producers have elected to market milk that is rBST free.

I have tried to present facts in this text and avoid imparting opinion as opposed to solid science. A tremendous amount of research is available on the function and safety of rBST. Unfortunately, this issue is not only about research but must include consumer impressions and concerns. It is important for the reader to understand that as a veterinarian, I use hormones and antibiotics in the treatment of dairy cattle. I rely on research and testing to ensure that the food supply remains safe. At this point in time, no tests can distinguish milk taken from cows treated with rBST from those not treated. However, if consumer demand requires that rBST-free milk be available, the farmers should be rewarded economically for that product. In the clinical relevance section, more information will be presented on the science of rBST.

Table 10–1 Sebastian's Blood Results

Test	Units	Reference Range	July 30	Aug. 2	Aug. 15	Sept. 7
Glucose	mg/dl	65–120	86	101	78	81
Urea nitrogen	mg/dl	16–24	79	53	23	23
Creatinine	mg/dl	0.4–1.4	3.5	1.9	1	1.1
Sodium	mEq/dl	140–151	135	138	147	145
Potassium	mEq/dl	3.4–5.4	8.7	7.2	5.6	5.3
Calcium	mg/dl	7.9–12.0	13.3	11.4	11.2	11.4
Phosphorus	mg/dl	2.1–6.8	8.1	5.8	4.3	5.8
Amylase	units/L	400–1400	1185	538	433	709

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Numbers highlighted in red are above the normal reference range.

Numbers in blue fall below the normal reference range.

July 30: Chemistry profile shows azotemia (high urea nitrogen, creatinine), hyponatremia, hyperkalemia, and hyperphosphatemia. These values are consistent with Addison's disease and renal insufficiency.

Aug. 2: Three days into treatment the values begin to improve. The dosage of medication had been increased.

Aug. 15: Treatment at the higher dosage level has brought the elevated blood levels almost to normal. Potassium is still slightly above the reference range.

Sept. 7: Current treatment dosage has brought blood levels to the normal range.

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ENDOCRINE SYSTEM

Objective

- Describe the Endocrine System

Endocrine glands do not contain ducts—rather, hormones are released into the extracellular fluid or the bloodstream. The hormones are then transported throughout the body. The hormones may have effects throughout the body or may target only specific cells. Once delivered, the hormones influence the activities of these target cells. The endocrine and autonomic nervous system are closely related and play a critical role in regulating the function of the body.

Hormones have a wide variety of roles in the body. They help to regulate growth, sexual development, and the metabolism of the cells. In addition, the endocrine system is essential in maintaining homeostasis in the internal environment.

Hormones are divided into four chemical groups. One group of compounds is derived from fatty acids (Figure 10–1A). This group of hormones includes the prostaglandins, one of which has been discussed in the context of the estrous cycle (see Chapter 8). The

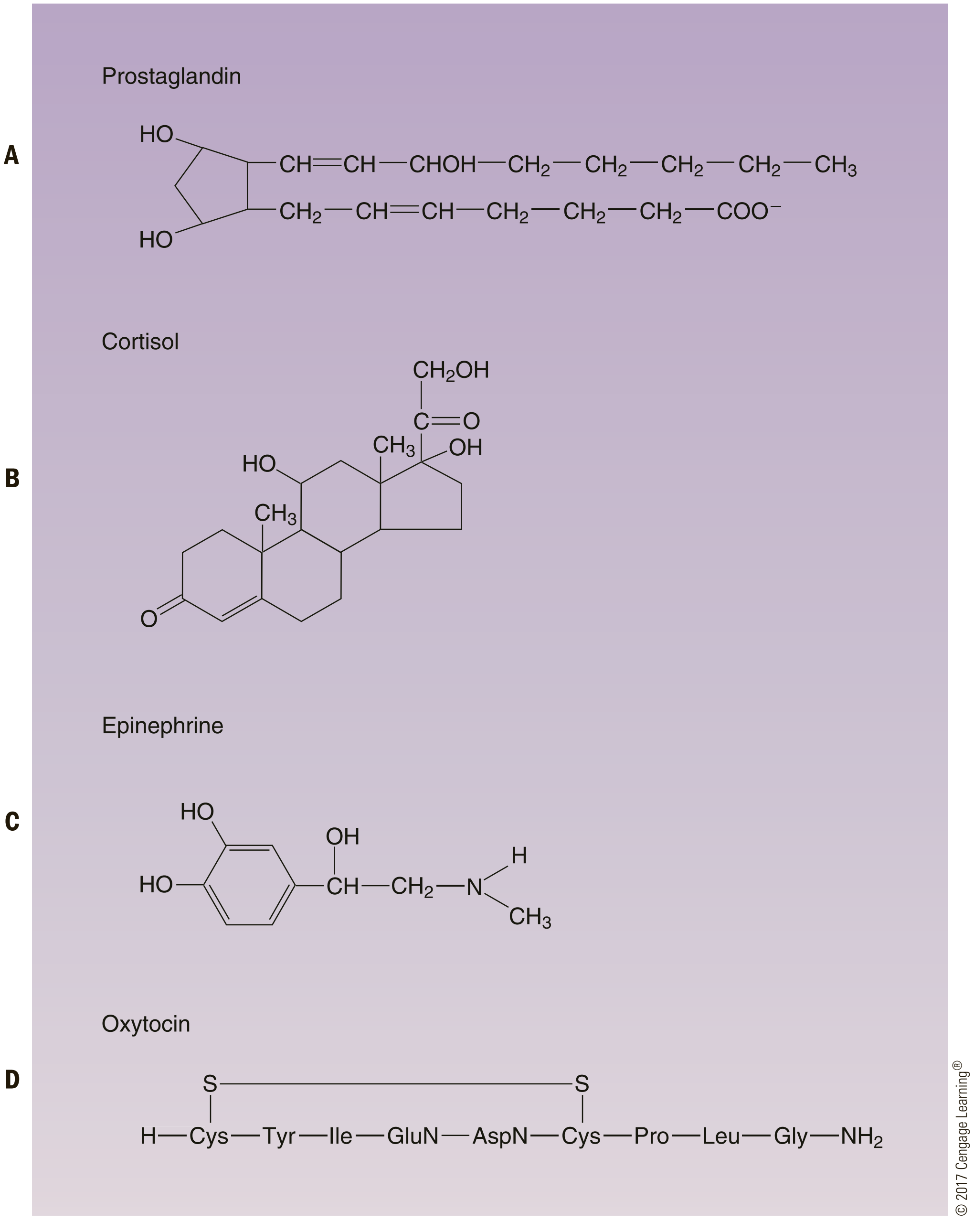

FIGURE 10–1 Four chemical groups of hormones. A. Fatty acid derivatives (prostaglandin). B. Cholesterol derivatives (cortisol). C. Amino acid derivatives (epinephrine). D. Peptide hormones (oxytocin).

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second group is the steroids, which are derived from cholesterol (Figure 10–1B). A great deal of attention is given to the role of cholesterol in heart disease of humans. Cholesterol is an essential compound in the physiology of mammals. Estrogen is one example of a steroid hormone.

A third group of hormones is derived from amino acids (Figure 10–1C). For example, the thyroid hormones are a combination of iodine and the amino acid tyrosine. Chemically, these are the simplest of the hormones. The final class is the peptide hormones (Figure 10–1D). These are the largest of the hormones and can be a short peptide chain (such as oxytocin, with nine amino acids) or a large protein.

Once a hormone is delivered, it must signal the target cell to alter its activity. Hormone receptors are present on the cell membrane or within the cytoplasm or nucleus. The analogy of a lock and key is used to describe the receptor and the hormone (Figure 10–2). The molecule making up the hormone has a distinct shape (like the key). The receptor therefore has to accept this specific shape (like the lock).

The steroid and thyroid hormones are transported in the blood bound to carrier proteins. These relatively small lipophilic molecules enter the cells and attach to receptors located within the cytoplasm or in the nucleus, stimulating the production of mRNA to direct protein production. The larger peptide hormones have receptors on the surface of the cell membrane. A mechanism must then exist to convert this extracellular signal to one that influences the interior of the cell. When the hormone attaches to the receptor, an enzyme is activated that creates a second messenger. The most common of these second messengers is cyclic adenosine monophosphate (cAMP). The second messenger then increases the activity of preexisting enzymes within the target cell. Utilizing existing enzymes provides a much faster onset of action for these hormones than for the steroid hormones, which rely upon new protein synthesis. The use of a second messenger allows a small hormone signal to be amplified. The final result of the hormone depends on the type of specialized cell that is activated. The second messenger must also be destroyed to prevent excess stimulation by the hormone.

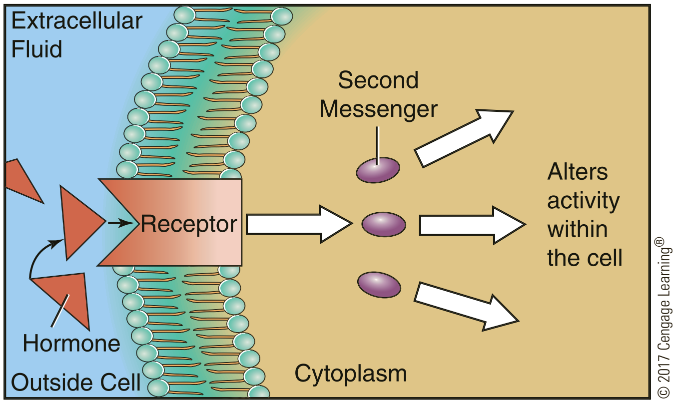

FIGURE 10–2 A hormone receptor in a cell membrane joins with the hormone in a lock and key manner. This causes the release of a second messenger that is active within the cell.

The endocrine system is most commonly regulated by an arrangement known as negative feedback. In this type of system, the hormone is secreted in response to a change within the internal environment. Once significant correction is accomplished, the secretion is stopped. An example of this mechanism is the release of insulin when the level of blood sugar rises. As the blood sugar level drops, insulin secretion is stopped. In this situation, the effect of insulin is relatively slow. To prevent the blood sugar from falling excessively, glucagon is released to elevate the blood sugar. It is through this mechanism that the sugar level within the blood is held in a tight range. The other key control depends on organs such as the liver and kidney to metabolize the circulating hormones, limiting the duration of their action.

ENDOCRINE GLANDS

Objective

- Name the Major Endocrine Glands, List the Hormones Secreted by Each Gland, and Describe the Functions of These Hormones

The hypothalamus and pituitary gland closely associate in location and function. The hypothalamus not only functions as an endocrine gland but also helps to control much of the body's endocrine system. The hypothalamus provides a link between the nervous and endocrine systems. The pituitary gland, or hypophysis, lies at the base of the brain, contacting the hypothalamus (Figure 10–3). The pituitary divides into two regions, the anterior and posterior lobes.

A nervous system connection exists between the hypothalamus and the posterior lobe of the pituitary gland, or neurohypophysis (Figure 10–4). This region of the gland actually develops from brain tissue in the embryo. Neuron bodies are present in the hypothalamus and have axons that extend into the posterior pituitary. The neuronal endings in the posterior lobe acts as a reservoir for hormones produced in the hypothalamus. When the hypothalamic neurons are stimulated and depolarization occurs the posterior lobe releases the hormone.

Two peptide hormones are released from the posterior lobe. One hormone, oxytocin, is responsible for contraction of smooth muscles and stimulates the muscles in the wall of the uterus and ducts of the mammary gland. This hormone plays an important role in the process of parturition or birthing. The release of oxytocin aids in the dilation of the cervix and results in contraction of the uterus to help in the delivery of the newborn.

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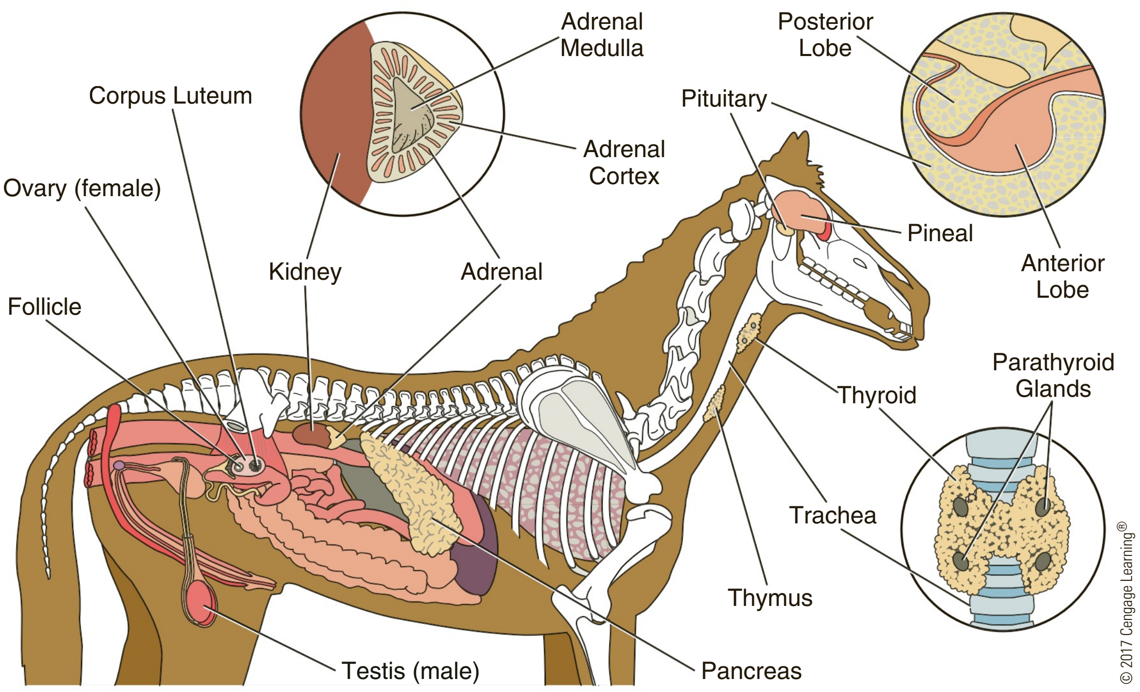

FIGURE 10–3 General location of endocrine glands in a horse.

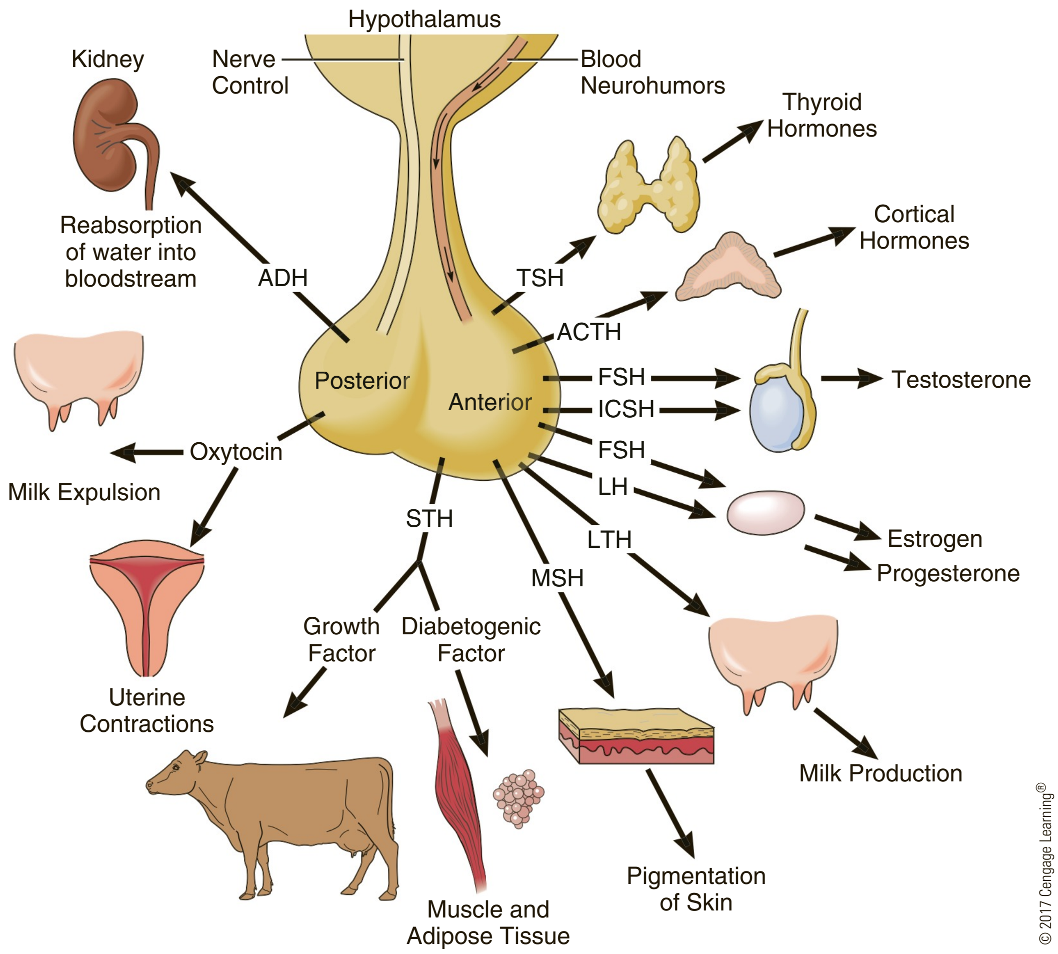

FIGURE 10–4 Hypothalamus–pituitary structure. The posterior lobe has neural secretion. The anterior lobe is stimulated by releasing factors carried in the blood from the hypothalamus.

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Once born, the newborn suckling the mother causes a sensory stimulation to be sent to the pituitary. The pituitary then releases oxytocin to stimulate the smooth muscles within the mammary gland. This forces milk into the teat cistern and canal, providing an ample supply of milk to the newborn. Oxytocin is available in an injectable form. This drug is often used to stimulate uterine contraction during delivery of a newborn. It is also used to stimulate release of milk from the mammary gland. Release of milk is commonly called letdown.

Mastitis is an infection within the mammary gland. The gland can become so swollen that the animal's natural oxytocin release may be ineffectual in allowing the release of milk. Supplementing the cow with an oxytocin injection can allow for a more complete release of the milk from the infected gland. This can help to remove the bacteria and toxins trapped within the udder and speed the recovery of the animal.

Antidiuretic hormone (ADH), or vasopressin, is also released from the posterior lobe of the pituitary gland. A review of Chapter 6 will emphasize the importance of ADH in the regulation of urine formation and water reabsorption. ADH, also a peptide hormone, has two major functions. One function causes constriction of arterioles, which increases blood pressure. The other function causes the distal tubules within the kidneys to become more permeable to water. As a result, more water is retained and the urine becomes more concentrated. The release of ADH is controlled by receptors within the hypothalamus, which detect changes in the osmotic pressure of the blood. It is predictable that a lack of ADH results in very dilute urine. This condition is called **diabetes insipidus**. Affected animals have an uncontrolled thirst and urinate excessively. Along with this very dilute urine, owners often notice that pets needs to urinate at night or become incontinent. Dogs and cats normally have water intake in the range of 20 to 70 ml/kg/day. Water intake over 100 ml/kg/day is considered excessive.

The anterior lobe of the pituitary gland, or adenohypophysis, is a classic endocrine gland. It receives signals through the blood and releases its hormones into the bloodstream (Figure 10–4). The hypothalamus also helps to regulate the function of the anterior lobe. Rather than the neural control of the posterior lobe, the hypothalamus produces several releasing and inhibiting factors to control the anterior lobe. For example, the hypothalamus produces a growth-hormone-releasing factor and a growth-hormone-inhibiting factor. These two compounds respectively increase and decrease the pituitary's production of growth hormone. The anterior lobe produces and releases at least six polypeptide hormones under the control of the hypothalamus. These releasing factors are transported to the pituitary gland though a venous portal system.

The anterior pituitary secretes growth hormone, or somatotropin, which is responsible for growth in young animals. Growth hormone is very species specific in its action (i.e., a hormone from one species will not be active in an unrelated species). Growth hormone stimulates all the cells in the body to increase the synthesis of protein. Somatotropin has a particular effect on the growth of bone and muscle tissue. In addition, it signals the cells to utilize fat reserves and conserve carbohydrates. The fat reserves are mobilized and broken down to provide more energy for the animal. Because less sugar is taken in by cells, the level of sugar in the bloodstream typically rises. The growth of the animal results from the increased protein synthesis. Somatotropin has a role in animals of all ages and regulates the metabolism of all cells. In older animals, the increased protein synthesis may be directed primarily to repair of tissues rather than to growth.

Growth hormone does not directly stimulate the growth of bones and cartilage necessary for the increase in size of young animals. Instead, this hormone stimulates the liver to produce another molecule, somatomedin, which stimulates the growth of bone and cartilage.

Prolactin is another peptide hormone of the anterior pituitary. Prolactin stimulates the development of the mammary glands in preparation for milk production. In addition, prolactin signals the epithelial cells of the mammary gland to produce milk as the pregnancy comes to an end. Prolactin works in coordination with other hormones, such as growth hormone, to control milk production. Nursing or milking provides the stimulation that causes the release of prolactin. Once these signals stop, milk production rapidly declines.

The pituitary gland is called the master gland because of the control it has over the body and other endocrine glands (Table 10–2). One example of this master control is the means by which the pituitary controls the thyroid gland. The pituitary secretes thyroid-stimulating hormone (TSH), which in turn stimulates the thyroid gland to produce thyroxine. The role of the thyroid gland is discussed later in this chapter. Increased levels of thyroxine provide negative feedback, causing the release of TSH to diminish. The increasing level of hormone, therefore, provides the signal to slow its release.

Luteinizing hormone (LH) and follicle-stimulating hormone (FSH) were discussed extensively in Chapter 8. In males, LH stimulates the interstitial cells of the testes to produce testosterone. FSH helps to control sperm production within the seminiferous tubules. In females, the same hormones are essential in regulating the estrous cycle. FSH stimulates the formation of the follicle, which then produces estrogen. A surge in LH signals ovulation and the formation of the corpus luteum. The corpus luteum produces progesterone which is essential in maintaining a pregnancy.

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Table 10–2 **Summary of Pituitary Gland: Hormones and Actions**

Location	Hormone	Target	Action
Posterior lobe	Oxytocin Antidiuretic hormone (ADH)	Uterus, mammary gland Kidneys	Stimulates smooth muscle contraction Stimulates water reabsorption
Anterior lobe	Growth hormone (STH) Prolactin (LTH) Thyroid-stimulating hormone (TSH) Luteinizing hormone (LH) Follicle-stimulating hormone (FSH) Adrenocorticotropic hormone (ACTH)	Nonspecific Mammary gland Thyroid gland Ovaries/testes Ovaries/testes Adrenal glands (cortex)	Stimulates growth Stimulates milk production Stimulates thyroxine production Stimulates ovulation and corpus luteum formation Stimulates testosterone production Stimulates follicle formation Stimulates sperm production Stimulates aldosterone and cortisol production

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The release of LH and FSH is controlled by the hypothalamus. The hypothalamus produces and releases gonadotropin-releasing hormone (GnRH). GnRH is released in surges in response to the level of other reproductive hormones. GnRH is necessary to maintain a normal estrus cycle.

Adrenocorticotropic hormone (ACTH) is a peptide hormone that helps to regulate the function of another endocrine gland. In this case, ACTH regulates the function of the adrenal glands. The adrenal glands are also discussed in more detail later in this chapter. ACTH stimulates the adrenal cortex (outer region) and its production of aldosterone and cortisol. Aldosterone was mentioned earlier in the text in relation to control of blood pressure and urine production. When the animal is under stress, the increase in ACTH can stimulate a very rapid rise in the blood levels of cortisol. As the stress on the animal declines, the elevated cortisol signals the pituitary to decrease its production of ACTH. This is another example of a negative feedback loop.

The pancreas was discussed in Chapter 7. The pancreas plays the dual role of endocrine and exocrine gland (see Figure 7–11). Clusters of cells, called islets of Langerhans, are scattered throughout the gland. These cells are responsible for the endocrine functions, producing insulin and glucagon. There are two cell types within the islets that secrete these hormones. The beta cells produce insulin, and the alpha cells produce glucagon.

The two hormones, insulin and glucagon, work together to maintain tight control over the level of blood sugar. Following a meal rich in carbohydrates, the blood sugar level increases rapidly. In response, the pancreas releases insulin, which is transported through the bloodstream. Insulin transported through the hepatic portal vein stimulates the liver to convert glucose to glycogen and fat. Insulin stimulates cells throughout the body to become more permeable to glucose. Once in the cell, the sugar can be metabolized. The net effect is that the blood sugar level declines.

If this were the only associated regulating mechanism, blood sugar would fall too low. Without another meal to supply more carbohydrates, the use by the liver and the body's cells would make the blood sugar decline to dangerously low levels. Therefore, as the blood sugar declines, the pancreas releases glucagon (Figure 10–5). The net effect of glucagon is to increase the level of blood sugar. Glucagon stimulates the liver to break down glycogen to produce more glucose. In addition, glucagon stimulates the liver to convert amino acids and fats into new glucose molecules.

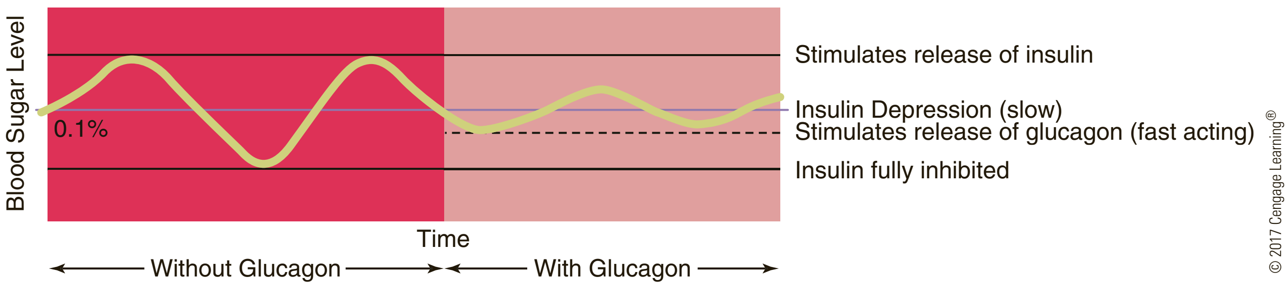

FIGURE 10–5 Regulation of blood sugar level. With only insulin, blood sugar undergoes wide swings. With the combination of insulin and glucagon, the fluctuations are much less pronounced.

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Diabetes is a disease in which an animal is consistently hyperglycemic (has elevated blood sugar levels). The complete term for this disease is **diabetes mellitus**. This distinguishes it from the ADH deficiency in diabetes insipidus. In lay terms, *diabetes* is generally used to refer to diabetes mellitus. The classic signs of diabetes in animals are similar to those in humans. The common history for pets with diabetes includes an animal that is drinking and urinating excessively. Technically, these signs are called **polydipsia** and **polyuria**, respectively. In medical records, this is often abbreviated PU/PD. In addition, these animals often lose weight in spite of having an aggressive appetite.

In dogs, one common form of the disease occurs when the beta cells of the pancreas deteriorate. This destruction may actually occur as a result of the body's own immune system attacking these cells. More than 75% of the beta cells must be destroyed before signs of diabetes become evident. The standard treatment for diabetes is to supplement insulin. Insulin has activity that is not very species specific. This allows for insulin produced from one species to be used for diabetes control in another species. (In fact, prior to the bioengineering of insulin for humans in the late 1970s and early 1980s, insulin from animals was utilized to treat humans with diabetes.) Insulin, a peptide hormone, is destroyed in the stomach if given orally. Therefore, insulin must be given by injection. Fortunately, the hormone is given with a very small needle, depositing the medication under the skin. In general, animals do not react painfully to such a small injection.

In controlling diabetes it is imperative to maintain a consistent diet on a regular schedule. The dosage of insulin is determined by monitoring blood sugar levels periodically throughout the day after the injection. If the diet or the level of activity changes, the insulin requirement also changes. The goal is to keep the blood sugar levels close to normal throughout the day.

Over the lifetime of an animal, diabetes can result in many side effects. Poorly regulated diabetes increases the risk of such side effects. Vision is often damaged by diabetes. Elevated sugar levels often cause the development of cataracts (an opacity in the lens of the eye) or damage to the retina itself. In addition, the long-term-effects of high sugar levels include damage to the nerves and the kidneys. The damage can eventually result in kidney failure. The signs of nerve damage are quite varied, depending on which nerves are involved.

Controlling diabetes requires careful attention. The needs of the animal can change with time and also with differences in appetite, exercise, and illness. For example, vomiting, which limits the intake of the animal greatly, lowers the need for insulin. An overdose of insulin results in **hypoglycemia**. Initially, the animal becomes weak, lethargic, and ataxic, or unable to coordinate muscle movement. If the blood sugar level falls further, the animal can enter a coma or develop seizures. Death can result if hypoglycemia is not treated. When caught in the earliest stages, owners can rub syrup on the gums of the animal to provide a rapid source of glucose. More severe cases may require the intravenous delivery of glucose by a veterinarian.

If inadequate insulin is delivered, blood sugar can reach such high levels that the animal also becomes very ill. These animals also become weak and lethargic. The signs can be difficult to distinguish from hypoglycemia. These pets often begin to vomit as well. Treatment in these cases requires additional insulin and often intravenous fluids to keep the animal hydrated. It is extremely important to distinguish these two conditions because treatments are so different.

The pancreas is an endocrine gland closely associated with the digestive system. The stomach also has endocrine function, with the release of gastrin. Gastrin, a short peptide, is released into the bloodstream upon stimulation of the stomach by food. When the gastrin is returned to the stomach, it stimulates the release of hydrochloric acid (HCl) by the parietal cells. The duodenum also has endocrine functions. The cells lining the duodenum secrete three hormones: cholecystokinin (CCK), secretin, and gastric inhibitory peptide (GIP). CCK stimulates the pancreas and gallbladder to release their digestive enzymes. Secretin stimulates the release of sodium bicarbonate from the pancreas and the liver to produce bile. GIP is released to slow the activity of the stomach. A more thorough discussion of these hormones and the digestive system can be found in Chapter 7.

The adrenal glands lie just cranial to each kidney (Figure 10–6) and are divided structurally into a central region, called the medulla, and a larger outer region, the cortex. These two regions have distinctly different functions.

The adrenal medulla is closely associated with the sympathetic nervous system. This region secretes epinephrine (adrenaline) and norepinephrine (noradrenaline) (Figure 10–7). Norepinephrine is the same chemical used as a neurotransmitter in the sympathetic nervous system. The cells within this region of the adrenal gland are actually modified nerve cells.

The adrenal medulla releases these hormones in periods of stress, such as injury or fright. The effects of epinephrine and norepinephrine are the same as those resulting from sympathetic nervous system activation (see Chapter 9). Most notably the heart rate increases rapidly, along with an increase in blood pressure, as arterioles are constricted. Flow of blood is shifted from the skin and intestinal organs to the skeletal muscles, coronary arteries, liver, and brain. The metabolic rate and blood sugar increase. The bronchioles dilate to provide more oxygen to the tissues. The pupils also dilate. These changes prepare the animal for sudden

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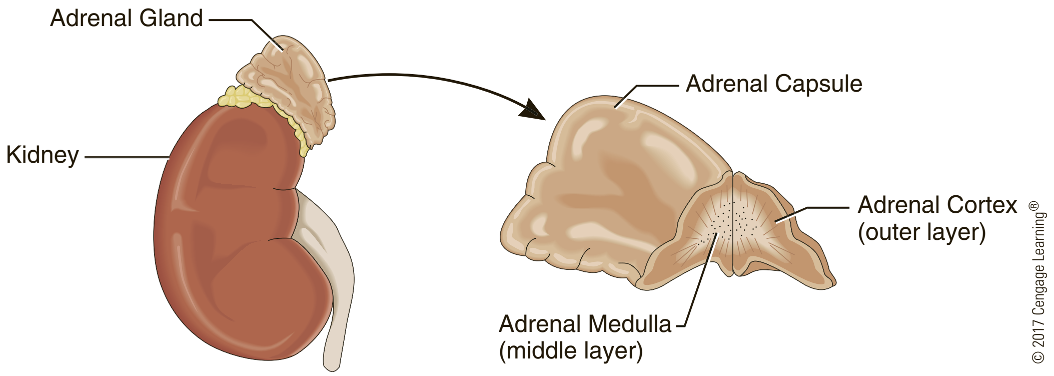

FIGURE 10–6 Location and structure of the adrenal glands.

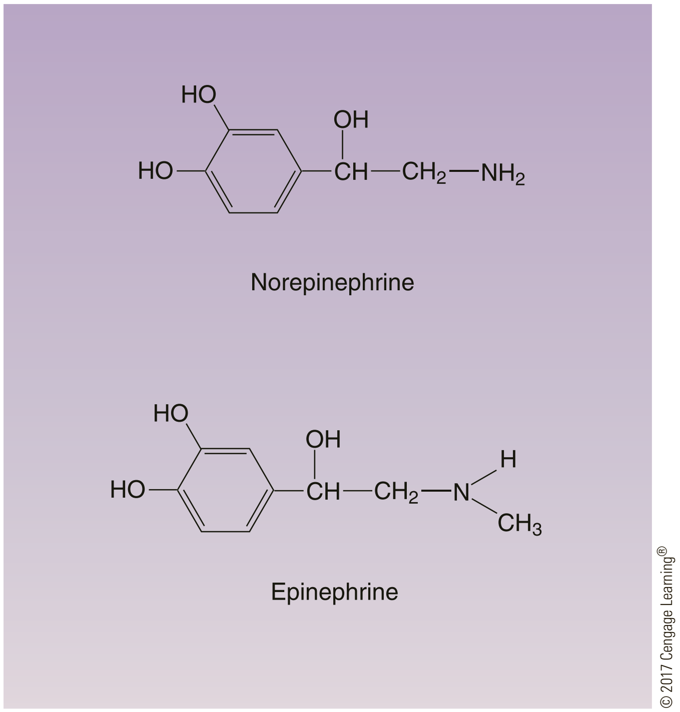

FIGURE 10–7 Chemical structure of norepinephrine and epinephrine.

increases in physical activity, such as fleeing a predator (fight or flight).

The stress that stimulates the adrenal medulla to release its hormones also causes a release of ACTH from the pituitary gland. The ACTH stimulates the adrenal cortex. All the hormones secreted by the cortex are derivatives of the molecule cholesterol. The adrenal cortex produces two major types of hormones, mineralocorticoids and glucocorticoids. In much smaller amounts, the male and female sex hormones, androgens and estrogens, are also produced.

Cortisol, or hydrocortisone, is the primary glucocorticoid produced by the adrenal cortex. The action of cortisol is primarily at the level of the liver. Cortisol stimulates the liver to convert fat and protein into glucose. Gluconeogenesis describes this creation of new glucose molecules. This action increases the supply of glucose and glycogen at the level of the liver and also increases the blood sugar level. In addition, cortisol has the potent effect of minimizing inflammation.

In times of stress, the cellular demand for energy is often increased. Initially epinephrine is released by the medulla, **shunting** blood supply to areas needing it the most. Epinephrine has only a short duration of action. The elevated stress signals a release of ACTH from the pituitary. The increased cortisol level then provides a longer term effect, maintaining adequate fuel to the cells and inhibiting new protein synthesis. As the stress subsides, the elevated cortisol suppresses the release of ACTH, and cortisol returns to a normal level.

Aldosterone is the primary mineralocorticoid. Aldosterone has been discussed in relation to the control of blood pressure and mineral control in Chapters 4 and 6. Its primary action is to increase the reabsorption of sodium ions (Na^+) in the distal tubules and collecting ducts of the kidney. As a result, more water is also held in the bloodstream. The actions of aldosterone therefore maintain sodium balance but also influence blood pressure by increasing blood volume.

The kidney helps to control the release of aldosterone. When blood pressure falls, the kidneys release renin. In turn, renin accelerates the formation of angiotensin, which also stimulates an increase of blood pressure. The angiotensin then signals the adrenal cortex to produce more aldosterone.

The thyroid gland is located in the neck, with a lobe on each side of the trachea. The actual position is variable among animals. The thyroid is unique, being the only endocrine gland that can be palpated. In most animals, however, this is only possible if the gland becomes enlarged. The thyroid gland produces two hormones, thyroxine and calcitonin. The glandular cells have a spherical arrangement creating follicles that provide storage of thyroid hormone.

Thyroid hormone, or thyroxine, is produced from the amino acid tyrosine combined with iodine. Because iodine is essential, the storage capability of the gland

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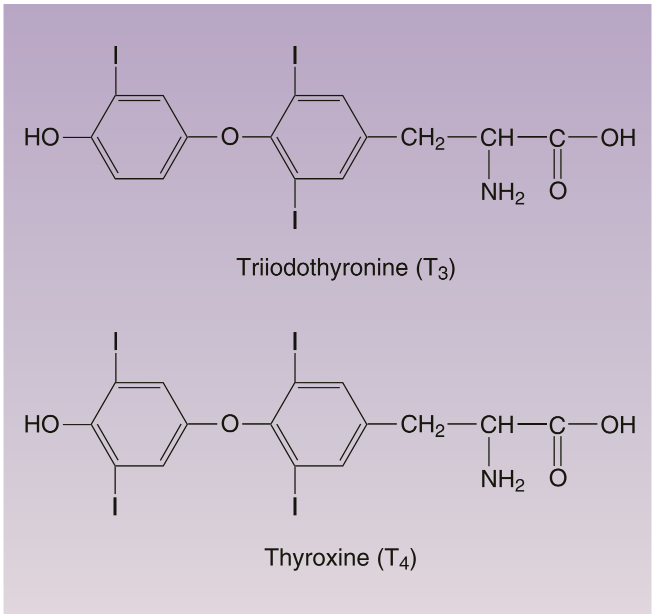

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FIGURE 10–8 Chemical structure of T_3 and T_4.

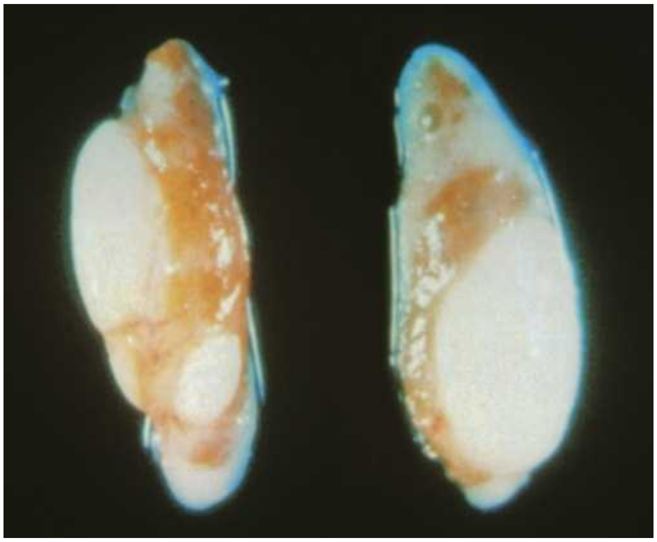

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FIGURE 10–9 Thyroid and parathyroid glands from a cat. The white and tan areas are very enlarged parathyroid glands. Normal parathyroid glands would not be visible.

allows for thyroid hormone to be available during temporary deficiencies in intake. Two forms of thyroxine, T_3 and T_4, are differentiated based on the number of iodine atoms within the molecule (Figure 10–8). T_3 is the more active and potent form of the hormone. T_4 is often converted into the more active form at the tissue level. Thyroxine enters the cell and binds a receptor on the nucleus.

Thyroxine increases the metabolic rate and oxygen consumption in almost all tissues. As a result, there is also an increase in heat production. In the heart, thyroxine increases the speed and strength of contraction. In addition, it makes the heart more sensitive to the effects of epinephrine from either the sympathetic nervous system or the adrenal glands. The thyroid hormone stimulates the breakdown of adipose or fat tissue and stimulates erythropoiesis. Animals with prolonged exposure to cold have an increase in thyroxine release. The resulting increased heat production aids in the maintenance of proper body temperature. Thyroid hormone is also necessary for normal growth and development. In coordination with growth hormone, thyroxine increases the synthesis of protein.

Control of thyroxine production is influenced by thyroid-stimulating hormone (TSH), already discussed in relation to the pituitary gland. As mentioned, this control is a classic negative feedback loop. TSH increases the production and release of thyroxine. As a result, thyroxine levels increase in the bloodstream. It is this increase in blood levels that then signals the pituitary to release less TSH. This feedback loop maintains homeostasis within the animal.

As mentioned, the thyroid also produces calcitonin. Along with parathyroid hormone, calcitonin is involved in the regulation of calcium levels. The parathyroid glands lie adjacent to the thyroid gland and may even be embedded within the thyroid (Figure 10–9). They produce parathyroid hormone, a protein hormone involved in calcium metabolism.

The general effect of parathyroid hormone is to increase the blood level of calcium. This action occurs at three levels. One action is to increase the mobilization of calcium from bone. Parathyroid hormone stimulates the actions of osteoclasts, releasing calcium. It also stimulates increased absorption of calcium from the gastrointestinal tract. Finally, parathyroid hormone stimulates the kidney to increase the reabsorption of calcium while decreasing the absorption of phosphate (PO_4^{3-}).

Vitamin D is essential for the absorption of calcium from the intestinal tract. Vitamin D can be ingested in feeds but is also produced in skin exposed to ultraviolet light, from the sun or from artificial sources (Figure 10–10). Vitamin D is a derivative of cholesterol. To become activated, vitamin D is transported to the liver, where it undergoes its first modification. The kidneys then pick up this intermediate molecule, and it is converted to the active form. This final modification is accelerated by the presence of parathyroid hormone. Lack of vitamin D prevents normal absorption of calcium and prevents adequate deposition in the bone. If this deficiency occurs during childhood, it results in a condition called **rickets**. Animals with rickets have deformed and weakened bones.

As the level of calcium increases, parathyroid gland production is suppressed. In addition, calcitonin is released from the thyroid gland. Calcitonin is an antagonist to the actions of parathyroid hormone. Calcitonin decreases the activity of the osteoclasts and

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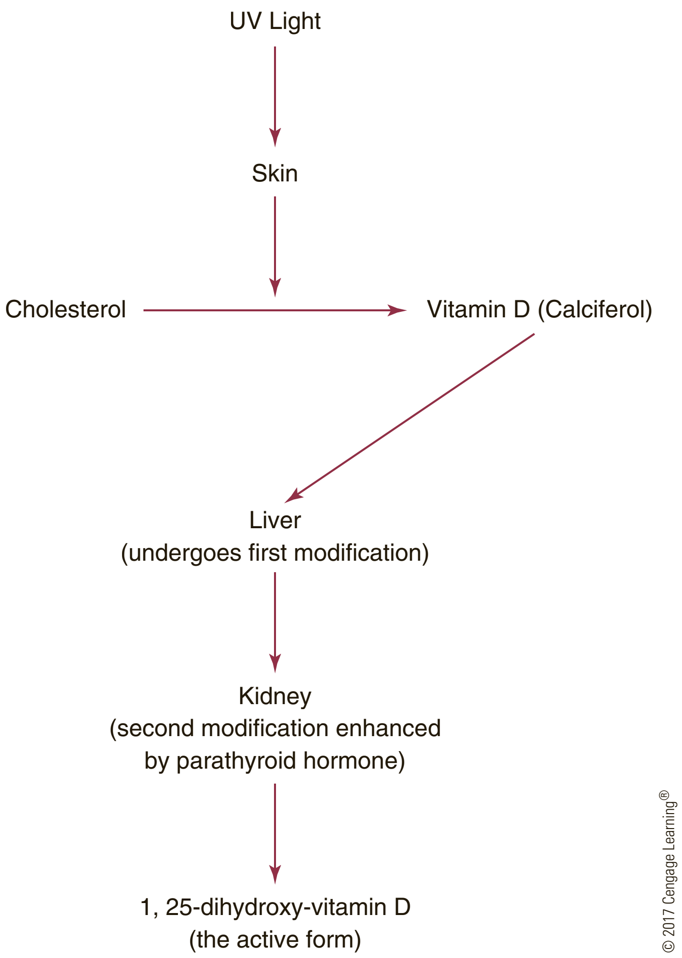

FIGURE 10–10 Summary of vitamin D metabolism.

decreases the reabsorption of calcium from the kidney and the gut. The action of the two antagonistic hormones helps to maintain homeostasis.

The kidney has also been mentioned in several sites as an endocrine gland. The kidney releases renin, which helps to regulate blood pressure and the release of aldosterone. The kidney converts vitamin D into the active form necessary for calcium metabolism. Erythropoietin also originates from the kidney and is essential to stimulate bone marrow in the production of blood cells.

CLINICAL PRACTICE

Objective

- Discuss the Clinical Significance of Excesses or Deficiencies of Endocrine-Related Hormones

Many disease conditions can result from either an excessive or deficient production of a hormone. In Chapter 4 the prefixes *hypo-* ("below") and *hyper-* ("above") were introduced to describe the level of compounds within the bloodstream. The same prefixes are used to describe disease conditions when hormone levels lie outside the normal range. Many diagnostic tests are available to measure the level of hormones within the bloodstream. For example, hypothyroidism describes a deficiency in thyroxine. Hyperthyroidism describes an excessive production.

With an understanding of the function of the thyroid hormone, it is possible to predict many of the signs in these disease conditions. Thyroxine plays an essential role in the rate of cell metabolism. In hypothyroidism, the body's cells lack stimulation by thyroxine. As a result the body's metabolism slows. The common signs of lethargy, weight gain, weakness, and intolerance to cold are all predictable. In addition, many of these animals first present because of hair coat or skin problems. These animals often have areas of thin hair coat or baldness (**alopecia**). Infection of the skin is also a common side effect of hypothyroidism. Treatment of these animals involves oral dosing of a manufactured form of thyroxine. The treatment replaces the deficiency of thyroxine and in general is required for the lifetime of the animal. The treatment is not designed to stimulate thyroid production, but instead acts as a substitute for it.

Hyperthyroidism is most commonly seen in elderly cats (Figure 10–11). Again, many of the signs are predictable based on the effect of thyroxine in increasing cellular metabolism. The most consistent feature of the disease is weight loss, often in spite of an above-normal appetite. Many of these animals drink and urinate excessively and have increased activity. On physical examination, these cats often have an extremely rapid heart rate, and the thyroid gland is enlarged enough to palpate. As the disease progresses, many of these animals develop diarrhea and vomiting.

Several treatment options exist for hyperthyroidism. Surgical removal of the thyroid gland is extremely effective. Often these animals develop hypothyroidism

Courtesy Mark Jackson, North Carolina State University.

FIGURE 10–11 A cat showing signs consistent with hyperthyroidism or diabetes mellitus.

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and require daily thyroxine supplementation. A more serious complication occurs when the parathyroid glands are also removed or damaged during surgery. The parathyroid and thyroid glands lie in such close association that the two may not be distinguished during surgery. Removal of the parathyroid glands results in a severe hypocalcemia, which must then be treated.

Another treatment option is radioactive iodine. Iodine is included only in the molecules of the thyroid hormones. When radioactive iodine is administered, the thyroid gland rapidly picks up the iodine from the bloodstream. The regions of the thyroid that are extremely active (overproducing) pick up the majority of the iodine. Being radioactive, this iodine damages the thyroid tissue. The less active thyroid regions are then left undamaged. It is possible to underdose or overdose animals, leaving the cat hyperthyroid or creating a hypothyroid condition. This procedure is generally very effective. Its usage is limited due to the availability of centers able to handle the radioactive material.

The third option is to administer an oral medication (such as methimazole) that blocks the synthesis of thyroxine. The dosage of this drug must be adjusted to bring the thyroxine levels back into the normal range. This dosage often requires adjustment over the lifetime of the animal. If the medication is stopped, the cat will revert to the hyperthyroid condition. The advantages are that it requires no advanced surgical training, avoids the risk of hypoparathyroidism, and does not require handling of the radioactive iodine. The disadvantages are that treatment is generally required for the lifetime of the cat, failure to treat allows the condition to recur, and side effects to the medication are possible.

Recently another treatment option has become available in the form of an iodine-restricted diet. As mentioned, thyroxine production is totally dependent on the availability of iodine. Diets are now available through veterinarians that have a very controlled level of iodine. Over the course of several weeks as the cat consumes the special diet, thyroid hormone production declines to normal levels. This technique has the advantage of being done completely at home and does not require administration of medicine to the cat. Dietary control does have limitations: the cat must be restricted to only this diet (i.e., this option will not be effective for outdoor cats), and the cat must find the food palatable.

The adrenal cortex can also be involved in conditions with excessive or deficient hormone production. Hyperadrenocorticism is also called **Cushing's disease** after the doctor who discovered the condition. In this condition the blood levels of cortisol are excessive. This can be a result of a pituitary tumor producing excessive ACTH (the majority of cases in dogs) or an adrenal tumor producing excessive cortisol. This condition can also be caused by excessive use of cortisone medications by a veterinarian. **Iatrogenic** is a term that describes a condition caused by treatment (e.g., iatrogenic hyperadrenocorticism).

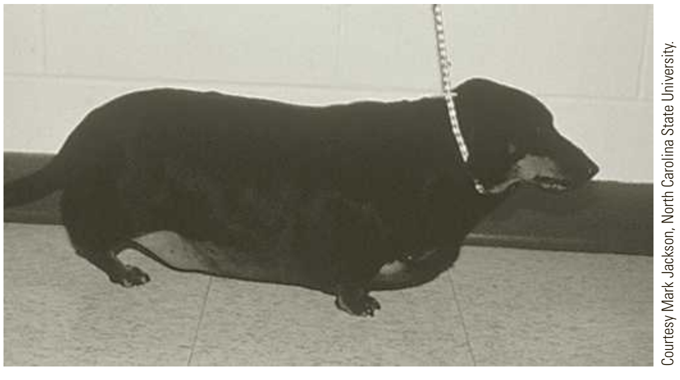
The clinical signs and history are all consistent with the variety of effects that cortisol has within the body. The most common clinical signs are excessive thirst and urination, excessive appetite, thin skin and hair coat, panting, enlarged abdomen, weakness, and lethargy (Figure 10–12). Most animals do not show all these signs.

Once Cushing's disease is suspected, diagnosis requires an understanding of the adrenal glands and stimulation by the pituitary gland. A single measure of cortisol in the bloodstream is helpful but does not prove the diagnosis. Cortisol levels rise and decline during the day, plus the stress of being at the veterinarian's office may result in an elevated level. Several tests are available to confirm the diagnosis.

One such test is called the dexamethasone suppression test. In this test, blood is taken to establish a baseline blood level for cortisol. Then dexamethasone (an injectable corticosteroid) is administered. The cortisol levels are sampled four and eight hours later. In normal animals the dexamethasone is detected by the animal, which causes a decrease in the secretion of ACTH. As a result, cortisol levels decline (Figure 10–13A). In animals with an adrenal tumor, the gland produces cortisol without the need for ACTH. In animals with a pituitary tumor, ACTH is produced without the normal negative feedback from cortisol in the blood. As a result, animals with Cushing's disease do not show the normal decline in cortisol following the dexamethasone injection (Figure 10–13B).

Treatment of animals with hyperadrenocorticism can be surgical or medical. Surgical treatment involves removing the adrenal tumor if that is the site of the problem. Medical treatment involves using a medication that damages the adrenal gland, lowering the cortisol production. The medication is generally required for the life of the animal.

Either treatment can cause such damage that the animal can develop hypoadrenocorticism. This disease can develop naturally as well, if the adrenal glands fail to produce normal levels of hormones.



Courtesy Mark Jackson, North Carolina State University.

FIGURE 10–12 A dog with hyperadrenocorticism.

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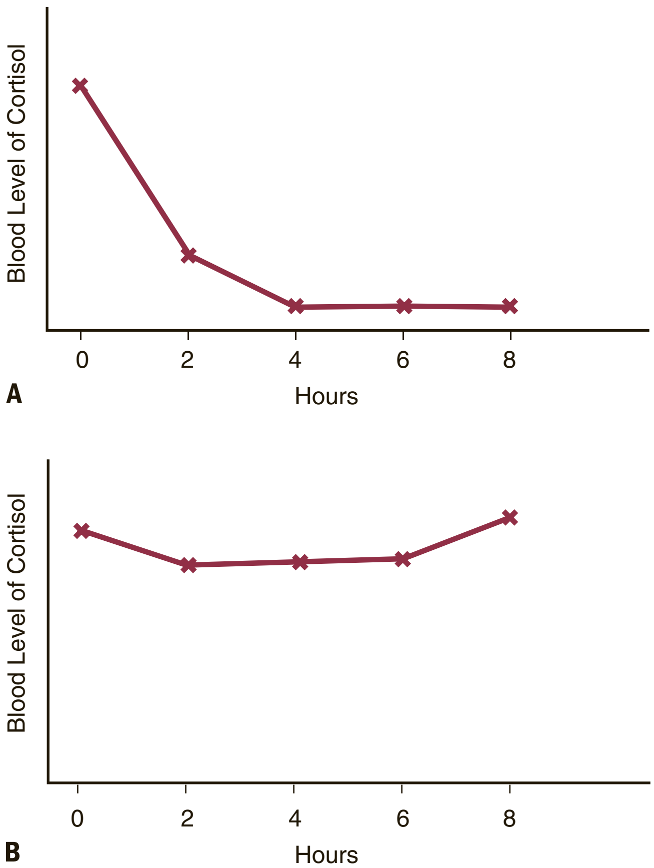

FIGURE 10–13 Dexamethasone suppression test. A. Response of blood cortisol levels in a normal animal. B. The same test in an animal with hyperadrenocorticism. Cortisol is not suppressed to low levels and begins to rebound about eight hours after the administration of dexamethasone.

Hypoadrenocorticism is also called Addison's disease, again after the clinician who discovered the condition. In hypoadrenocorticism there is a deficiency in both the glucocorticoids and mineralocorticoids. Although Sebastian was being treated, he showed all the typical symptoms of hypoadrenocorticism.

The low level of cortisol shows as lethargy, weakness, and weight loss. Often many gastrointestinal signs are evident, including poor appetite, vomiting, and diarrhea. The lack of aldosterone leads to a loss of sodium, chloride, and water. In addition, potassium levels increase. The loss of water can lead to a low blood volume and low blood pressure, which adds to the weakness. As the potassium level increases, it can affect the contraction of muscles, including the heart. This too contributes to weakness and fatigue. Often the pet shows no sign until the condition is quite severe. These pets often present as medical emergencies, with severe weakness, vomiting, diarrhea, and low blood pressure.

Hypoadrenocorticism is often suspected when a chemistry profile shows hyponatremia (low sodium) and hyperkalemia (high potassium). While waiting on the blood results, animals in such critical condition must be treated. Based only on the clinical signs, these animals are often treated with intravenous fluids and given glucocorticoids. Fortunately, this symptomatic treatment often yields very positive results while the blood results are pending.

The sodium and potassium changes are very suggestive of Addison's disease. To confirm the diagnosis, an ACTH stimulation test is performed. In this test a resting cortisol level is taken. Then ACTH is administered, and a second cortisol level is taken one to two hours later. In a normal animal, the cortisol increases significantly between the two tests. In an animal with hypoadrenocorticism, ACTH is already quite high. The low cortisol levels stimulate the pituitary gland to release ACTH, as a way of increasing the levels naturally. In these animals, administering additional ACTH results in very little increase in cortisol levels.

To treat affected animals, a mineralocorticoid must be administered. This may be given in a long-lasting injectable form or in a pill form. Many of these pets do not require routine treatment with a glucocorticoid. However, when additional stress or trauma occurs, administering more cortisone is helpful. This mimics the body's normal reaction of increasing the cortisone level during times of stress. The story of Sebastian shows that animals under treatment must be evaluated and dosages adapted if the need arises.

In medicine the terms *glucocorticoid*, *cortisone*, *cortisol*, and *steroids* are all used interchangeably to describe medications mimicking the natural effect of the glucocorticoids. The multiple terms can at times lead to confusion, but all are referring to the same class of medication. Steroids are used in a variety of cases. The primary usage is for their anti-inflammatory and immunosuppressive effects. There is a wide dosage range that varies based on the desired effect.

One of the most common uses for the anti-inflammatory effect is in the skin diseases of dogs and cats. Many allergic reactions in pets (such as allergic reactions to flea bites) result in severe itching and skin inflammation. Even when the underlying cause is removed (e.g., flea treatment with insecticides), the animal can remain very itchy. Students may relate this to having a mosquito bite. The insect is gone, but the itchiness continues for some time. The biting and scratching that occur can perpetuate the signs (i.e., the itching actually makes the skin worse). Glucocorticoids can be administered to relieve this inflammation in the skin and allow it to recover.

Other causes of inflammation, such as trauma, are also treated with glucocorticoids. Trauma to the spinal cord or brain is often treated with this class of drugs. The trauma can even occur from within the animal itself. Intervertebral disk disease traumatizes the spinal cord, and steroids are a standard treatment for this problem.

There are conditions in which an animal's immune system attacks its own cells. (More discussion of this

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topic is presented in the following chapter.) In this type of disease, the dosage level is much higher to provide the immunosuppressive effect. With this type of treatment, the function of the immune system is diminished. It is important to realize that this is a general effect, making the animal more susceptible to other infectious diseases.

Other hormones are available to treat animals as well. We have discussed the role of the veterinarian in the reproductive cycle of cattle. I often use hormones to treat cattle, thus influencing their reproductive patterns. Because a goal in dairy cattle production is to have the cow calve on a regular basis, it is helpful to be able to predict when a cow will show estrus. When a cow has a functional corpus luteum, an injection of prostaglandin can be administered. Although this naturally occurs on about day 17 of the cycle, the injection can be given much earlier. Just as with the natural release of prostaglandin, the cow comes into heat following the injection (usually within three to five days). The advantages of such treatment include fewer days to breeding, better prediction of when a cow will be in heat, and being able to group cows, which improves how well the heat is shown.

Another condition that occurs in cattle is a follicular cyst. A follicular cyst appears as a very large follicle (greater than 1 inch in diameter). Functionally, a follicular cyst does not ovulate normally. If left untreated, the cow does not progress through the estrus cycle. Treatment of a follicular cyst is with an injection of GnRH. The medication causes an increase in the release of LH and FSH from the pituitary gland. The follicular cyst may ovulate in response to the GnRH or may form a corpus luteum. When successful, both results start the cow into another estrus cycle.

Bovine somatotropin (bST) is the natural hormone produced in the pituitary gland. There are actually four different forms of this protein hormone that vary by 1 or 2 amino acids out of a total of 190 or 191. Posilac has the identical sequence of 190 of the 191 amino acids. This provides essentially identical biologic activity in the cow.

Posilac is produced by splicing the gene responsible for bST production in the cow into a special bacterium. This bacterium has been specially modified so that it can survive only in very controlled laboratory conditions. The bacteria are fermented in these controlled conditions producing large numbers. Because the gene from the cow is within the bacteria, they produce recombinant bST (rBST) within the cell. The bacteria are harvested, killed, and lysed. The rBST is then isolated and purified from the mixture. This is the same procedure used to produce human insulin and interferon used in the human medical field.

Overall, rBST increases the supply of nutrients to the mammary gland and increases the rate of milk production. Nutrients are conserved in other regions of the body to increase the supply for the mammary gland. Glucose uptake by muscle and fat cells is decreased and the liver increases its production. Fatty acids are conserved as less fat is deposited. The amount of protein turnover declines, increasing the amino acids available for milk production. The increased availability of nutrients combines with an increased blood supply to the mammary gland, resulting in higher milk production. Although the specific mechanism has not been confirmed, there may also be an increased rate of milk synthesis by each mammary cell, or there may be an increased number of cells formed.

The safety of Posilac has been studied extensively. It has been shown that rBST lacks biologic activity in humans. Hormones rely on receptors on the cell to provide their activity. The structures of bovine and human somatotropin are not similar enough to affect the opposing species. Growth hormone also requires the release of somatomedins to affect the animal. A principal somatomedin for bST is the insulin-like growth factor 1 (IGF-1). This 70-amino-acid protein is identical to the human form. IGF-1 is found in milk from all cows, not just those treated with Posilac. There is a variation in the normal levels found in milk from different cows. Both the age of the cow and the level of milk production impact this level. No difference can be detected in the level of IGF-1 from treated and untreated cows. In addition it is unlikely that ingested IGF-1, a protein, would be absorbed into the bloodstream without digestion in the stomach and small intestine. This is the reason that the treatment of diabetes mellitus cannot be accomplished with oral insulin. The levels of IGF-1 found in milk are 100 to 1,000 times lower than normal blood levels found in humans. As a result even if absorbed, the levels consumed could have very little metabolic effect.

Another concern over the use of Posilac is that the level of mastitis may increase. Mastitis is an infection within the mammary gland. Consumer concern stems from the possibility that higher levels of mastitis will result in a greater risk of antibiotic contamination in the milk. Studies do show that higher-producing cows have a higher risk of mastitis. The risk seems to be based on production level, not on the use of rBST. In addition, stringent testing requirements help to prevent antibiotic residues from occurring in commercial milk.

Hormone treatment in food-producing animals can have a negative connotation for some consumers. However, rBST has been studied extensively for its safety both before and since 1994, when it was introduced into the market. Regardless of the research, the consumer ultimately controls the market, and dairy farmers must be able to sell their product to maintain a business. The debate over the use of rBST is far from over.

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SUMMARY

As mentioned, the endocrine system via ductless glands allows remote communication with distant areas of the body. Specific hormones were studied in previous chapters, but now students understand how these hormones are related to total body function. The endocrine system through its varied hormones controls many body processes.

REVIEW QUESTIONS

1. Define the following terms:

    Addison's disease
    diabetes insipidus
    diabetes mellitus
    polydipsia
    polyuria
    hypoglycemia
    shunting
    rickets
    alopecia
    Cushing's disease
    iatrogenic

2. True or False: Endocrine glands contain ducts.
3. True or False: Luteinizing hormone has no effect in the male body.
4. True or False: Poor vision can result from diabetes.
5. The pituitary gland is often called the ___ gland.
6. The release of follicle-stimulating hormone is controlled by the ___.
7. Vitamin ___ is produced by the skin when exposed to sunlight.
8. In general, is the endocrine system regulated by positive or negative feedback?
9. What hormone causes milk letdown?
10. Which hormone stimulates the development of the mammary gland?
11. What is the name for low blood sugar?
12. Which gland is the only one in the endocrine system that can be palpated?
13. Renin helps to regulate which vital sign?
14. What is somatotropin?
15. Which two hormones work in tandem to regulate blood sugar?

ACTIVITIES

Materials needed for completion of activities:

milk samples from a pregnant cow and one in estrus
milk progesterone test kit

1. Ask a diabetic member of the school to discuss his or her disease condition along with best management practices for maintaining appropriate control.
2. Obtain milk from a pregnant cow and another cow close to estrus. Run milk progesterone tests on each sample. The pregnant cow will have high levels of progesterone in her body, which will also be present in the milk. The cow in heat will have very low levels of progesterone, which also will be quite low in the milk. The milk progesterone test kit evaluates the level of progesterone and shows the results as a color reaction. (How this test works is discussed in Chapter 11.) Identify which sample is from the pregnant cow.
3. Do an Internet search for rBST. Engage with other students in a mock debate, presenting the pros and cons of the product. Use references for building cases.
4. Measure the water intake of a dog or cat for a day to determine if it falls within the normal range of 20 to 70 ml/kg. For more accurate results, measure the intake for a week and then divide by seven for a daily average.

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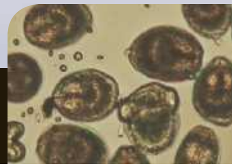

CHAPTER 11

The Immune System

Objectives

Upon completion of this chapter, you should be able to:

- Define the term *antigen* and explain its significance in immunity.
- Distinguish between passive and active immunity, differentiate between humoral and cellular immunity and their relationship in immunity, and explain primary and secondary immune responses.
- Discuss the clinical significance of the academic material learned in this chapter.

Key Terms

abscess
banded
tetanus
antigen
lymph
stocking up
phagocytized
edema
humoral immunity
primary response
secondary response
pus
modified live vaccines
killed vaccines
active immunity
passive immunity
colostrums
intranasally
kennel cough
pruritus
atopy
anaphylaxis
titer
seroconversion
ELISA test

Introduction

The immune system is responsible for protecting the animal from potentially harmful organisms attempting to invade. For many diseases the animal will become sick from an organism only once. The immune system remembers the organism and if exposed again will mount a very quick response, protecting the animal from disease. The immune system is very complicated and detailed. We will try to learn the basics of the immune system to understand how it protects animals from disease.

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A Day in the Life
Saving Lives and Stomping Out Disease and Pestilence . . .

In the description of my day I often share the dramatic and interesting cases with you. However, much of my day can be classified as routine. When I am working in the small animal clinic, a large percentage of my time is spent performing routine examinations and giving vaccines to healthy animals (Figure 11–1). Although less exciting to describe, these are the most valuable procedures for pet owners. By maintaining up-to-date vaccinations, we try to keep animals healthy and prevent disease. For many diseases, such as rabies, there is no cure once the disease is contracted. Prevention is the key. Not quite as exciting as saving lives in acute situations but equally important.

A common complaint in small animal work is an itching pet. Dogs and cats often develop allergies that cause them to scratch and bite themselves. The pets may be allergic to fleas, pollens, or even their food. In this situation, the immune system, instead of preventing disease, causes problems.

Cows continue to impress me. One poor cow I treated chewed her cud contently despite having a huge swelling on the back of her leg (Figure 11–2). Her owner was concerned about the **abscess** (an accumulation of pus). Infection was introduced under the skin (possibly from an injection), and the cow developed a large abscess. Treatment was gross and dramatic. I lanced the abscess by cutting a large hole into the skin. What looked like several gallons of very fluid pus squirted from the hole in this abscess, and the cow did not even seem to mind. The cow's immune system was trying to clean an infection and had accumulated a large amount of fluid and debris in this pocket.

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FIGURE 11–2 A draining abscess on a cow's leg.

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FIGURE 11–1 Dr. Lawhead talks with his young friend Libby about keeping her cat healthy.

There are times when the immune system produces an emergency situation. It has been many years, but I remember one case quite well. A horse had developed an infection, and the attending veterinarian administered an injection of penicillin, an antibiotic. Within a couple of minutes the animal began to breathe heavily, started sweating, and then became severely ataxic. I scrambled to the truck to get a bottle of epinephrine and a syringe. By the time I returned to the stall, the horse was on its side and experiencing extreme difficulty in breathing. We immediately administered the epinephrine, but it was too late. In the matter of a few minutes the horse had developed a severe reaction

continues

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A Day in the Life continued

to the medication and died! This case impacted me greatly. How could a treatment meant to cure this animal result in such a horrible outcome?

I went on another call to see a young sheep that was not doing well. The sheep had recently been **banded**. In this procedure a special rubber band is placed at the base of the scrotum, which consequently cuts the circulation to the testes. This is a nonsurgical means of castrating a ram. This sheep was standing, but his stance was very wide and his movement was stiff. On examination I was unable to open his mouth. Unfortunately for this animal, he had developed **tetanus**, or lockjaw. Bacteria had developed in the region of the testes due to the poor circulation. The bacteria then released a toxin that caused all the clinical signs the sheep was experiencing. Treatment was not successful. How could this disease be prevented?

Recently, I was performing routine pregnancy exams at a dairy farm. The producer's wife wanted me to look at a sick calf. She said that she treated the calf several times for a respiratory tract infection. Further, it was much smaller than other calves the same age. This time the calf just was not getting better. The woman's treatment protocol seemed appropriate so I was concerned that the calf's immune system was suppressed. I took a notch of skin from the calf's ear and submitted it to the diagnostic laboratory to be tested for bovine viral diarrhea (BVD). The testing would not help me to cure the calf, but would help to explain why it was not responding. The calf did test positive for BVD and was culled from the herd. This calf had been born infected with the BVD virus and would carry it forever. Although it was disappointing to lose a calf, the bigger concern was the potential threat of BVD to the remaining herd.

ANTIGENS AND IMMUNITY

Objective

- Define the Term Antigen and Explain Its Significance in Immunity

The immune system must be able to recognize substances that are foreign to the body. To accomplish this it must also recognize what is natural to the body. An **antigen** is any foreign molecule that is capable of stimulating an immune response. The term *antigen* refers to molecules that are within the body itself. Large molecules within the intestinal tract are not considered antigens. These molecules are broken down into smaller fragments before being absorbed into the body.

In general, antigens must be large. Small molecules, such as glucose, do not elicit an immune response. Most antigens are very large proteins or polysaccharides. Smaller molecules may bind to protein and then become antigenic. In addition to being large, the antigens are also complex. This complexity gives the molecule a specific shape that can be recognized by the immune system.

An antigen must not be a naturally occurring molecule within the body (i.e., it must be foreign). This feature keeps an animal's immune system from attacking itself. This is also the reason that the immune system will attack a transplanted organ. Large molecules on the surface of cells give them a distinct characteristic that can be recognized by the immune system. Closely related individuals have similar-appearing antigens on the surface of the cells, which makes them better organ donors.

Each antigen is a complex molecule; however, the antigen is recognized by only a small part of the molecule. This site of recognition is called the antigenic determinant. These regions have a specific shape that can be recognized by the body's immune system. The recognition is very specific for each antigen. Large and complex molecules may have several antigenic determinants and are considered quite antigenic because they greatly stimulate the immune system.

The body has collections of lymph tissue distributed throughout to detect antigens quickly. For example, tonsils are collections of lymph tissue within a connective tissue framework. The tonsils are strategically located at the back of the pharynx. In this location they are able to trap many of the invading organisms that might enter through the nose or mouth.

The body has a network of small vessels in addition to the arteries and veins. These lymphatic vessels begin as small capillaries in the tissues and form larger veins that drain fluid back to lymph nodes scattered throughout the body and eventually back to the bloodstream. The fluid that they carry is called **lymph**. Lymph begins as the interstitial fluid that forms between the cells.

As blood enters the capillaries, a portion of the water and small molecules are squeezed from the vessels. This fluid nourishes the cells. The concentration of protein in the blood helps to retain much of the fluid in the bloodstream. The osmotic pressure created

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by the protein keeps the water drawn into the blood. Animals that develop conditions where the protein declines to very low levels will accumulate more fluid in the tissues. All of this fluid is not reabsorbed into the bloodstream. The lymphatic vessels pick up this fluid, which is then called lymph.

The fluid eventually drains back into the bloodstream. The lymph travels passively—there is no pump to force it through the lymphatics. Activity by the animal helps to keep the fluid flowing. Horses tied in a stall for extended periods may develop a fluid-caused swelling in their legs. The lack of activity allows fluid to build up because it has difficulty fighting gravity. This condition is called **stocking up**. When the horse returns to activity, the contraction of the muscles surrounding the lymphatics helps to force the lymph upward and back into the circulation.

The lacteals are also lymphatics that are responsible for absorbing lipids from the intestinal tract. (Review Chapter 7.) Each lacteal begins within the villi of the small intestine. These lacteals join into a larger thoracic duct, which empties into the circulatory system in the thorax.

As mentioned, the lymphatic vessels drain into regional lymph nodes (Figure 11–3). These lymph nodes are also lymph tissue encased in connective tissue. The lymph nodes protect the body from invading organisms in that region of the body. Tissue macrophages within the lymph nodes filter the lymph for disease-causing organisms.

The spleen, a large, reddish brown organ located within the abdomen, is also involved in the immune system. Just as the lymph nodes filter the lymph, the spleen filters the blood. The spleen contains a large number of immune cells scanning the blood for antigens. The spleen also houses cells that respond to antigens. Many of the cells produce a large protein called an antibody. Antibodies are an important step in the immune system and are discussed more thoroughly later in the chapter. The spleen also removes aged red blood cells from the circulation. The spleen serves as a reserve for red blood cells. Smooth muscles within the spleen can contract to force red blood cells into the bloodstream during times of need.

Although the spleen conducts many important tasks, it is not essential for the animal to live. Fortunately, the lymph nodes can function to detect antigens and house the cells producing antibodies. The spleen is a common site for tumors to develop (Figure 11–4). In addition, the spleen can be damaged by trauma. The spleen has a

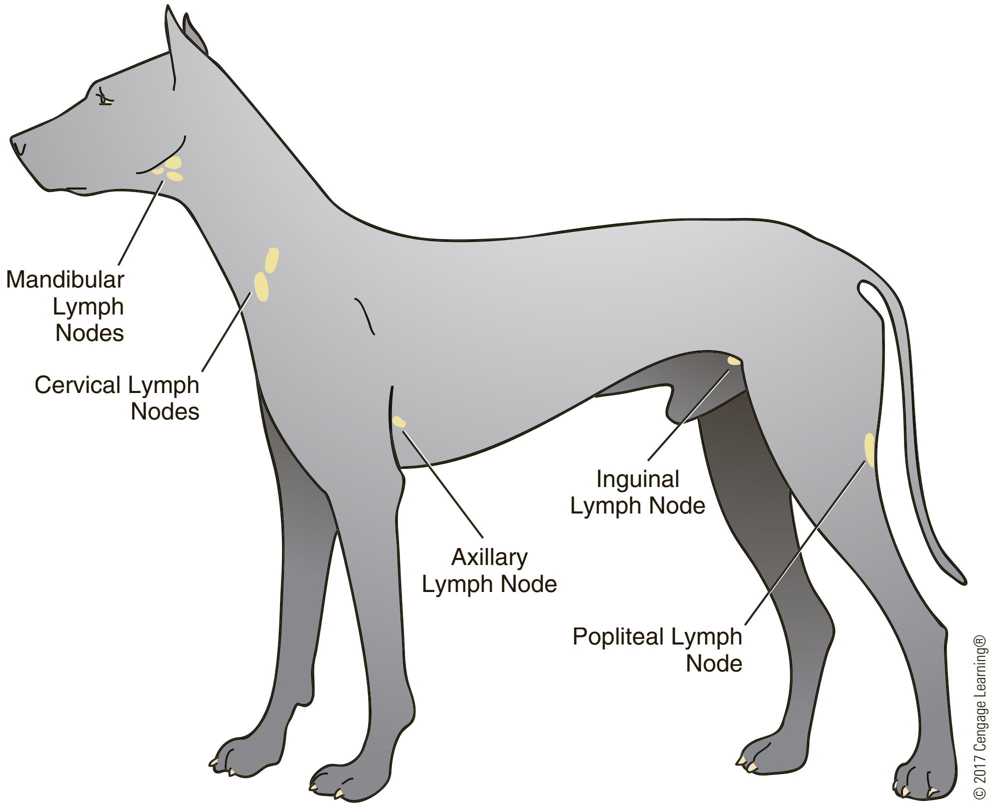

FIGURE 11–3 Location of lymph nodes able to be palpated on a dog.

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A

B

FIGURE 11–4 A. Intraoperative photograph of a spleen with tumors. B. A spleen with tumors following surgical removal.

very rich blood supply, and if it is torn by injury (such as when a dog is hit by a car), there can be extensive bleeding. In either of the situations, tumor or injury, the spleen may be surgically removed.

The bone marrow is an essential part of the immune system as well. The bone marrow produces the white blood cells, which are the functional cells of the immune system. When the body first detects an antigen, it is **phagocytized**. Neutrophils and macrophages are the primary cells responsible for this. The macrophages arise from blood-borne monocytes that enter tissues. Once the antigen (such as a bacterium) is phagocytized, it is broken down within the cell. Fragments of the antigen are then moved to the surface of the cell. These antigen-presenting cells are responsible for stimulating the activity of many other immune cells. The macrophages release cytokines that stimulate the general immune response.

Cytokines have a variety of functions. They may kill viruses or slow their replication. Release of these substances attracts other immune cells to the area and makes antigens easier to phagocytize. Some of the factors also kill damaged cells. One of the factors affects the hypothalamus, which controls the body's temperature. This results in a fever or elevated body temperature, which is a common occurrence in infectious diseases. Monitoring body temperatures is an important part of a complete physical examination. Table 11–1 lists the normal resting body temperature for many animals. It is critical to recognize that excitement and high external temperature and humidity can alter the animal's temperature without an underlying illness.

Fever makes an animal feel poorly but is specifically designed to aid in the fight against pathogens. The higher temperature may hinder the replication of an infectious organism or actually kill it. The fever helps to destroy virally infected cells. The activities of lymphocytes, phagocytes, and antibodies are all stimulated by higher body temperatures. There is also stimulation of the sleep center, which helps the animal conserve energy.

Table 11–1 **Normal Body Temperatures***

Species	Temperature Taken Rectally (°F)
Cat	101.5
Cow	101.5
Dog	102
Goat	102
Horse	100
Swine	102.5
Sheep	103

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*It is important to recognize that the temperatures are in a range around the number in the table. Body temperatures vary during the course of a day and are altered by external temperatures, activity level, and excitement.

Inflammation can be a result of physical injury or a reaction to the invasion of a pathogen. Numerous factors released by the cells of the immune system are involved in the control of inflammation. These products cause local blood vessels to dilate and the capillaries to become more permeable. This is specifically designed to deliver more white blood cells and antibodies to the area.

The increase in blood flow often results in the area becoming warm and red. The increased capillary

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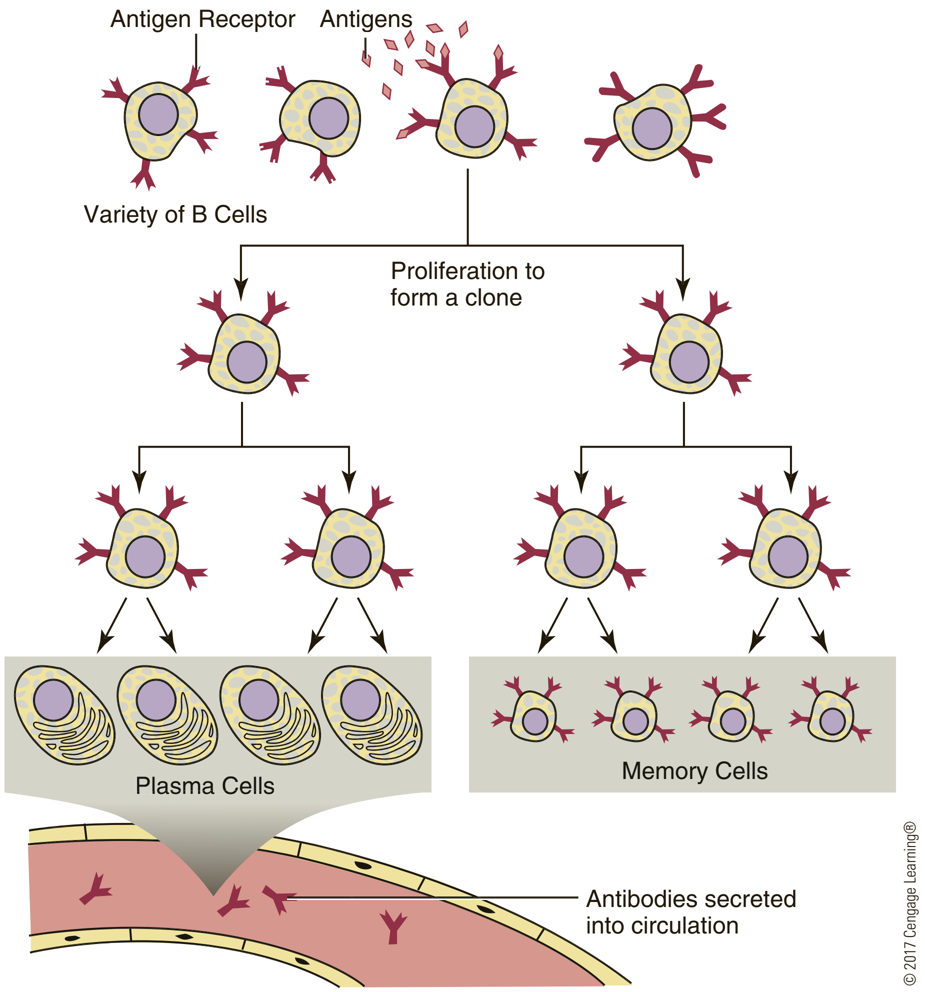

FIGURE 11–5 Summary of the clonal expansion of lymphocytes.

permeability allows more fluid to enter the tissues, causing **edema**, or swelling. The excess fluid in the tissues results in a higher pressure, which in turn compresses nerve endings. As a result, pain is often associated with these signs. The four classic signs of inflammation are warmth, redness, edema, and pain.

With inflammation, a large number of white blood cells enter the infected area. Lymphocytes come into contact with the antigen-presenting cells. Each lymphocyte is programmed to respond to a specific antigen. The exposure to the antigen stimulates the cells to undergo repeated mitosis. The result is a large number of lymphocytes specifically designed to react to this particular antigen. Because all the resulting cells are identical, this rapid growth in cell number is called clonal expansion (Figure 11–5).

One type of lymphocyte is called a B cell or B lymphocyte. B cells develop and mature in the bone marrow and lymph tissue in the intestine. Again, each B cell responds to only one antigen. During clonal expansion, many of the B cells develop into plasma cells. Plasma cells develop a large amount of rough endoplasmic reticulum and Golgi apparatus for protein production and secretion. Plasma cells secrete a specific type of protein, called antibody. The production of antibody in response to an antigen is called **humoral immunity**.

The antibody binds to the same antigenic determinant that stimulated the B cell. Antibodies are large protein molecules made of four polypeptide chains. The resulting molecule takes on a **Y** shape (Figure 11–6). The arms of the **Y** have regions that are responsible for detecting the antigen. The receptor region varies among different antibody molecules. As with all receptors, binding occurs when the shape of the antigen fits into the antibody (as in a lock and key) (Figure 11–7).

The protein found in blood divides into albumin and globulin. Antibodies are large proteins found in the globulin fraction. The antibody protein is also called immunoglobulin (Ig). A given plasma cell produces large amounts of identical antibody molecules, all designed to attack the same antigen.

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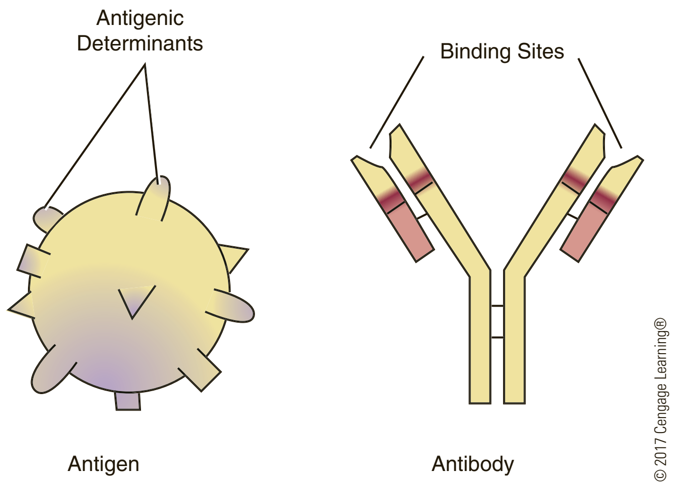

FIGURE 11–6 Structure of an antibody and antigen.

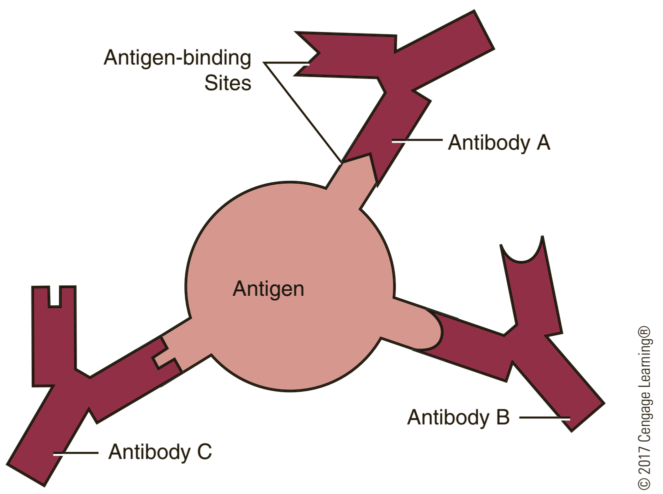

FIGURE 11–7 Multiple antibody molecules bound to an antigen.

Five classes of immunoglobulin are described. IgM is the initial antibody produced in the primary immune response. As the immune response progresses IgG becomes the predominant antibody. The relative levels of IgM and IgG can be helpful in determining the duration of an illness. IgA is found less commonly in the blood and more predominantly on the mucosal surface. This immunoglobulin can provide the first level of protection when pathogens come in contact with the mucous membrane in the nasal passages. IgE is closely associated with basophils and mast cells. These two cells have granules with histamine and, as a result, IgE is closely linked to the allergic response. There are tiny amounts of IgD in the blood, with this immunoglobulin being bound to the membranes of the B cells.

A pathogen has numerous antigenic determinant sites on its surface. Many antibody molecules bind to the surface of the pathogen. This antibody–antigen complex stimulates phagocytic cells and is more readily phagocytized and destroyed. The antibodies binding to the surface may themselves inactivate the pathogen. One type of pathogen, a virus, must attach to the surface of a cell before it can invade it. An antibody-coated virus is incapable of attaching to the cell surface.

Antibody production occurs primarily in lymph nodes but also in the spleen and bone marrow. The lymph nodes are strategically located so that a rapid immune response may prevent the pathogen from entering the bloodstream and rapidly spreading throughout the body. For example, lymph nodes in the chest and abdominal cavities are closely associated with the lungs and intestines.

IMMUNITY AND IMMUNE RESPONSE

Objective

- Distinguish Between Passive and Active Immunity, Differentiate Between Humoral and Cellular Immunity and Their Relationship in Immunity, and Explain Primary and Secondary Immune Responses

For a pathogen to stimulate an immune response it must first get past the general protective defenses of the body. Skin offers a physical protective barrier that prevents many pathogens from entering the body. It typically requires a traumatic break in the skin to introduce the pathogen (e.g., a bite wound). The superficial mucous membranes such as in the nose, mouth, and eyes offer another potential entry point for antigens. Enzymes (e.g., lysozymes) in secretions along with alterations in pH can help to prevent the establishment of infection. Physical removal of invading pathogens can occur as milk is flushed through the teat sphincter or as urine flows through the urethra.

Phagocytic cells are present in the tissues to quickly engulf any bacteria that make it through the physical defenses of the body. This nonspecific response is called innate immunity. Neutrophils typically offer the initial response and are signaled by tissue damage. The neutrophils are effective at phagocytosis but do not act as antigen-presenting cells and therefore do not stimulate a further immune response. Macrophages in the tissues (derived from monocytes that leave the bloodstream) respond to the activity of the neutrophils and enter the damaged area. These cells are highly effective at phagocytosis and do play a role in regulating the immune response (e.g., through release of cytokines). Following removal of the pathogen, macrophages stimulate repair of the damaged tissues by stimulating blood supply and the activity of fibroblasts to lay down collagen.

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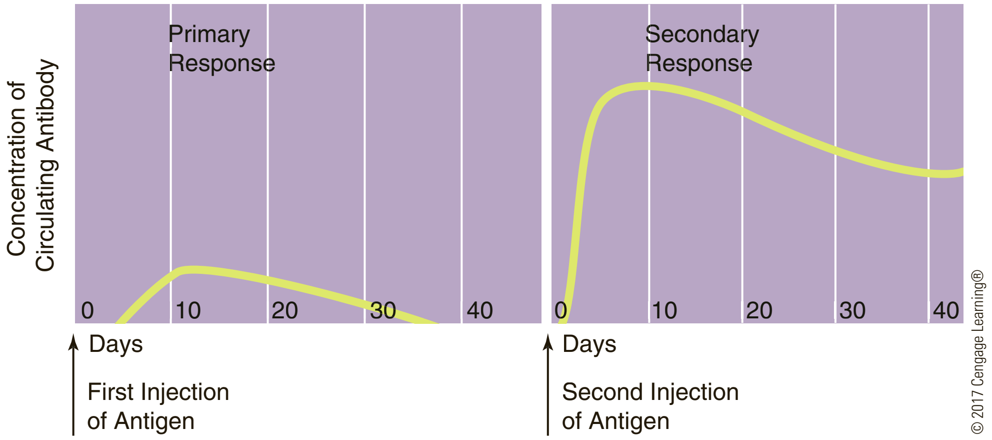

FIGURE 11–8 The antibody response found in primary and secondary immunity.

Antigens that successfully bypass the physical barriers and the nonspecific innate immunity will stimulate a long-lasting specific response called acquired immunity. This immunity will include the formation of antibodies as well as a cell-mediated immunity.

When an animal is first exposed to an antigen, it generally requires 3 to 14 days for a significant amount of antibody to be produced. This **primary response** triggers recognition by the lymphocytes, clonal expansion, and production of antibodies. The plasma cells can produce millions of antibody molecules every hour once they are activated. With this tremendous demand, plasma cells usually survive for only four or five days. Not all the cells of the clonal expansion develop into plasma cells.

Some of the clonal cells develop into memory cells. Unlike plasma cells, memory cells do not actively produce huge amounts of antibody. These cells, however, survive for long periods. The role of the memory cell is to mount a much quicker response the next time the same antigen is encountered. With the presence of memory cells, much less antigen is required to stimulate the reaction by the immune system. Not only is the response quicker, but also even higher amounts of antibody are produced (Figure 11–8).

It is this **secondary response** that prevents an animal from developing an infectious disease a second time. One may wonder why humans have repeated episodes of the cold or flu. The secondary response is highly effective at preventing the same disease, but the response is very specific. Diseases such as the human common cold are caused by viruses, which have many strains different enough not to stimulate the secondary response.

The immune response involves more than just humoral immunity provided by antibody production. The immune system also mounts a cell-mediated response. In addition to the B lymphocytes, the body has a large supply of T lymphocytes. T cells also originate from the bone marrow, but they then mature in the thymus gland. At birth, the thymus gland is a relatively large lymphoid organ that is found in the thorax (cranial and ventral region). T lymphocytes enter the thymus and mature into a cell that is capable of responding to an antigen (the cell becomes immunocompetent). Each T cell is receptive to a specific antigenic determinant. Any immune cells that might respond to the animal's own antigens are destroyed.

Once mature, the T cells leave the thymus and enter other lymph tissues. The thymus is very active in the fetus and early in life. As the animal matures, the thymus shrinks into a small residual structure. In the dog, the thymus begins to lose lymphoid tissue after five to six months of age. Fat is often deposited in the connective tissue framework of the organ. Although the thymus might be quite small, remnants are often detectable even in an elderly animal.

In general terms, cell-mediated immunity works in combination with humoral immunity. Antibody production enhances cell-mediated immunity. T cells and macrophages are essential in destroying infected cells, altered cells, pathogens, and any foreign antigen. Cell-mediated immunity plays a critical role in the reaction that destroys organ or tissue grafts from other animals.

When the T cells are exposed to a foreign antigen, they undergo a clonal expansion, just as the B cells do. Two types of T cells exist: the T-helper cells and the cytotoxic cells. The T-helper cells release cytokines to stimulate the immune response. The cytotoxic T cells leave the lymph node to attack damaged cells. T cells can detect some cancer cells because they develop different surface antigens. A small fraction of T lymphocytes also develop into memory cells. Just like the memory B cells, these lymphocytes are long-lived cells

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that provide a quick response with subsequent exposure to the same antigen. Active immunity also relies on the cell-mediated response to quickly destroy the invading pathogen. Whereas antibody levels are able to be measured in the blood, cell-mediated immunity is not easily measured.

A tremendous number of cells migrate to the site of infection. Neutrophils, lymphocytes, and macrophages all are present to help fight against the invading pathogen. In addition, there is the invading pathogen, destroyed and dying tissue cells, and tissue fluid. The accumulation of all the cells and cellular debris is called **pus**. (The correct adjective when discussing pus is *purulent*. It is incorrect to add –*y* or –*sy* to the end of pus. For example, the correct usage is, "The wound has a purulent discharge.") When the pus becomes trapped in a pocket, it is called an abscess. The cow discussed in the introduction showed a dramatic example of the accumulation of pus in an abscess.

The ability of an animal to defend itself from a second infection was detected by investigators. The role of memory cells to respond quickly and prevent infection is the underlying mechanism for vaccines. Edward Jenner, an English physician, is credited with administering the first vaccination in 1796. Cowpox is a viral disease causing sores on the teats of cows. Jenner recognized that farm laborers who had been exposed to cowpox were not susceptible to the much more serious human disease smallpox.

Jenner performed an experiment in which he inoculated a human volunteer with material from the sores of a cow infected with cowpox. The volunteer developed only a localized sore at the site of the inoculation. Several months later, Jenner exposed the volunteer to smallpox. The subject did not develop any signs from the exposure. What Jenner had discovered was that the two viruses causing cowpox and smallpox were very closely related. The patient had developed antibodies to cowpox that were protective against the smallpox virus. The two viruses shared similar antigens that allowed the antibodies to prevent a new infection.

Protection against disease can come from a natural infection or from vaccination. Vaccination or immunization relies on the development of memory cells, preparing the animal to respond quickly upon exposure to the natural disease. Vaccines can be made from modified strains of the pathogen. The strain is weakened, allowing it to divide after injection but not create clinical disease. These vaccines are called **modified live vaccines**. Other vaccines are made from a killed pathogen. The pathogen will no longer divide but still has all its antigens to stimulate an immune response (Table 11–2).

Some diseases are not caused by the invading bacteria, but by the toxin that they produce. In this type of disease a modified toxin is used as the vaccine. This toxoid is still antigenic but is modified enough that it does not cause clinical signs.

In recent years researchers have discovered that some pathogens share common antigens. For example, a related group of bacteria, called gram negative, share similar antigens. Immunity to these core antigens provides protection against all the bacteria in this class. Development of these core antigen vaccines allows for one vaccine to protect against several diseases.

Another advance in vaccines capitalizes on the fact that gram-negative bacteria require iron as an essential nutrient. Free iron is not readily available in living animals, as most is bound within cells. For example, a significant amount of iron is found within the hemoglobin of red blood cells. To compensate, the gram-negative bacteria have developed an extremely efficient system to transport iron into the cell. Essential parts of this transport system are

Table 11–2 Vaccine Comparison

Type of Vaccine	Benefits	Disadvantages
Passive vaccines	Protection is immediate	Provides only temporary protection
Modified live vaccine (MLV)	High level of protection Longer duration of protection Booster dose not always needed	Easily inactivated with sunlight and disinfectants Must be handled carefully Some vaccines cannot be used in pregnant animals, may harm the fetus
Killed vaccine	Very safe vaccines, can be used in pregnant animals	Must be followed by booster dose
	Good protection	Shorter duration of protection compared with MLV

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siderophore receptors and porin proteins found in the cell walls of these pathogenic bacteria. The specific proteins associated with these receptors are isolated and developed into a vaccine. (Because the vaccines use the siderophore receptor and porin proteins, the technology has been dubbed SRP.)

SRP vaccines have been developed for *Salmonella* and *Escherichia coli* O157:H7. Both of these bacteria pose a threat of infection to people as well as animals. Once the animal is properly vaccinated, antibodies are developed specifically against these receptors of the iron transport system. When challenged with an infection by the specific organism, the antibodies bind to the bacteria and block absorption of iron. Without the iron the bacteria die.

For **killed vaccines** the first dose is given to stimulate the primary immune response. Two to four weeks later a booster dose is given, which activates the secondary response. High levels of antibody are produced, and memory of the antigen is established. For many modified live vaccines, only a single vaccination is required to establish a strong level of immunity. Because the pathogen in the vaccine replicates within the animal, it presents a high level of antigen. In effect it is simulating a natural infection without causing clinical signs.

The use of vaccines or exposure to natural infections provides the animal with active immunity. Exposure to the antigen allows the animal to mount an immune response and to develop a memory for the disease. With any subsequent exposure the animal's memory response is quickly activated, and the disease-causing organisms are killed. **Active immunity** can last for very long periods. The immunity generally lasts at least six months but often provides protection for years or even a lifetime.

For many diseases, annual revaccination is recommended. This annual booster activates the immune response and elevates the level of antibody present. Once again memory cells are produced, and the animal is prepared for exposure to the natural disease.

Passive immunity, on the other hand, develops when antibodies are transferred from one animal to another. This routinely occurs from the mother to her offspring through the first milk produced. During pregnancy the first milk that the mother produces is very high in antibodies. This antibody-rich milk is called **colostrum**. Very early in life, the gastrointestinal tract of the newborn is able to absorb these antibodies without destroying them. (Remember that antibodies are protein molecules and would be digested and inactivated in normal digestion.) The antibodies are absorbed into the bloodstream, providing the newborn with immediate immunity. The ability to absorb antibodies declines rapidly (Figure 11–9). To receive this benefit, it is extremely important for the newborn to nurse soon after birth.

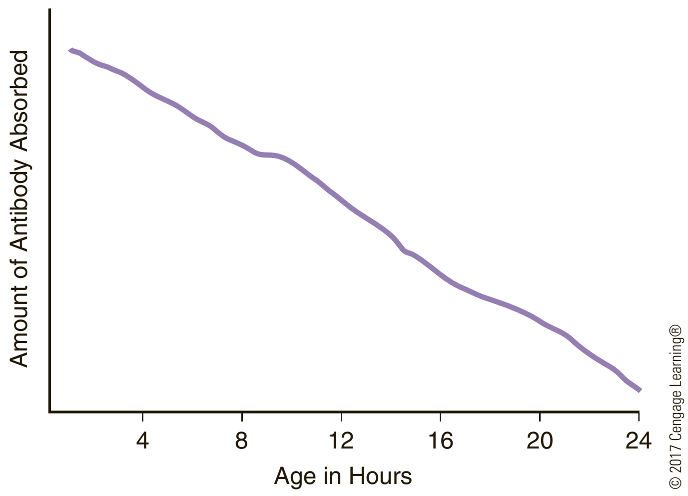

FIGURE 11–9 The absorption of colostral antibodies as it relates to age of the newborn.

Passive immunity can also be transferred through commercial products. Antibodies can be harvested from the plasma of highly vaccinated animals. The globulin portion of the plasma is isolated and packaged to allow other animals to be treated. These products are available in an injectable form or as an oral product that can be given shortly after birth to supplement the colostrum.

Passive immunity provides only temporary immunity. The duration of this type of immunity is generally several weeks to months. The higher the level of antibody transfers, the longer the duration of the immunity. Passive immunity must be considered when vaccinating young animals. This issue is evaluated in developing a vaccination schedule for puppies and kittens. When a modified live vaccine is administered to a puppy, the antibodies derived from the mother may immediately inactivate it. Because the pathogen in the vaccine does not replicate, the puppy develops very little immunity from that vaccine. As the maternal antibody declines, the puppy eventually is able to respond to the vaccine and develop an active immunity.

The problem arises because it is impractical to determine when a young animal will respond to the vaccine. Within a litter of offspring there will be significant variation in when the response will occur. An aggressive healthy kitten that nurses quickly after birth and drinks a large quantity of colostrum will have a high level of passive immunity (Figure 11–10). A kitten that is born weak, is slower to nurse, and drinks less will have a lower level of immunity. This second kitten will respond to the vaccine at an

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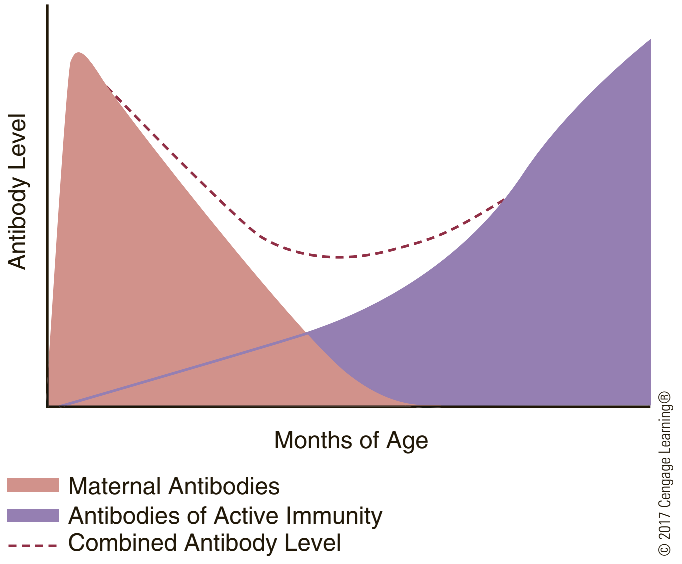

FIGURE 11–10 Decline of passive immunity and immune stimulation.

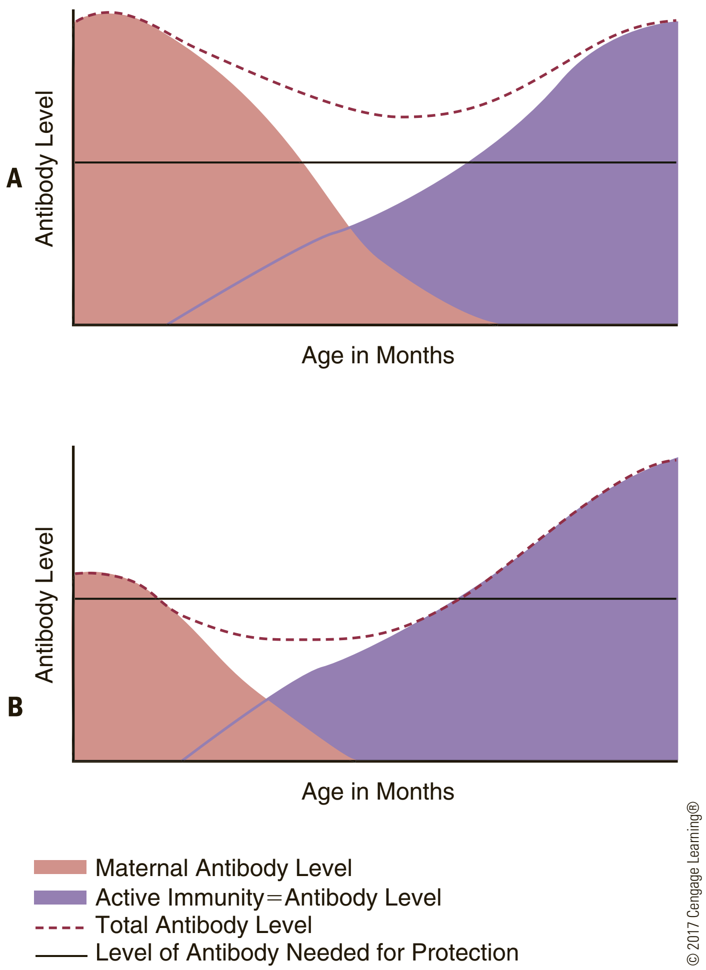

FIGURE 11–11 Maternal antibodies begin at a high level and then decline. During that time, natural immunity develops. The ideal situation occurs when the total antibody level stays high enough to prevent disease. A. The animal starts with high levels of maternal antibodies. The total antibodies stay at a level that is protective against disease. B. The animal starts with a low level of maternal antibodies. The total antibodies fall below the protective level, leaving the animal susceptible to disease.

earlier age due to the shorter duration of the passive immunity.

Therefore, vaccination schedules are developed to give periodic boosters in an attempt to provide active immunity as early as possible. There is not one set vaccination protocol for all animals. Vaccination schedules need to be adapted to individual settings and the risk that the animal faces. For puppies, a typical vaccination schedule would be for the first vaccine to be given at six to eight weeks of age. Boosters are then given every three to four weeks, until the pup is 14 to 16 weeks of age. Animals at higher risk may require a modified vaccine schedule. The vaccines may need to be started at an earlier age, given more frequently, or continued longer.

Even with such a vaccination schedule, there can be a window of opportunity for a pathogen to invade. Imagine that the animal is vaccinated at a time when the maternal antibody is just high enough to inactivate the vaccine. Over the next weeks, the antibody levels continue to decline (Figure 11–11). If the animal is exposed before the next vaccine, there may be inadequate levels of antibodies to protect it. That is why animals in higher risk environments may require more frequent vaccinations. (For example, a puppy in a large breeding kennel may have a higher exposure risk than a single puppy in an individual's home.)

CLINICAL PRACTICE

Objective

- Discuss the Clinical Significance of the Academic Material Learned in This Chapter

Much of the discussion of the immune system has revolved around prevention of disease with the use of vaccines. The sheep suffering from tetanus could have been spared the dreaded disease had the farmer planned ahead. A toxin released from the organism *Clostridium tetani* causes tetanus. This bacterium survives in wounds where there is little to no oxygen. Banding as a means of castration provides an environment where this kind of infection is possible. This disease is common in farm animals, especially following castration or dehorning.

The farmer could have prevented this disease with proper vaccination. One option would have been for the animal to be given passive immunity with an injection of antitoxin. Antitoxin is antibody against the toxin that is harvested from animals that are highly vaccinated. Administering the antitoxin would have provided passive immunity for the time in which the animal was at risk. The passive immunity

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is temporary, but the benefit starts immediately after the injection.

This animal could also have been vaccinated with a toxoid, or inactivated toxin. The toxoid has no harmful effects on the animal but does allow the animal to mount the immune response against it. Ideally, this type of vaccination should have been done at least a week or two prior to the period of risk. This would have allowed the animal to develop an active immunity before it was at risk.

Most vaccines come in an injectable form. Several vaccines are administered **intranasally** (in the nose). The intranasal vaccines are generally modified live vaccines that allow the animal to develop a very strong local immunity. These vaccines are for respiratory diseases that enter through the nasal passages. By increasing the levels of antibodies (specifically IgA) in the nasal passages, the vaccine keeps the virus from attaching to cells and the disease is prevented. **Kennel cough** in dogs can be prevented this way. Kennel cough, which may be caused by several different organisms, is spread among dogs through the nose. As its name implies, the disease causes affected dogs to develop a severe cough. The disease is much more common in situations where dogs are kept in close quarters, such as a kennel. The vaccine is very effective in preventing this disease.

Not all immune reactions work to prevent disease in animals. Some immune response occurs against antigens that are not harmful. An example is when a dog mounts an immune response to pollens common in the air (e.g., ragweed, trees, and grasses). Only a low percentage of animals exposed to these antigens develop an immune response (i.e., they are weak antigens). *Sensitization* describes the animal's immune response to such allergens. IgE is the specific type of immunoglobulin that is produced in high amounts in these animals. The IgE is bound to the surface of basophils and mast cells. When the IgE comes in contact with the antigen, it causes the cell to release histamine and serotonin. These products cause smooth muscle constriction and increase permeability in the capillaries. In pets the reaction is often severe itchiness (**pruritus**).

Atopy describes this kind of sensitization to foreign antigens. In dogs and cats, atopy can be to a wide array of pollens, dusts, and dust mites. Atopic animals typically present because of hair loss and pruritus. The animal may irritate its skin so severely that a secondary infection develops. Humans who develop the same type of sensitization show the signs of hay fever. The release of histamine in the upper airways and eyes causes the signs of runny nose, sneezing, and watery itchy eyes.

Antihistamines are used to treat this type of allergic condition. An antihistamine binds the same receptor that histamine uses to cause its effect. To be effective, antihistamines must be administered before the exposure to the antigen. Once the histamine has bound the receptor, antihistamines will not reverse the effect. The benefit of antihistamines is that they prevent the attachment of histamine to the receptor.

When the allergic reaction is generalized and life threatening, it is termed **anaphylaxis**. Animals may develop anaphylaxis in response to drugs, vaccines, insect stings, and serum from other animals (e.g., as in a blood transfusion). The horse that died from exposure to penicillin succumbed to anaphylaxis. The horse had been treated with penicillin before without any bad effects. Unfortunately, this horse had become sensitized to the molecule. Penicillin is a relatively small molecule, but it is complex enough that certain animals mount an immune response to it. The same problem can develop in humans as well.

The generalized release of histamine and serotonin from mast cells causes bronchoconstriction and leaky vessels. Initially, the skin can become red, swollen, and extremely itchy. Heart rate typically increases, although blood pressure declines. As the condition worsens, the larynx becomes swollen and the bronchioles constrict. The animal develops respiratory distress and shock. Epinephrine counteracts the physiologic effects of histamine and is the treatment of choice. Unfortunately, in the case of this horse our treatment was unsuccessful.

The immune system can also be used to help make a diagnosis in many infectious diseases. In cattle, a group of infectious diseases cause abortion (premature delivery of a nonviable fetus). Tests are available to measure the level of antibodies against these diseases in the bloodstream. **Titer** is the measure of antibody levels in the bloodstream. The serum is diluted repeatedly, and the last tube that is positive defines the titer. Titers are reported as a ratio describing this dilution. For example, a titer of 1:256 has more antibody than a titer of 1:64.

If a single sample of blood is tested and comes back with a high titer, it proves that the animal had been exposed to the pathogen. Unfortunately, it does not prove when the exposure occurred and may even be the result of a vaccination. To prove that the infection was recent and the cause of the abortion, paired tests are run. For this, a sample is taken immediately (the acute sample) following the abortion and then another is taken two to four weeks later (the convalescent sample). A titer is evaluated for each sample. To prove the cause of the abortion, the titer must change by a factor of four, as described below. When this occurs, the animal has undergone **seroconversion**.

Two possibilities exist in seroconversion (Figure 11–12). The first occurs when the abortion

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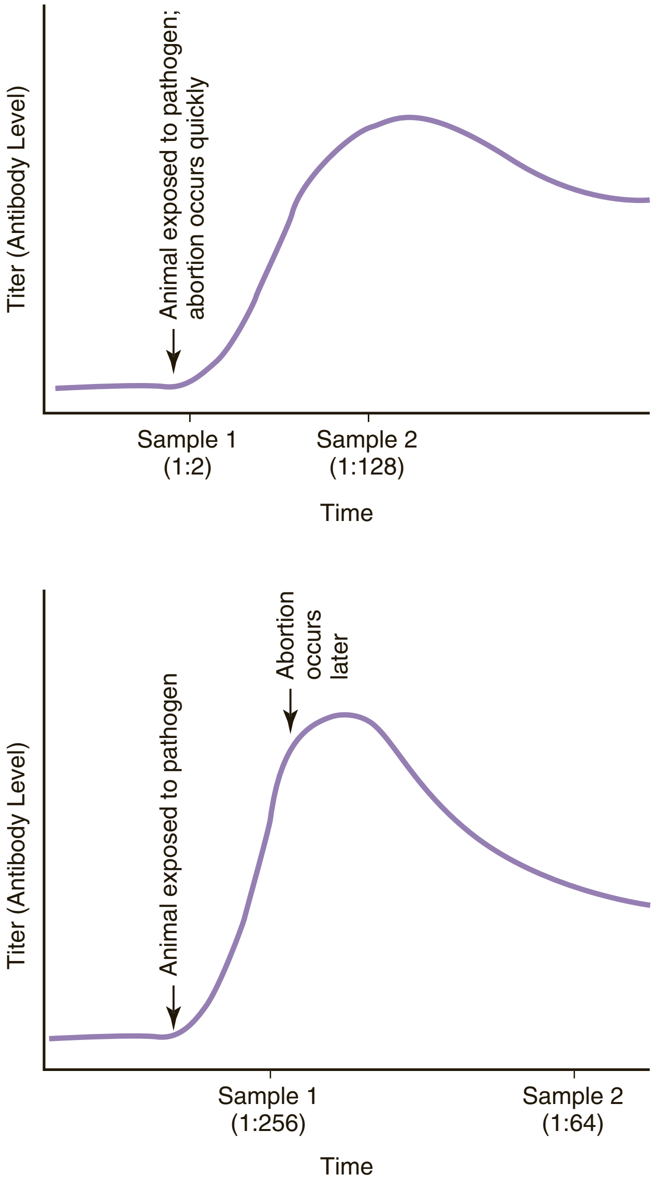

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FIGURE 11–12 Sample of seroconversion—paired sera evaluation.

results immediately after exposure to the pathogen. In this situation, the titer is very low on the first sample. Over the following weeks, the animal mounts an immune response and the second sample has a much higher titer (i.e., it increases by four times or more). In the other situation, the actual infection occurred prior to the abortion, and the titer on the first sample comes back high. Because the infection is cleared, the antibody levels decline with time and the titer of the second sample is much lower (i.e., it decreases by four times or more). This, too, is considered a seroconversion. This paired testing is used to diagnose many infectious diseases.

An **ELISA test** measures the level of progesterone in milk. ELISA is the abbreviation for enzyme-linked immunosorbent assay. Many of these tests are available to measure either antigen or antibody in the blood. Many different tests are commercially prepared, so that they may be run without expensive laboratory equipment and without extensive knowledge. One parasitic disease, heartworm, is commonly diagnosed with an ELISA test (Figure 11–13).

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FIGURE 11–13 An in-office ELISA test. This test evaluates for the presence of heartworm disease. Three tests are shown. The first test is in process (left). A positive result, showing two red lines (upper right). A negative result, showing only the red line of the control (lower right).

In the milk progesterone test, antibodies against progesterone are bound to the bottom of the test cup. Milk is added to the cup, and any progesterone in the milk is bound to the antibodies. Then progesterone bound to an enzyme is added to the cup. Any unbound antibody is then filled with this enzyme-bound progesterone. A substrate is added to the test kit that causes a color reaction with the enzyme.

If the milk is high in progesterone, all the antibodies will be filled and no color reaction occurs. If the milk is low in progesterone, much of the enzyme-bound progesterone is attached in the test cup. When the final substrate is added, a color reaction occurs. This same principle is used in many diagnostic tests. Many variations exist in which radioactive or fluorescent materials are bound. Special equipment is then required to evaluate the results of these tests.

In Chapter 3, the condition of joint ill was discussed. In this condition, bacteria enter the umbilical vessels, spread through the bloodstream of the newborn animal, and deposit in the joints. Newborns have a capable immune system; they are able to mount an immune response to foreign antigens. However, they have basically no circulating immunoglobulin of their own to fight off invading organisms. Their initial

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protection depends on the transfer of antibodies from the mother through ingested colostrum. (It is interesting to note that antibodies are able to cross the placenta from the mother's blood and into the baby in humans. Human babies therefore are born with circulating immunoglobulin.) As already discussed, this passive immunity is temporary. The higher the initial antibody level, the longer the protection lasts.

If the newborn animal fails to gain adequate amounts of antibody from the colostrum, it is much more susceptible to diseases. These animals suffer a much higher incidence of joint ill, as well as diarrhea, pneumonia, and brain infections. This lack of colostral antibodies is called failure of passive transfer. The newborn has the greatest ability to absorb antibodies in the first 6 to 12 hours. The absorption declines rapidly over the first day. Absorption has basically ceased by the end of the first 24 hours. Continuing to feed colostrum does not increase the circulating antibody level but does provide some local protection by producing higher levels in the gastrointestinal tract. Having these antibodies in the gut helps to keep ingested pathogens from attaching to the lining of the gastrointestinal tract.

Several factors may contribute to failure of passive transfer. One factor is poor-quality colostrum. This more often occurs in younger animals, those that deliver early, or those that leak colostrum before the birth. The quality of colostrums can be estimated with a colostrometer. The colostrometer has a tube to hold milk and a float that submerges into the milk (Figure 11–14). Higher-quality colostrum has elevated levels of immunoglobulin protein, which increases its density. As a result the float within the colostrometer is higher. When the float is high, the top of the column of milk is seen on the green region of the scale. Conversely, in poor-quality colostrums the float settles deeper into the milk, and the scale is read in the red range.

Even when colostrum quality is high, the animal must consume an adequate volume. This may not occur if the newborn is weak, such as after a difficult delivery. These weak animals often have a delay before nursing. The longer the delay, the lower the number of antibodies absorbed. Several tests are available to measure the level of antibody in the blood, evaluating the passive transfer. Measuring these levels may help the veterinarian care for the individual, but it is also quite helpful in evaluating the management on a farm.

The calf mentioned in the introduction had a lifetime infection with the BVD virus. This virus can cause a severe and potentially deadly diarrhea in cattle. In addition, infected cattle are more susceptible to infertility, abortions and birth defects, and pneumonia.

A

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B

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FIGURE 11–14 A colostrometer is used to measure the quality of colostrum. A. The weighted float is placed into a column of milk. The higher the quality, the higher the float will rise. The scale on the float is used to judge the quality. B. This milk sample shows the float in the red zone and would not be a source of good colostrum.

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The fact that some calves can have a lifetime infection allows the virus to persist within a herd for years. These persistently infected (PI) calves mount no immune response to that particular strain of virus.

As mentioned, BVD can cause abortion and infertility. To become persistently infected, the calf must survive the initial infection. From 90 to 120 days of gestation, calves develop the ability to mount an immune response and also learn to detect the antigens of their own tissues. (It is this immunity that protects their own tissues and prevents transplant of organs from unrelated animals.) The calf will recognize the BVD antigens as "self" when the virus is present during this time.

Persistently infected calves shed the virus intermittently and are therefore a continual threat. As a result other animals in the herd are at a higher risk. This is a common problem in beef feeder cattle, where a large number of calves from multiple sources may be commingled. Herdmates exposed to a PI calf often have higher incidence of disease than would other cattle without such an exposure. In addition, the PI calf often has a suppressed immune system and is more susceptible to other diseases. Many PI calves die before a year of age. Unfortunately, it is the one that lives that provides the highest threat to herds.

The immune system is extremely effective at identifying foreign antigens. Nonetheless diseases do exist in which the immune system mistakenly attacks "self." One such disease is autoimmune hemolytic anemia. Often there is no explainable cause (i.e., the condition is idiopathic), but certain infectious diseases may bind antigens to the surface of the red blood cells. Antibodies then bind to these new antigenic sites and stimulate an immune response against the red blood cells. While the entire process may take weeks to develop, affected animals often present with a sudden onset of weakness. On physical examination the mucous membranes are very pale and blood work shows a dramatic anemia (low red blood cell count). This condition is life threatening, and treatment includes medications that hinder the immune response. Blood transfusions may also be required. The immunosuppressive medications make the animals more susceptible to other infections but are necessary in the treatment. If the anemia can be controlled and the blood count returns to normal, the medications can be tapered, but the pet must be closely monitored to watch for further episodes.

SUMMARY

Foreign molecules that stimulate an immune response are called antigens. Immunity to antigens can be passive (i.e., obtained from drinking colostrum or injected as a vaccine) or active (i.e., established after infection). The primary immune response occurs in the first days after invasion of the antigen, whereas the secondary immune response prevents a second episode of the same disease. The immune system response is strengthened by overall good animal health.

REVIEW QUESTIONS

1. Define any 10 of the following terms:

   abscess
   banded
   tetanus
   antigen
   lymph
   stocking up
   phagocytized
   edema
   humoral immunity
   primary response
   secondary response
   pus
   modified live vaccines
   killed vaccines
   active immunity
   passive immunity
   colostrum
   intranasally
   kennel cough

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pruritus
atopy
anaphylaxis
titer
seroconversion
ELISA test

2. True or False: Horses may experience leg swelling when tied for an extended period.
3. True or False: All pathogens have only one site of determinant.
4. Lymph begins as ________ fluid that forms between the cells.
5. What is the typical life span of plasma cells?
6. Do larger or smaller molecules typically elicit the immune response?
7. What is the site of recognition on an antigen called?
8. What removes aged red blood cells from circulation?
9. What gland controls body temperature?
10. What type of molecule are antigens?
11. What human disease is closely associated with cowpox?
12. Who is credited with the first vaccination?
13. What two cells have the primary responsibility for phagocytizing antigens when first detected by the body?
14. Do naturally occurring molecules cause an immune reaction?
15. Do blood vessels dilate at the site of infection, causing reddening or inflammation?
16. How does fever aid in the fight against pathogens?

ACTIVITIES

Materials needed for completion of activities:

colostrum samples
colostrometer

1. The discussion of passive transfer emphasized that the quality of the colostrum influences the amount of antibody absorbed by the newborn. A colostrometer is a tool that measures the antibody level in colostrum. This exercise requires collection of colostrum samples from local farms. Colostrum can be frozen without damaging the antibody level. This allows samples to be collected over time and accumulated. Each sample should be recorded with the animal's identification and her age or lactation number. In addition, any comments about the animal should be recorded. Important facts could include any illness, leaking of colostrum, parturition in relationship to due date, and the number of milkings when the sample was taken. Measure each colostrum sample with the colostrometer. Can any comparison be made with the other factors recorded about the animal using the samples obtained? (For example, did the younger animals have poorer quality colostrum? Did the quality decline with later milkings?)
2. Farmer Watkins calls because his cows have been aborting. You elect to take blood samples on the cow that most recently aborted and another herdmate that was also pregnant but did not lose her calf. You follow up with another blood sample three weeks later. Titers were evaluated on several of the diseases that commonly cause abortions in cattle. (Do not be concerned about the actual disease name; many of these are discussed later in the text.) The results are shown as follows:

	Cow #416 (Aborted 9/16)		Cow #184	
Disease	**Acute**	**Convalescent**	**Acute**	**Convalescent**
IBR	1:8	1:8	Negative	Negative
BVD	1:16	1:512	1:8	1:4
Lepto	Negative	Negative	1:100	1:100

Farmer Watkins calls your office and asks if you found anything on those blood samples. Can you make a diagnosis?

a. Did either cow seroconvert to any pathogen? If yes, what organism?
b. If there were any changes in titers, what degree of change was there?
c. If there was a seroconversion, was the infection very recent or had it occurred much before the time of the abortion?

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3. Have students review their vaccination schedules. Ask them to file this information for their personal records.
4. The recent rise in life-threatening peanut allergies has caused concern as well as precautionary protocols in schools. Investigate and report the protocol in your school system for avoiding peanut contamination and possible endangerment of a peanut-allergic classmate.

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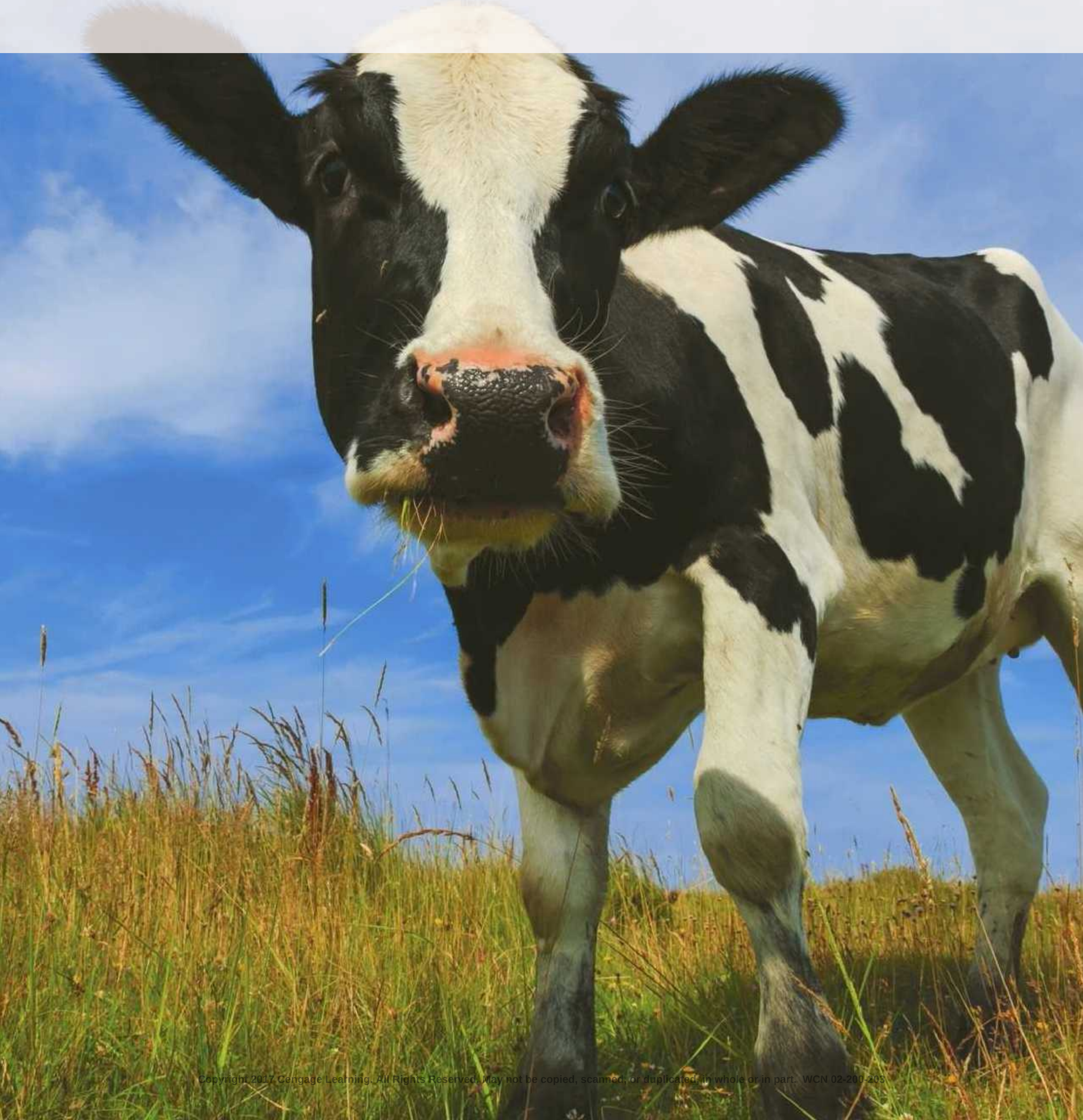
Unit II

Nutrition



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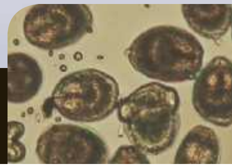
CHAPTER 12



Basic Nutrients

Objectives

Upon completion of this chapter, you should be able to:

- List the six major components of animal diets, and discuss their structure and significance in nutrition.
- Discuss the clinical significance of the academic material learned in this chapter.

Key Terms

necropsy	flatulence	rodenticide	dry matter
postmortem	calorie	free radicals	hemolysis
constipation	hydrolysis		

Introduction

In Chapter 1, we learned about the basic structure of lipids, carbohydrates, and proteins and their importance in cell structure. Later we learned how these different molecules are digested. In this chapter we review many of these nutrients and discuss their importance in an animal's diet.

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A Day in the Life
I Love My Job...

One of the greatest rewards of my profession is the people that I get to meet. This is especially true of the farm clients that I see every few weeks. The farmers and I typically work together for hours and have plenty of time to talk and get to know each other. Over the years friendships develop. I get to see farm children grow up, and it is quite rewarding to see their ensuing successes.

I really enjoy my job. Most of my farmer clients like to joke a bit. Many a time I have been moving down a line of cattle, performing pregnancy checks, when I inevitably start to struggle and experience difficulty in finding the uterus or cervix. I look up and see the farmer smiling and realize that I have been trying to perform a pregnancy check on a bull!

I visited a farm just yesterday that made me think of these kinds of pranks. I was on the job only a few months when I went to Mel's farm for the first time. As a new veterinarian, I was trying hard to make a good impression. This was especially true when I first visited area farms. At this particular farm, I needed to work on a cow's sore hind foot. For this procedure I used a rope to hold the affected leg. In many barns I can loop a rope over an exposed beam. In Mel's barn I needed to use a beam hook. This is a hard metal hook that is driven into each side of a beam. When the rope is threaded through the loop in the bottom, it pulls the hooks tighter into the beam, making it very secure.

I retrieved my beam hook and asked Mel for a hammer. Mel came back with a rubber mallet. I looked at the rubber hammer, realizing that I could not drive the metal hook with that. My mind raced with questions: Doesn't he know you can't hammer metal with a rubber hammer? What do I do next? Should I tell him this is stupid? I would love to have seen my expression of bewilderment as I looked up and saw him smiling. He pulled the real hammer from behind his back as we both started laughing. He was just testing me and keeping the first meeting on a light note. I knew at that moment I was going to have a lot of fun in my chosen vocation.

Most farm animals being sold or shown in competition require health charts from a veterinarian. These health charts show that the animal has been examined and is free of visible signs of infectious or contagious diseases. These animals may require some testing for contagious diseases or even vaccination to prevent diseases. The requirements vary considerably among locations.

I had the opportunity to examine two rams heading to a show. The animals appeared quite healthy, and I issued the paperwork. I received a call from the owner the day these animals were trucked to the fair. He told me he took them early in the morning, and they appeared healthy then. Now, late in the afternoon, both were quite sick. Officials requested that he pick them up, so he brought them by the office for examination.

As I waited for the animals to arrive, I wondered what I missed. The two rams were well grown, strong, and in good body condition. When these animals arrived, it was quite obvious that they were seriously ill. They were showing weakness and had pale gums and very dark urine. How could they have become so sick so fast? All the signs were suggestive of an excess of copper in their diets. A small mistake in their nutrition over a long period had initiated a major illness.

I was on an emergency call one late November evening. I had just treated a milk fever case and hoped that my day was finally finished. I called into the office to discover that another farmer had a weak and shaking cow. I was disappointed but of course drove to the next emergency. By the time I arrived, the cow could not stand. She seemed perfectly normal earlier in the day and had just come inside after spending some exercise time in the pasture.

The producer had just changed the herd ration, and I figured the cow had low calcium levels. I began to treat her with intravenous calcium and dextrose. As I treated her, another cow in the barn collapsed. Worse yet, the first cow was not responding to my treatment. I was confused. Then I grew concerned that the cattle had ingested some toxin in the pasture. I took a blood sample from the second cow and submitted it to the diagnostic laboratory. Neither cow was responding to my treatment, so I needed more information. Table 12–1 shows the results of the blood test. Find what changes are present.

Last summer I visited a farm with two down heifers. A heifer had already died the day before, and now two more were showing symptoms. Both heifers were lying flat on their sides with their heads stretched upward. These animals appeared to be blind, and their muscles quivered. The signs suggested a deficiency of vitamin B_1 (thiamine). Moreover, I could not rule out a brain infection. I started treatment with high levels of antibiotics and thiamine. Unfortunately, one of these animals died and was submitted for a **necropsy**, or **postmortem**.

Every week our practice submits several blood samples to the diagnostic lab for analysis. One week the volume was particularly large. The week before, a large

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A Day in the Life continued

manufacturer of dog and cat food had announced a recall. It had been discovered that pets were dying from kidney failure after eating certain types of food. Many apprehensive pet owners were calling for advice and many wanted their pets screened for kidney damage. I feel fortunate that none of the pets examined had problems secondary to this pet food incidence. Subsequently, chemicals used in plastic manufacturing were blamed as the underlying contaminants. In general, we take for granted the quality and balance of our pet foods. The details of the nutrients involved in feeding animals are very important.

Table 12–1 Blood Chemistry Results for Star, a 3-Year-Old Female Jersey

Test	Units	Result	Reference Range
Glucose	mg/dl	90	40–74
Urea nitrogen	mg/dl	14	10–35
Creatinine	mg/dl	0.8	0.8–1.5
Sodium	mEq/L	178	135–157
Potassium	mEq/L	3.7	3.7–5.8
Chloride	mEq/L	135	90–110
Bilirubin	mg/dl	0.1	0.0–0.5
Total protein	g/dl	8.8	6.0–9.0
Calcium	mg/dl	8.9	9.0–11.5
Phosphorus	mg/dl	6.1	4.3–8.6
Magnesium	mEq/L	2.3	1.1–2.3

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This cow had mild hyperglycemia (elevated glucose) and mild hypocalcemia (low calcium).
This cow had dramatic hypernatremia (elevated sodium) and hyperchloremia (elevated chloride).
Numbers highlighted in red are above the normal reference range. Numbers in blue fall below the normal reference range.

NUTRIENTS

Objective

- List the Six Major Components of Animal Diets, and Discuss Their Structure and Significance in Nutrition

Diets are divided into six classes of nutrients. A nutrient is a component of food necessary to support life. The first three nutrients, carbohydrates, proteins, and fats, supply energy and structure for the cells of the body. Water and minerals are not used for energy but are utilized in many of the functions and structures of the body. The final class, vitamins, plays a key role in metabolic functions of the cell.

Carbohydrates supply energy and provide structure within the cell. Carbohydrates in the diet also provide energy to the animal. In addition, the carbohydrates supply fiber and bulkiness in the diet. The absolute necessity of carbohydrates in the diet remains low, because the animal can convert amino acids and fats into sugars.

Carbohydrates provide glucose to maintain blood sugar levels, which is critical for maintaining cell function. Carbohydrates create the lactose that is found in milk. Carbohydrates are also converted to glycogen as a cellular reserve of energy, and to fat as a body reserve. Carbohydrates are also necessary to complete the metabolism of fat.

The simplest carbohydrates, the monosaccharides, are easily absorbed from the intestines. Glucose and fructose provide two common examples of monosaccharides (Figure 12–1). The monosaccharides form the building blocks for more complex carbohydrates. The disaccharides, such as lactose (glucose + galactose), are a combination of two monosaccharides joined by a glycosidic bond. In digestion, these sugars are broken down by enzymes released in the intestines to allow for absorption.

The polysaccharides are long chains of simple sugars. Two types of chemical bonds can be found in the polysaccharides. Starch is an example of a polysaccharide, a chain of glucose molecules joined by

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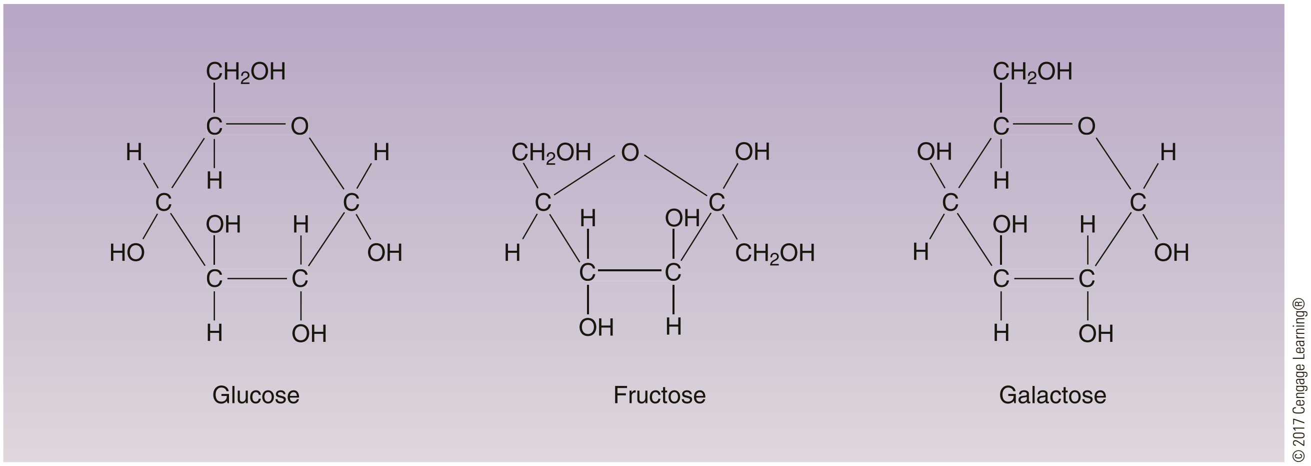

FIGURE 12–1 Chemical structure of simple sugars.

alpha bonds. The starch molecule can have many side branches, all identically linked. The alpha bond is significant, because the amylase enzyme secreted during digestion can break it down. Amylase converts the long-chain starch into single molecules of glucose and disaccharides that can be further digested. All of the domestic species are able to easily digest starch.

Dietary fiber or roughage is also composed of polysaccharides. The fiber derives from plants, where it is used for structural support. Fiber is also composed of chains of monosaccharides, but these are linked with beta bonds. The enzymes secreted in the digestive system of mammals are unable to digest these polysaccharides. The microorganisms found within the gastrointestinal tract of animals may be able to digest this fiber and allow the host animal to use the nutrients. This concept of symbiosis was introduced in the discussion of ruminants and horses in Chapter 7.

Cellulose serves as a classic example of the long-chain polysaccharide found in plant fiber. Just as in starch, glucose forms the building block of the cellulose molecule. These long straight chains of glucose molecules are linked with beta bonds (Figure 12–2). Plant fiber has many components, including cellulose but also hemicellulose and lignin. These different fibers have varying digestibilities by the microorganisms found in the intestinal tract.

Fiber, even though it is not digested in monogastrics, does affect the digestive tract. Fiber in the diet slows the emptying of the stomach and helps to protect the lining cells in the intestines. Fiber within the feces increases the amount of water held. This effect helps to maintain a normal rate of movement through the intestines. Adding fiber to the diet can be helpful in both diarrhea and **constipation**. In diarrhea, stools are very liquid and move through the animal too quickly. Additional dietary fiber helps to hold more of the water and slows down the movement of feces through the intestines. Constipation occurs when the feces is too dry and moves too slowly. Again, fiber helps to retain water within the feces and increases the rate of passage to a more normal level.

Added fiber within a diet does increase the volume of feces. Owners will note that pets placed on a high-fiber diet have much larger stools than before the dietary change. In addition, higher fiber levels can increase **flatulence** in pets. Flatulence is an accumulation of gas in the intestinal tract, which is produced as intestinal bacteria ferment the fiber. *Flatus* describes when the gas is passed through the anus. The majority of the gas produced is odorless; however, a small percentage that contains sulfur contributes to the foul odors produced. If the condition becomes too severe, changing to a highly digestible low-fiber diet can be helpful.

Proteins are composed of chains of amino acids linked by peptide bonds. The long chains of amino acids have branches and folds that give the protein molecule a distinct three-dimensional shape. As we have seen throughout the text, proteins play a key role in the structure and many of the functions of cells. Proteins serve in the structure of cells but also act as enzymes, hormones, and antibodies. The three-dimensional shape of these molecules along with the combination of subunits has an essential role in their function. Proteins can also be utilized as a source of energy for the animal.

The amino acids are either essential or nonessential. The essential amino acids must be supplied in the diet, whereas the nonessential ones can be synthesized from other amino acids. Each species has its own list of essential amino acids. Table 12–2 lists the 10 essential amino acids of the dog. Cats have the same 10, plus an additional requirement of taurine. Cysteine and tyrosine are occasionally listed as essential amino acids. This is the case if the diet does not contain adequate methionine and phenylalanine, which are necessary to produce cysteine and tyrosine.

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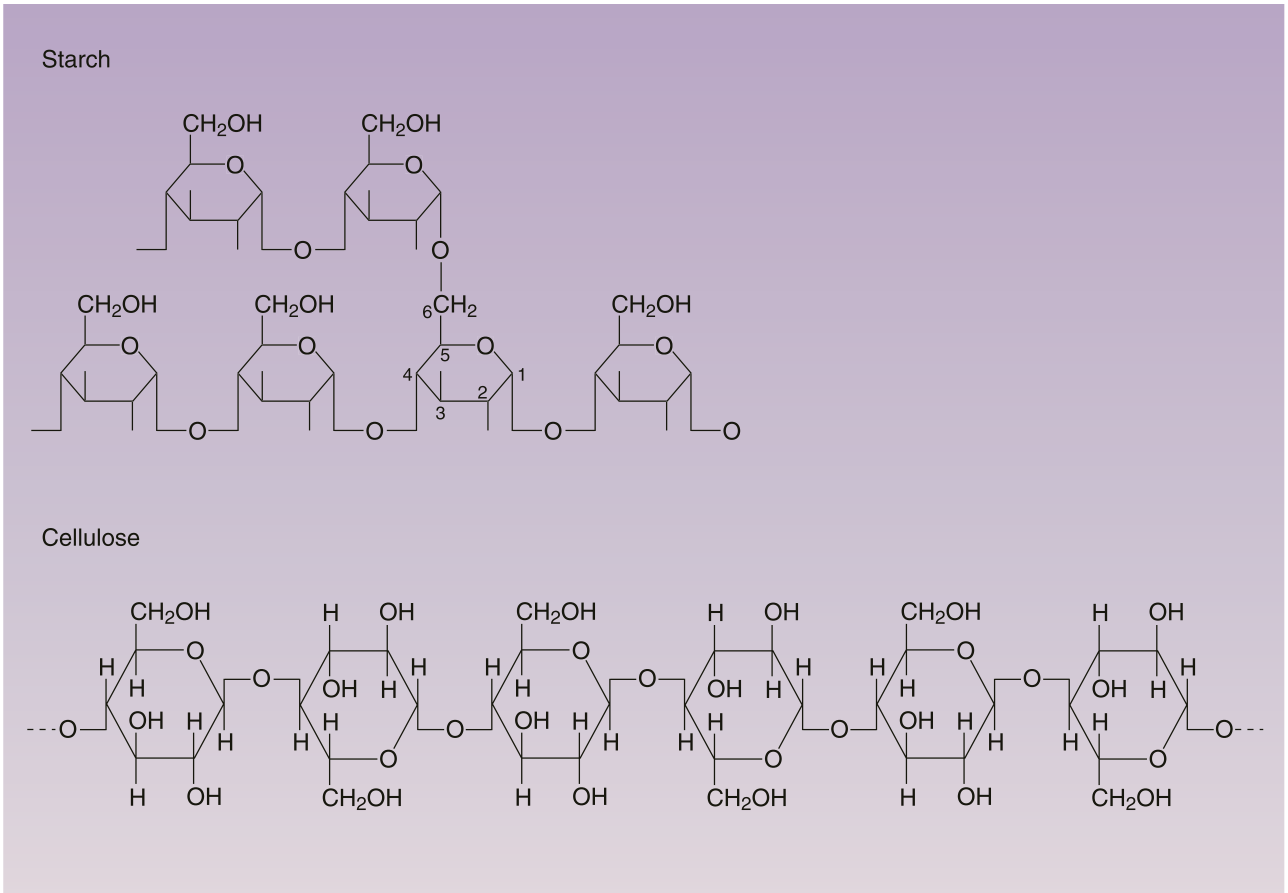

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FIGURE 12–2 Chemical structure of starch and cellulose. Notice that the bonds joining the molecules are oriented differently in the two molecules.

Table 12–2 Essential Amino Acids of the Dog*

Arginine
Histidine
Isoleucine
Leucine
Lysine
Methionine
Phenylalanine
Threonine
Tryptophan
Valine

*Cats have all of the same essential amino acids plus taurine.

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During digestion the peptide bonds of proteins are cleaved to create individual amino acids or short polypeptides for absorption. In ruminants, some ingested protein is used in the rumen by the microorganisms. This fraction of the ingested protein is called rumen degradable protein (RDP). The microorganisms utilize and grow on this fraction of the protein. Eventually, microorganisms pass out of the rumen and into the abomasum and small intestine where they are digested. The ruminant therefore uses the microorganisms as a source of protein. In addition a portion of the ingested protein escapes the rumen and is digested just as in a monogastric. This fraction of the ingested protein is called bypass protein (i.e., it bypasses breakdown in the rumen) or rumen undegradable intake protein (RUP). It is the combination of microbial and bypass protein that provides the nutrient needs of the ruminant.

A deficiency of protein in the diet often shows clinically as poor growth or low body weight. These animals many times have a poor appearance to their hair coats and are more susceptible to disease (poor immunity). If energy intake is adequate the excess is deposited as fat, but the protein deficiency prevents normal increase in frame size. On the other hand, excessive protein is used as an energy source or converted to fat. This metabolism produces ammonia, which is converted in the liver to urea. The urea is released into the blood and must be cleared by the kidney. In animals with decreased kidney function, the

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nitrogenous wastes increase in the bloodstream, worsening the clinical signs of the condition.

The biologic value describes the quality of a protein source. The value is based on how efficiently the protein is utilized. The more closely the protein matches the amino acid needs of the animal, the higher the biologic value. Proteins with high biologic value are more highly digested and result in less waste than those with lower value. Biologic value is expressed as a percentage, comparing the amount retained by the body with the amount excreted. The animal requires less protein if the biologic value closely matches its requirements for essential amino acids. For dogs and cats, animal proteins generally have a higher biologic value than plant proteins. Table 12–3 shows the biologic value of several protein sources found in dog food.

The third class of nutrients, lipids, consists of fats and oils. Fats are solid at room temperature, whereas oils are in a liquid state. The simple lipids come in a form with three fatty acid molecules bound to a molecule of glycerol. This compound has classically been called a triglyceride and more recently triacylglycerol. Lipids can be conjugated with other molecules such as proteins.

Fatty acids are long hydrocarbon chains with a carboxyl end (COOH). Most fatty acids have an even number of carbons. If all of the carbon atoms have two hydrogen atoms attached the fatty acid is described as saturated. Unsaturated fatty acids have at least two carbon atoms joined by a double bond. If the hydrogen atoms are missing from the same side the fatty acid is labeled as *cis*, and if the hydrogen is missing from opposite sides it is termed *trans*. Fatty acids are often named but are also numbered based on the number of carbon atoms and the number of double bonds (Figure 12–3). For example, the 18-carbon stearic acid is fully saturated and is written as C18:0. Linoleic acid is unsaturated and is described as C18:2 (n-6). This numeric description defines the fatty acid as having 18 carbons with two double bonds, the first of which begins after the sixth carbon. Linoleic acid is described as an omega-6 fatty acid. A multitude of information is available on the importance of omega-3 fatty acids in human nutrition for controlling levels of cholesterol and triglycerides. More emphasis is now being placed on feeding adequate levels of omega-3 fatty acids in domestic animals.

Table 12–3 Biologic Value of Protein Sources Found in Dog Food

Source	Biologic Value (%)
Egg	100
Fish meal	92
Milk	92
Liver	79
Beef	78
Soybean meal	67
Corn	45

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Fats can be used as an immediate supply of energy or stored in the fat reserves of the animal. A deposit of fat not only provides a source of energy, but also aids in insulating the animal from the cold and provides some degree of protection to organs as well. Lipids are used in producing certain hormones and structurally within cell membranes. Fats generally increase the palatability (or tastiness) of the food. Fat in the diet is necessary to allow for the absorption of certain fat-soluble vitamins.

Lipids are a source of fatty acids. Certain fatty acids are required to be supplied within the diet and, just as with amino acids, are called essential. The essential fatty acids vary with species as well. In dogs, linoleic acid assists in production of linolenic and arachidonic acids. Cats, on the other hand, also require arachidonic acid in the diet. Fats are found in both plant and animal sources. Arachidonic acid is found only in animal sources.

These first three nutrients are all potential sources of energy for the animal. The energy found in the form of chemical bonds metabolizes within the cell. The animal utilizes much of the energy; some is released as heat, which maintains the normal body temperature. A **calorie** is the unit of measure that defines the energy contained within a food. By definition, a calorie is the amount of energy required to raise one gram of water one degree Celsius (specifically from 14.5 to 15.5°C). Many feed labels report the value in kilocalories (kcal or C), which is 1,000 calories.

Feedstuffs are burned in a special device, called a calorimeter, to measure the amount of heat released and therefore determine how many calories it contains. In addition, the efficiency of digestion is considered to establish the total energy that can be obtained from an ingredient. In human physiology it is common to report the values of 4 kcal/g for both carbohydrates and protein and 9 kcal/g for fat. Using standard values for the efficiency at which average dog and cat foods are digested, the values decrease to 3.5 kcal/g for carbohydrate and protein and 8.7 kcal/g for fat.

Although protein, fat, and carbohydrate play an essential role in the diet of animals, water remains the most critical nutrient. An animal can lose almost all its fat and up to half its protein and survive, but dehydration can quickly become life threatening. In Chapter 6 the significance of fluid balance was emphasized. A loss of 10% of the body's water becomes very serious, and loss above 15% are generally life threatening.

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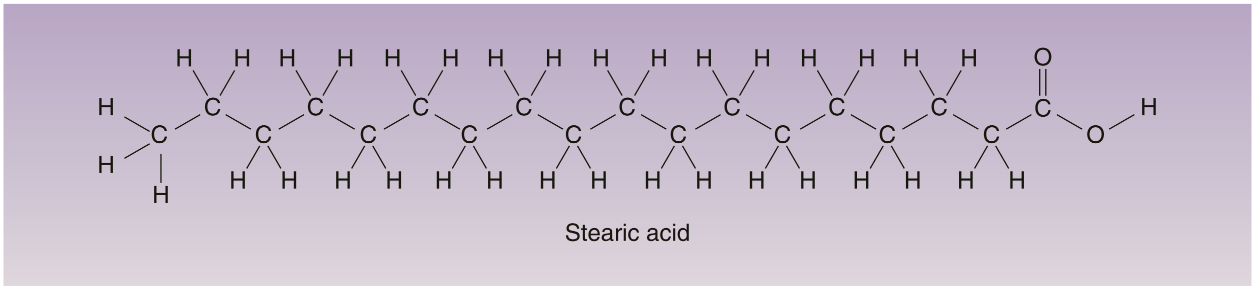
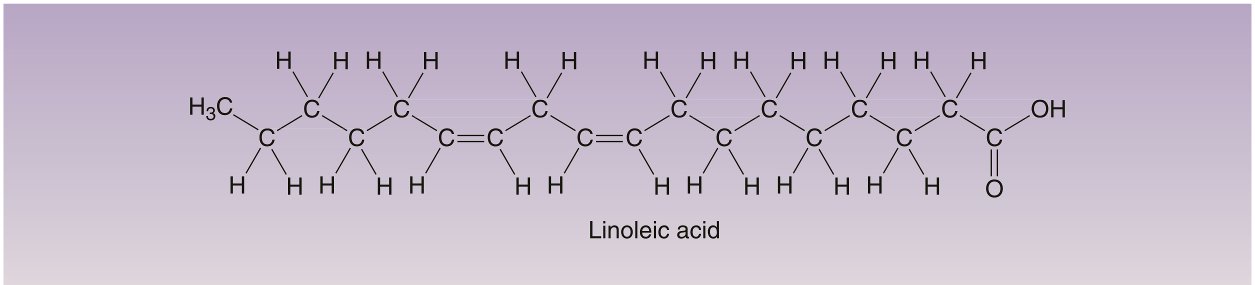
Stearic Acid: C18:0—a saturated fatty acid:
[$CH_3–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–COOH$]



Linoleic Acid: C18:2 (n–6)—an unsaturated omega 6 fatty acid:
[$CH_3–CH_2–CH_2–CH_2–CH_2–CH{=}CH–CH_2–CH{=}CH–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–COOH$]



αLinolenic Acid: C18:3 (n–3)—an unsaturated omega 3 fatty acid:
[$CH_3–CH_2–CH{=}CH–CH_2–CH{=}CH–CH_2–CH{=}CH–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–COOH$]

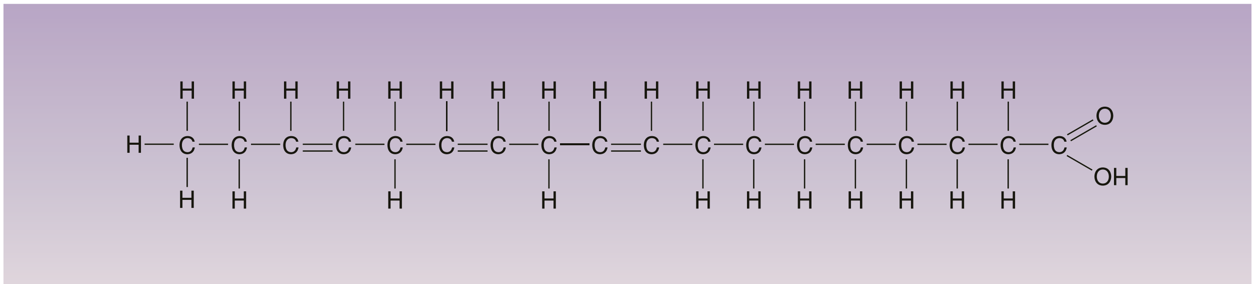


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FIGURE 12–3 Fatty acids are often named but are also numbered based on the number of carbon atoms and the number of double bonds.

Some water is actually produced during metabolism. This is a relatively small amount compared with how much is obtained in feed ingredients and is directly consumed. Depending on the type of diet, the amount of water consumed in feed can be quite significant. A cat eating canned food takes in much more water in its food than a cat eating strictly dry food. An adult Holstein dairy cow often consumes more than 100 lb of total feed that has more than half its weight as water. In the feed alone, the cow will have consumed 50 lb of water.

Water plays a tremendous role in many functions. Up to two thirds of the body is composed of water, including that found within and among the cells and in the bloodstream. Within cells, water provides a medium for chemical reactions to occur. In addition, the process of **hydrolysis** adds water to a molecule to cleave it into smaller parts. Water also plays a role in transporting nutrients, wastes, and hormones in the blood and lymph. A developing fetus is bathed in liquid that is supportive and protective.

Environmental temperature, humidity, and physical exertion have an impact on the daily water requirement. During panting and sweating, evaporation of water helps to control body temperature. In addition to these losses, the body also loses water in urine and feces. The tremendous loss of water with diarrhea, and its effect on dehydration has already been discussed. In lactating animals, producing and secreting milk also causes tremendous water loss. It is quite common for

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the average Holstein cow to be producing 70 to 100 lb of milk a day. A major portion of milk is composed of water, and therefore milk production needs to be considered in evaluating the water requirements of the cow. The water requirement of an animal is an accumulation of all the demands and is based on the size and weight of the animal, activity level, temperature, humidity, and production losses (e.g., milk production).

Many laboratories do water quality tests, evaluating bacterial contamination and chemical makeup of water samples. Both the amount of an animal's intake and its performance may be impacted by the quality of water provided to it. For example, high levels of nitrate in the water may impact reproductive performance or growth. More extensive testing is available to check for contamination by toxins such as heavy metals or pesticides. Table 12–4 shows some of the criteria evaluated in a standard water quality evaluation.

Vitamins are organic compounds necessary in relatively small amounts to maintain the health and function

Table 12–4 Analysis of Water Supplies

Item	Average*	Expected†	Possible Cattle Problems‡
pH for cows	7.0	6.8–7.5	< 5.1 or > 9.0
pH for veal calves		6.0–6.4	
Stability index	8.5	6.0–7.5	
Saturation index	−0.68		
Turbidity (Jackson units)	5.5	0–30	
Color, PCU§	0.7	0–15	
Odor threshold	0.07		
	Parts per Million (ppm)		
Dissolved solids	368	≤ 500	> 3,000
Phenolphthalein alkalinity	0.9	0–trace	
Total alkalinity	141	0–400	> 5,000
Bicarbonate alkalinity	139		
Carbon dioxide	46	0–50	
Chloride**	20.2	0–250	
Sulfate	35.5	0–250	> 2,000
Fluoride	0.23	0–1.2	> 2.4 (mottling)
Phosphate	1.4	0–1.0	
Total hardness	208	0–180	
Calcium	60.4	0–43	> 500
Magnesium	13.9	0–29	> 125
Sodium	21.8	0–3	> 20 for veal calves
Iron	0.8	0–0.3	> 0.3 (taste, veal)
Manganese	0.3	0–0.05	> 0.05 (taste)
Copper	0.1	0–0.6	> 0.6 to 1.0
Silica	8.7	0–10	

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Table 12–4 *continued*

Item	Average*	Expected†	Possible Cattle Problems‡
Potassium	9.1	0–20	
Arsenic	–	0–0.05	> 0.20
Cadmium	–	0–0.01	> 0.05
Chromium	–	0–0.05	
Mercury	–	0–0.005	> 0.01
Lead	–	0–0.05	> 0.10
Nitrate as NO_3††	33.8	0–44	> 100
Nitrite as NO_2	0.28	0–0.33	> 4.0–10.0
Hydrogen sulfide	–	0–2	> 0.1 (taste)
Barium	–	0–1	> 10 (health)
Zinc	–	0–5	> 25
Molybdenum	–	0–0.068	
Total bacteria/100 ml	336,300	< 200	> 1 million
Total coliform/100 ml	933	< 1	> 1 for calves; > 15–50 for cows
Fecal coliform/100 ml§§	–	< 1	> 1 for calves; > 10 for cows
Fecal strep/100 ml	–	< 1	> 3 for calves; > 30 for cows

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*For most parameters, averages are from approximately 350 samples. Most samples were taken from water supplies on farms with suspected animal health or production problems.

†Based primarily on criteria for water fit for human consumption.

‡Based primarily on research literature and field experiences.

§PCU = platinum cobalt unit.

**Free or residual chlorine levels up to 0.5 to 1 ppm have not adversely affected ruminants. Municipal supplies with 0.2 to 0.5 ppm have been successfully used. Swimming pool water with 1 ppm has no demonstrable effects on cattle. Levels of 3 to 5 ppm in farm systems with short contact time have caused no apparent problems.

††Should not be consumed by young human infants if over 44 ppm NO_3 or 10 ppm NO_3-N.

§§If pollution is from human wastes, fecal coliform should exceed fecal strep by several times. If pollution is from an animal source, strep should exceed coliform in refrigerated samples run soon after taking.

of the animal. Vitamins may act as an enzyme, helping to control a chemical reaction. Other vitamins act as coenzymes by combining with a protein to create an active enzyme. In addition, other vitamins serve as precursors to enzymes. These vitamins are converted into an active enzyme once they are absorbed into the body.

Vitamins are divided into two classes: fat soluble and water soluble. The water-soluble group includes eight B vitamins and vitamin C. Vitamins in this class are not stored in the body, and any excess is excreted in the urine. Because these vitamins are not stored, they basically require daily intake to maintain adequate levels in the body. Most daily requirements for vitamins are listed in milligrams or micrograms. The requirements for vitamins A, D, and E are listed in international units (IU). Rather than a measurement of weight the IU is an evaluation of the potency and its ability to improve signs of a deficiency. Table 12–5 summarizes the vitamins, their functions, and the signs associated with deficiencies.

The fat-soluble vitamins are A, D, E, and K. These vitamins are absorbed from the intestinal tract with fat. Any excess absorbed is stored in the fat reserves of the body. Daily input is not required, because reserves are available. Because these vitamins are stored, it is possible for toxicity to occur with excessive intake. One class of **rodenticide** (poisons for mice and rats) uses high levels of vitamin D to cause a toxic effect. Excessive intake creates severe hypercalcemia. This causes damage to many organs, including the kidneys and heart. These products are designed to kill mice but are also toxic to pets when consumed in high enough levels.

Vitamins A, C, and E, along with the minerals selenium, copper, iron, manganese, and zinc, are all

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Table 12–5 **Summary of Vitamins**

Vitamin	Functions
Fat Soluble	
A	Plant sources are precursors of vitamin A (e.g., beta-carotene) Essential in the pigments of the retina, especially low light vision Necessary for healthy cell division, bone growth, blood cell formation Aids in the health of epithelial tissues; important in reproduction and disease resistance
D	Synthesized in skin with exposure to UV light from the sun Maintenance and formation of bone and teeth Affects calcium and phosphorus metabolism (through kidneys, bone, and intestinal absorption)
E	Closely associated with selenium Antioxidant—protects lipids and cell membranes; stabilizes red blood cells Important role in immune and reproductive systems
K	Essential for blood clotting
Water Soluble	
B_1 (thiamine)	Carbohydrate and energy metabolism Maintenance of the nervous system
B_2 (riboflavin)	Carbohydrate, fat, and protein metabolism; involved in many enzymes Important in growth, maintaining healthy skin, and nervous system
B_5 (pantothenic acid)	Carbohydrate, fat, and protein metabolism Necessary for antibody production Important for skin health
B_3 (niacin)	Carbohydrate, fat, and protein metabolism Maintenance of healthy oral tissues Can be synthesized from the amino acid tryptophan except in cats
B_6 (pyridoxine)	Amino acid and energy metabolism; necessary for growth Maintenance of healthy nervous and immune system Important in hemoglobin formation
Folic acid	Necessary for nucleic acid synthesis and cell division Closely associated with B_{12} in red blood cell formation
Biotin	Synthesis of glucose and energy metabolism; growth Necessary for healthy skin and hooves (through collagen maintenance)
B_{12} (cobalamin)	Closely associated with folic acid in red blood cell production Important in nervous system function; fat, carbohydrate, and energy metabolism Contains the mineral cobalt
C	Important in wound healing and collagen formation Maintains strength of capillaries and mucosa Important antioxidant

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considered antioxidants. Antioxidants help to protect the lipid membranes by neutralizing **free radicals** released within the body. Free radicals have a single free electron, which attracts another electron from neighboring atoms. Free radicals have some beneficial functions, including the destruction of invading pathogens by the immune systems. Left uncontrolled, however, these free radicals can then damage the neighboring cells. The antioxidant vitamins and minerals work to eliminate the free radicals, therefore protecting the body's cells.

Minerals are also involved in the metabolism of the animal, but unlike vitamins are inorganic compounds. Minerals are divided into macrominerals and trace minerals, or microminerals. The categories are

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based on the relative amounts required in the body. The amount of macrominerals in a diet is generally expressed as a percentage of **dry matter**. Dry matter is the percentage of the feed ingredient that remains when all the water is removed (100% = Percent dry matter + Percent moisture). The microminerals or trace minerals are generally expressed in parts per million (ppm). One part per million is equivalent to 1 mg in 1 kg of feed. As an example, cattle require macrominerals in grams per day and the microminerals in milligram or microgram quantities.

The common macrominerals are calcium (Ca), potassium (K), sodium (Na), phosphorus (P), magnesium (Mg), sulfur (S), and chlorine (Cl) (Table 12–6). Many of these minerals have already been discussed in other chapters. Calcium and phosphorus play an important role in bone structure. Calcium also serves in the function of muscles. Sodium and potassium allow for nerve conduction and, along with sodium, are involved in the regulation of fluid balance in the blood.

The microminerals are commonly involved in enzyme reactions, helping to speed the chemical reaction. The trace minerals may also be included in hormones, such as iodine in thyroid hormone. Table 12–7 lists many of the trace minerals and summarizes some of their functions.

Table 12–6 Macrominerals

Mineral	Functions
Calcium	Development of bone and teeth, muscle, and nerve function Activates many enzymes, necessary in blood clotting
Chloride	Essential for acid–base, osmotic pressure, and fluid control in the blood
Magnesium	Development of bone and teeth, necessary for hemoglobin production, necessary for nerve and muscle function Important in energy metabolism and many enzymes
Phosphorus	Development of bone and teeth, structure of cell membranes (phospholipids) Involved in nucleic acid production, energy utilization, and many enzymes
Potassium	Necessary for the function of nerve and muscle; important in protein synthesis Essential for acid–base, osmotic pressure, and fluid control in the blood Majority is intracellular
Sodium	Necessary for the function of nerve and muscle Essential for acid–base, osmotic pressure, and fluid control in the blood
Sulfur	Is in the amino acids methionine and cysteine and in the B vitamins thiamine and biotin Involved in many enzymes and hormone production

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Table 12–7 Microminerals

Mineral	Functions
Cobalt	Involved in many enzyme reactions, including gluconeogenesis Included in vitamin B_{12}
Copper	Involved in bone and hemoglobin formation; necessary for proper iron metabolism Included in many enzymes—especially those of protein production
Iodine	Portion of thyroid hormone Necessary for proper reproductive cycle
Iron	Portion of hemoglobin and oxygen metabolism, many enzymes
Manganese	Activates many enzymes Involved in bone and connective tissue development Carbohydrate and fat metabolism
Selenium	Antioxidant, necessary for healthy immune system Function is dependent on adequate levels of vitamin E
Zinc	Many enzyme systems, especially protein synthesis Necessary for healthy skin, hooves, and immune system Important role in blood cell formation and wound healing
Molybdenum	Involved in many enzyme reactions

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A

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B

FIGURE 12–4 A. Koster tester positioned for heating a sample. B. Koster tester with sample being weighed. Measuring the amount of water removed allows the dry matter to be evaluated.

Deficiencies and excesses of the trace minerals can occur. Many of the trace minerals are absorbed from the intestinal tract by the same mechanism. Feeding an excess of one micromineral can result in a deficiency of another. For example, the absorption of copper is decreased as sulfur and molybdenum increase.

The concentration of a nutrient in a feed or diet can be expressed either on an as-fed or dry matter basis. An as-fed basis measures the concentration just as it is delivered to the animal. This is affected by the amount of water in the feed. It is difficult to compare two feeds with different moisture contents when the concentrations are reported on an as-fed basis. To make the comparison easier, concentrations are often reported on a dry matter basis. A dry matter basis calculates the concentration of the nutrient with all the water removed from the feed (Figure 12–4).

Table 12–8 shows a forage analysis report of an alfalfa haylage. Alfalfa is commonly fed to dairy cows. In haylage, alfalfa is put in storage with a relatively high amount of moisture. The two columns of the report show the concentrations on an as-fed and dry matter basis. The numbers describe the same feed, with and without water. A formula can be used to convert the numbers.

$$\frac{\text{Concentration as fed}}{\text{Percent dry matter}} = \text{Concentration on dry matter basis}$$

or

Concentration on dry matter basis × Percent dry matter = Concentration as fed

Using the numbers in Table 12–8:

Crude protein as fed = 5.3

Percent dry matter = 28.6

$$\frac{\text{53\% Crude protein}}{\text{0.286 Dry matter}} = \text{18.5\% Crude protein on dry matter basis}$$

The dry matter percentage of the feed is critical in evaluating how much food the animal is actually consuming. Consider a cow consuming 100 lb of a complete ration with a dry matter of 50%. The cow is actually consuming 50 lb each of dry matter and water. If the ration becomes wetter (lowering the dry matter to 45%), the cow will consume less feed and more water (45 lb of dry matter and 55 lb of water). Because a farmer wants to feed a cow the same amount of dry matter every day, in this case the cow must be fed more of the total ration.

To calculate the amount of total ration that must be fed to a cow, producers must know how much dry matter is required (50 lb in this example) and the percent dry matter of the total ration (45% in this example).

$$\text{Pounds of total ration} = \frac{\text{Pounds of dry matter}}{\text{Percent dry matter}}$$

$$\text{Pounds of total ration} = \frac{50}{0.45}$$

$$\text{Pounds of total ration} = \text{111 lb}$$

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Table 12–8 **Forage Analysis Report: Alfalfa Haylage**

	As Fed	Dry Matter
% Moisture	71.4	
% Dry matter	28.6	100
% Crude protein	5.3	18.5
% Acid detergent fiber	10.3	35.9
% Neutral detergent fiber	12.8	44.6
% Crude fat	1	3.4
Net energy of lactation (Mcal/lb)	0.17	0.58
% Calcium	0.43	1.5
% Phosphorus	0.08	0.29
% Magnesium	0.08	0.28
% Potassium	0.65	2.27
% Sodium	0.003	0.01
Iron ppm	27	95
Zinc ppm	7	24
Copper ppm	2	8
Manganese ppm	13	45
Molybdenum ppm	0.2	0.7

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CLINICAL PRACTICE

Objective

- Discuss the Clinical Significance of the Academic Material Learned in This Chapter

Copper is an essential mineral in the diet of animals. However, any species can develop toxicity if excess is fed. Some species of animals, such as sheep, are much more sensitive to excess copper. Sheep require much less copper (per pound of body weight) than do cattle. Because of this variation, feeding sheep with grain formulated for cattle can result in toxicity. Improper formulation of a sheep diet can lead to similar problems.

Copper is stored in the liver. With chronic exposure to excess copper, the levels continue to increase in the liver. When the animal is put under stress (such as trucking the sheep to a show), large amounts of copper are released into the bloodstream. As a result, the red blood cells begin to break down in the vessels (**hemolysis**). The animal becomes anemic, and large amounts of hemoglobin spill into the urine, which can damage the kidneys.

Clinical signs of hemolysis begin with depression, weakness, and a loss of appetite. As it progresses, the animal often develops diarrhea, has difficulty breathing, and becomes ataxic. Death usually occurs quickly after the animal begins hemolysis. The rams discussed at the beginning of this chapter both died. Postmortem examination confirmed the diagnosis. The level of copper in the liver was 458 ppm. The normal range for this test is 25 to 100, with the toxic range starting at 250 ppm. The postmortem was not helpful in saving any of the clinically affected animals. However, with a positive diagnosis, the diet of the remaining flock was adjusted and no further animals were affected. This is a common procedure in herd health medicine. The loss of an individual animal can be very helpful in treating or preventing disease in the remainder of the herd or flock.

Cattle are generally allowed free access to salt in addition to a base amount included in the feed. They can regulate intake based on their need. The kidneys excrete any excess that is consumed. This works well as long as cattle have free access to water. If the animal consumes a normal amount of salt (sodium chloride) but then water is restricted, the concentrations of sodium and chloride become elevated to dangerous levels. The water restriction can occur during times when electricity fails, a water pump quits, or troughs freeze. The animals from the introduction and Table 12–1 show evidence of severe hypernatremia (elevated sodium).

Salt toxicity is much more common in swine but does occasionally occur in ruminants. I failed to make this diagnosis until after the blood results had returned. Every source that I found listed salt toxicity in combination with some water restriction. These cattle had not been restricted in their water intake. In this farm situation the cattle had not had access to salt for a long period. The farmer had gotten salt that day and supplied them with a large amount of loose granular salt. Many animals consumed a large amount very quickly, with the two affected animals consuming even more.

I visited the farm the following day to check on these animals, and the first cow had already died. It was obvious that the herd in general had been consuming large amounts of water, and there was an excessive amount of urine in the gutter behind the cow. The elevated sodium in the blood had stimulated the thirst center, and the animals were consuming large amounts of water. The cattle were not eating well the following day.

The two most severe cases had obviously consumed quite excessive amounts. The level of sodium had increased to extremely high levels in the brain, stimulating the animals to drink. Unfortunately, the osmotic force of the sodium in the brain had drawn large amounts of water into the brain tissue, causing swelling (edema). The swelling then resulted in the clinical signs that I had observed: ataxia, inability to rise, muscle twitching, and death. The normal mechanism of providing water, which cured the problem for the majority of the herd, actually worsened the

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signs for the two worst animals. This incident proved a valuable lesson for the farmer and me. The farmer now keeps salt available at all times.

A different farm was having poor feed intake and poor milk production. Eventually two cows completely stopped eating. Blood chemistry results from these two sick cows and a healthy cow showed significant electrolyte abnormalities. The consistent low levels of hyponatremia (low sodium) and hypochloremia (low chloride) provided evidence of chloride deficiency (Table 12–9). The cows craved the salt when it was provided to them. In this situation salt was offered in a block form, which limited how fast the cattle could eat. It was determined that inadequate amounts of salt had been added to the grain mix and with no free choice available chloride became deficient. Once adequate amounts were provided the cattle began eating well and milk production quickly increased. These two cases emphasize that mineral levels must be maintained at proper levels, preventing both a deficiency or toxic condition.

Polioencephalomalacia (PEM or polio) occurs with a lack of thiamine in ruminants. (It is important that polio in ruminants not be confused with an infectious disease in humans that is also called polio.) Ruminants do not require a large source of thiamine in the diet, because the organisms in a normally functioning rumen produce adequate amounts. With certain feed changes, such as a high-grain diet, certain organisms that produce an enzyme called thiaminase can flourish in the rumen. Thiaminase destroys thiamine, leaving the animal deficient.

Thiamine is involved in the chemical reactions that produce energy for the cells. When deficiency occurs, the cells become starved for energy. The lack of energy to the cells of the central nervous system leads to the classic signs that these animals were exhibiting. Ataxia, inability to rise, and blindness are all typical signs with PEM (Figure 12–5). Treatment is straightforward and involves injection of high levels of thiamine. If the disease is caught early enough, it can be cured.

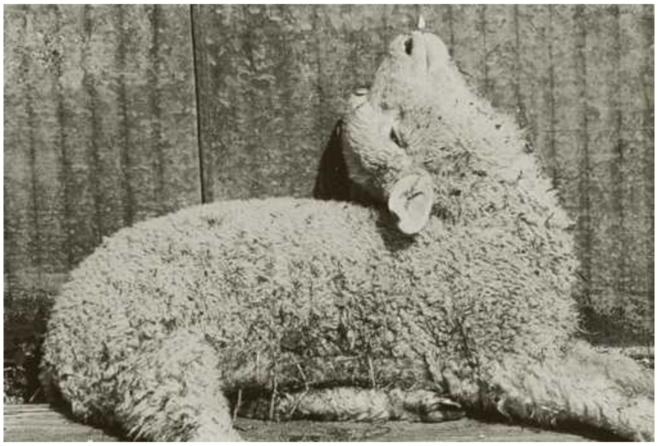
Courtesy of Ron Fabrizius, DVM, Diplomat ACT.

FIGURE 12–5 A sheep showing evidence of polioencephalomalacia.

Although many of our domestic species have tremendous similarities, small differences can be quite significant. The diets of cats and dogs may appear similar, but there are differences. Taurine is an amino acid that can be produced from other amino acids. Cats are unable to produce adequate amounts, and therefore it is considered an essential amino acid. Cats eating only dog food would become taurine deficient.

Several serious health problems can occur when a cat becomes taurine deficient. Blindness is one possible outcome, as the retina of the eye becomes damaged. Female cats will be unable to maintain a pregnancy and young animals will have growth problems. Most serious is a disease condition of the heart muscle. The muscle becomes weakened and damaged, leaving the heart functioning poorly. This condition can be fatal, although it is reversible if taurine is supplied early enough in the course of the disease.

High-producing dairy cattle require a large amount of water every day. For example, an adult Holstein cow producing 80 lb of milk and eating 50 lb of dry matter might require as much as 296 lb of water per day (about 35.5 gallons). If this same cow was eating a total of 100 lb of diet at 50% moisture, the cow would get 50 lb

Table 12–9 **Blood Chemistry Results for Sick versus Healthy Cows**

Test	Units	Reference Range	Sick Cow #1	Sick Cow #2	Normal Cow
Phosphorus	mg/dl	4.0–8.6	3.3	4.2	6
Calcium	mg/dl	8.0–12.0	7.3	6.9	8
Magnesium	mEq/L	1.80–3.00	2.74	1.82	3.72
Sodium	mEq/L	138–155	124	118	126
Potassium	mEq/L	3.9–6.4	3.3	2.6	2.8
Chloride	mEq/L	96–116	81	82	89

Numbers in blue fall below the normal reference range.

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of water through the feed. The cow must drink the remainder of this water.

Any restrictions on her ability or desire to drink would limit her ability to produce that much milk. Frozen waterers, limited flow, or competition may keep the cow from having free access to all the water required. In addition, quality problems may limit the palatability or taste of the water and the cow may intentionally drink less. Laboratory analysis of water quality can provide evidence of problems that might limit water consumption. Water is frequently analyzed for pH, mineral content, and bacterial contamination. Variations out of the normal reference range might represent a reason for decreased production in a herd.

SUMMARY

Carbohydrates, protein, fats, vitamins, minerals, and water comprise the six nutrients of animal diets. All working in conjunction allow the body to function efficiently and effectively. Deficiency in any of the six, especially water, will result in low performance or even death. To maintain a healthy animal, producers must ensure that all six nutrients are present in correct amounts in the daily ration.

REVIEW QUESTIONS

1. Define the following terms:

   necropsy
   postmortem
   constipation
   flatulence
   calorie
   hydrolysis
   rodenticide
   free radicals
   dry matter
   hemolysis

2. Carbohydrates provide _______ to maintain blood sugar levels.
3. Adding _______ to the diet is helpful in both diarrhea and constipation.
4. Proteins are composed of chains of _______.
5. One kilocalorie equals _______ calories.
6. Minerals are divided into two categories, _______ and _______.
7. Name the simplest carbohydrates.
8. Which remain solid at room temperature, fats or oils?
9. Addition of which nutrient generally adds palatability to food?
10. What proportion of the body is composed of water?
11. Does sweating cool or heat the body?
12. Which common barnyard ruminant is quite sensitive to copper toxicity?
13. List the three classes of nutrients used for energy supply and cellular structure.
14. List the three attributes of animal fat deposits.
15. List four fat-soluble vitamins.

ACTIVITIES

Materials needed for activities:

forage samples
Koster tester or gram scale and microwave oven
paper plates
label from human vitamin/mineral pill bottle

1. A very important technique in animal nutrition is the ability to measure the dry matter content of the feed. Several techniques are available to measure dry matter.
   a. A commercially available method is the Koster tester. This is an electrical unit that heats the sample and has a scale to measure the changes in weight as water is removed. These units come with complete instructions on proper usage.
   b. These units are relatively expensive, and the same technique can be accomplished with a gram scale and a microwave oven. A note of caution: Because the samples become extremely

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dry, it is possible for them to catch on fire! This is dangerous, plus the burning causes a loss of dry matter and an inaccurate reading. Always maintain observation on the sample—*do not* leave drying samples unattended.

c. Obtain a forage sample from a local farm; ideally this will be silage, such as corn silage or haylage, in which there is a significant amount of moisture. Dry hay can also be tested in the same manner, but the amount of moisture is quite low. Weigh a paper plate. Add a sample of the forage (approximately 50 g). Record the actual weight of forage. Spread the sample out thinly on the plate.

d. Heat the sample in the microwave for short periods. Table 12–10 lists approximate times for various forages and moistures. (Warning: Determining dry matter with a microwave does produce a distinctive cooked odor. Parents generally do not appreciate this procedure being done in the kitchen with the family microwave!) Following each heating, weigh and stir the sample. Use care not to lose any of the forage. As the forage becomes drier and more brittle, heat for shorter periods. Repeat the procedure until the weight does not change between samples. The goal is for all the water to be released as steam, leaving only the dry matter of the sample without any loss from combustion.

e. Record the final weight of the sample. Divide the final weight by the initial weight and multiply by 100 to calculate the dry matter percentage:

$$\text{Percent dry matter} = \frac{\text{Final weight}}{\text{Initial hight}} \times 100$$

2. A farmer recently purchased a Koster tester and has found that the moisture of available haylage has changed. You examine the ration, which says to feed 45 lb of haylage as fed, which is 45% dry matter. Using the Koster tester, the producer has determined that the haylage is now only 32% dry matter. Show the farmer how to calculate how much haylage should be fed.

3. A producer calls you to ask advice. An opportunity has presented itself to buy haylage from two neighbors. Both neighbors are asking $40 per ton. Haylage 1 has a crude protein of 6.3% on an as-fed basis and a dry matter of 32.3%. Haylage 2 has a crude protein of 7.8% on an as-fed basis and a dry matter of 44.3%. Which haylage would you recommend and why?

4. Look at the label of a human vitamin/mineral supplement container. See what the dosage may be. It could be more than one capsule or tablet. Then compare the recommended daily allowances of the vitamins and minerals to the amount provided. Determine which substances are given in excess.

5. Compare and contrast the ingredient labels of cat and dog food containers.

Table 12–10 Approximate Microwave Times for Dry Matter Analysis*

	Corn Silage (< 40% dry matter)	Haylage (< 40% dry matter)	Haylage (> 40% dry matter)
First heating	90 seconds	60 seconds	50 seconds
Second heating	45 seconds	35 seconds	40 seconds
Third heating	35 seconds	25 seconds	25 seconds
Fourth heating	30 seconds	15 seconds	15 seconds
Subsequent heatings	10–15 seconds	5–10 seconds	5–10 seconds

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*Heating times are approximate. Do not leave the sample unattended.
In general, the drier the sample, the shorter each heating time should be.
Do not allow the sample to burn, which will result in a loss of dry matter from the sample.

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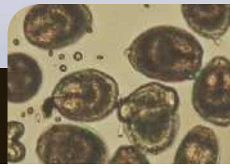
CHAPTER 13



Species Comparison

Objectives

Upon completion of this chapter, you should be able to:

- Explain the general principles in animal nutrition.
- Describe the important features found on pet food labels and compare and contrast the nutritional requirements for dogs and cats.
- Discuss the horse's ability to digest fiber and its role in equine nutrition.
- Detail the ruminant's ability to digest fiber and its role in ruminant nutrition.
- Link the clinical significance of the academic material learned in this chapter to veterinary practice.

Key Terms

free choice diet
resting energy rate
maintenance energy requirement
grazing
concentrates
float
forage
cribbing
bolt
total mixed ration

Introduction

Veterinary science presents the challenge of having to understand the anatomy and physiology of many species. Nutrition emphasizes these differences. There is tremendous variation in the anatomy and type of diet of domestic species. It is well beyond the scope of this text to describe the nutritional requirements of all the domestic species. This chapter describes many of the considerations used in the nutrition of dogs, cats, horses, and cows. The cow represents the classic ruminant digestive system and the horse provides an illustration of a different means of fiber digestion in the following discussion.

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A Day in the Life
Some Days the Odor is Overwhelming...

The veterinary profession is well respected, but it is not always a glamorous job. Many days when I return to the office, the office staff will tell me that I stink! Unfortunately, smelling badly is just part of my job. When working around animals, getting dirty and picking up distinct odors are routine.

A particularly smelly incident happened a number of years ago, but we still talk about it in the clinic. I was working on a cow with an obstruction in her teat. The farmer could not get milk from that quarter, and I was attempting to relieve the obstruction. The procedure causes some degree of pain, and the cow was not happy about my work. The farmer was attempting to control the cow and keep her from kicking me.

I placed my head firmly into the cow's flank. This kept me somewhat safe, because if the cow tried to move my way, I was shoved backward. In this position, my backside was dangerously close to the cow in the stall behind me. I was concerned about her kicking me as well, but I had to concentrate on the task at hand.

I was making progress, but it was a bit of a struggle. The cow was quite nervous, and all the activity was exciting the neighboring cows as well. Anyone who has worked around cattle knows that cows have a tendency to defecate when they get upset. I had definitely made the cow behind me nervous. I was in the middle of the procedure, when I noticed a wet, warm feeling on my backside. I finished as quickly as possible and stood up to find the problem. The cow had filled my back pocket with feces! The farmer and I just looked at each other and began to laugh. I have these kinds of days.

I was visiting Dr. Baker, my coauthor, when a very large black Lab walked into the house. This dog had obviously been eating quite well and had become downright fat. Dr. Baker's parents had adopted this former stray. How did this dog become so heavy? Moreover, the dog's housemate, a former barn cat, was also morbidly obese, weighing a hefty 30 pounds (Figure 13–1). Then, I saw another cat that had developed a skin infection around its hindquarters. This cat had become so heavy that it was unable to groom itself in that region. Obesity is a very common problem in small animal medicine.

In 2007, 12 different pet food manufacturers faced a problem when an overseas supplier contaminated wheat gluten and rice protein concentrate with products designed to elevate the apparent protein levels. Unfortunately these products sickened many pets and new recalls were announced almost daily. It took time to discover the underlying problem. Pet food commercials also have owners concerned over foods containing meat by-products and grain fillers. I am commonly questioned about pet foods. Some of my clients even elect to make their pet food.

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FIGURE 13–1 An obese cat.

I often remember the emergency calls. This may be because being rallied from bed in the middle of the night can be traumatic. It may also be because the cases are dramatic as well. One night while I was still in veterinary school, I was called to see a horse showing signs of colic. When I arrived at the farm, I discovered that the horse had gotten into the feed room and had consumed a huge amount of grain. The consumption of excessive feed had caused a severe illness. The digestive system of this horse, designed to digest forages, had become quite upset with the overload of such a large amount of grain.

I frequently examine cows that are not eating or milking well. These cows have often calved within the past few weeks. The following case was no exception. The cow that I examined had given birth two weeks earlier and started milking very well. The farmer was disappointed that the cow had decreased milk production and was not finishing her feed. On examination, I could not find any sources of infection; she did not have a displaced abomasum, but she did have ketosis. Ketosis is a common disease in high-producing dairy cattle that are not able to eat enough feed to meet their large energy demands. Understanding the digestive tract, nutrition, and metabolism of dairy cattle helps to explain how this occurs.

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ANIMAL NUTRITION

Objective

- Explain the General Principles in Animal Nutrition

Many factors considered in nutrition are consistent among the species. The basic goal of nutrition is to meet all the needs of the animal and maintain good body weight and condition. As discussed in the previous chapter, water quality and quantity must be considered in the animal's nutrition.

Several considerations influence the nutritional demands on an animal. When developing a diet, we begin by considering a resting animal in a comfortable environment. Dietary needs in this condition are referred to as maintenance requirements. Any change from these factors alters the needs of the animal. Increasing the level of activity immediately increases the animal's needs. The activity level can be dramatic for working animals. Race horses, draft horses, and hunting dogs serve as examples of animals that have nutritional needs much higher than maintenance levels. The environment also influences requirements. The same animal in cold wet conditions must expend more energy to maintain body temperature. This increase in energy must be supplied in the diet or the animal will mobilize fat to provide this energy.

Animals in other stages of life also require different levels of nutrients. Growth, pregnancy, and lactation increase the demands that must be supplied through the diet. A dog in peak lactation may have an energy requirement two to four times that needed for maintenance. Likewise, a young rapidly growing puppy may have twice the nutritional requirement of an adult dog of the same weight and size. Additionally, it is important to recognize the tremendous variation among individuals. Even littermates sharing the same environment can have quite different needs. It is common to see, in two pets in the same household, one that is dramatically overweight and the other in good body condition. Finally, the health status of an animal can dramatically change the requirements of the animal. Certain disease conditions can increase the metabolic needs of an animal.

Several methods are available to deliver feed to an animal. One of the simplest methods is to provide a **free choice diet**. The goal is to have good quality feed available for the animal at all times. Using the dog as an example, free choice feeding requires the least work and helps to eliminate any competition between animals. The pet can eat at any time. This can be helpful in quieting a confined dog. Free choice feeding is often beneficial in dogs with high requirements such as in pregnancy, lactation, or high physical activity. However, there are drawbacks to this type of feeding. In multiple pet households, it can be difficult to determine when a pet is ill and stops eating. The most common problem, however, is that with free choice feeding comes a higher risk of obesity. Many animals eat much more feed than is required. The excessive energy is converted to fat and deposited in the fat tissue.

The diet can also be delivered by controlling the time allowed for eating or the amount of feed supplied. This allows much greater control over the amount consumed by the animal. A pet that begins to gain too much weight can be fed less or allowed less time to eat. This does require more time commitment as meals are supplied multiple times throughout the day. The pet may also show more food hunting or begging behavior between meals.

Most animals should also have free access to water throughout the day. The diet should then provide all the necessary nutrients (carbohydrates, fats, protein, vitamins, and minerals) in the proper amount and proportions. The caloric need of the animal can be used to determine how much food is required. The **resting energy rate** (RER) is the amount of energy required by an animal at rest in a comfortable environment (temperatures not requiring the animal to heat or cool itself). Numerous formulas exist to calculate RER, based on the animal's body weight. An example of such a formula is:

$$\text{RER (kcal)} = 70 \times (\text{Weight in kg}^{0.75})$$

Notice that the formula does relate to the animal's weight, but that the weight is raised to the power of 0.75. The resting energy rate is impacted more significantly by the animal's body surface area than by its weight. This formula attempts to relate body weight to surface area.

The **maintenance energy requirement** (MER) accounts for the RER, plus any additional energy required for the normal activity of the animal. The MER for the typical or average dog is usually twice the RER. Cats, on the other hand, typically have an MER that is 1.4 times the RER. Although inactivity decreases the requirements, many of the other factors discussed create an extra need for calories. For example, a dog in peak lactation with a large litter may have energy needs two to four times that of a typical MER.

Every animal has a limit to the volume or weight of food that can be consumed in a day. To meet the high energy needs of the lactating or working dog, each amount of food may need to contain a higher amount of calories. Energy density describes the calories supplied by each weight unit of food (e.g., kcal per pound). Whereas the lactating dog may benefit from a higher energy density food, the overweight, inactive dog will benefit from a lower energy density food. With the lower energy density, the fat dog will feel

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satisfied with the volume consumed, while obtaining fewer calories.

PET FOOD LABELS

Objective

- Describe the Important Features Found on Pet Food Labels and Compare and Contrast the Nutritional Requirements for Dogs and Cats

Anyone who has walked down the pet food aisle in the grocery store will recognize that a wide variety exists in the types of foods available for pets (Figure 13–2). In addition to purchasing commercial feeds, it is possible to make diets for pets at home. For the sake of convenience, the vast majority of pet owners elect to purchase commercially available foods. The three basic feed types available are moist or canned, semi-moist, and dry foods (Figure 13–3).

Canned foods in general are about 75% water. These moist foods tend to be more palatable and digestible than dry food. Palatability describes how well the animal likes the food. Palatability is affected by several factors: odor, texture, nutrient content, and habit. Canned foods tend to have a higher level of water, protein, and fat, which also influences the odor. Fat plays a large role in the palatability of a food. The role of smell in the sense of taste is very important. An animal with an upper respiratory tract infection and a congested nose may become anorexic (have a poor appetite). Cleaning the nose and warming the food to increase the smell released can often help to improve the appetite of such an animal.

Dogs in general prefer canned food to dry. Cats are not so consistent. Cats often develop a preference for one type or shape of food. Manufacturers attempt to

Courtesy Giant food stores.

FIGURE 13–2 A tremendous variety of foods are available. Making a selection can be difficult.

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FIGURE 13–3 Three major varieties of food: canned, semi-moist, and dry.

take advantage of this habit of cats, by producing foods with a distinctive shape or texture. Cats can become such creatures of habit that it can be difficult to get them to switch foods if the need arises.

Canned foods have the advantage that any type of feed ingredient can be used (wet or dry). Once opened, canned foods should be refrigerated, because they can spoil. In general, canned foods are the most expensive on a dry matter basis. Because of the high palatability, canned foods are not often used on a free choice basis. Pets often eat food well beyond their needs, and obesity becomes a common problem if intakes are not regulated.

Semi-moist or soft-moist foods are generally packaged in a sealed foil or plastic package. This type of food generally contains about 15% to 35% water. The small pieces of food are coated with a carbohydrate and treated with an acid, which helps to retain moisture and prevent spoilage. Because of the external treatment, this type of food does not require refrigeration. The soft texture and high sugar content of semi-moist food make it a very palatable food source for dogs.

In general, similar ingredients are used in semi-moist and dry foods. Some wetter protein (meat) sources can be used in semi-moist food because of the

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higher water content. The cost of semi-moist food can approach the cost of canned food.

Dry food is most commonly used and is generally the least expensive of the three types of food. For many pets, dry foods are used free choice. The hard food particles also provide an abrasive action on the teeth. This helps to slow the accumulation of tartar on the teeth. Tartar is a hard mineral plaque that builds up on the teeth. Excessive accumulation allows for bacteria to invade the gums and can eventually lead to tooth loss.

Most commonly, the dry foods are packaged in paper bags or cardboard boxes. These foods are very stable, have a long shelf life, and do not require refrigeration. The fat in the food can become oxidized, lowering its nutritional value. It is recommended that the food be used within six months of when it is made. Because this date may not be known, it is ideal to purchase only amounts that can be used within a month or two.

The ingredients are limited in dry food, because the moisture content must be controlled. Because of this limitation, cereal grains are typically used to provide a high percentage of the carbohydrate supply. Dry foods typically have 10% to 14% moisture. This limits the amount of fat and fresh meat that can be used in manufacturing dry food. With the type of ingredients needed, dry food tends to be the least palatable and least digestible of the three food types.

The government establishes rules for the labeling of pet foods (Figure 13–4). Obviously, the label needs to list the name of the product, the words *dog food* or *cat food*, and the net weight. In addition, the name and address of the manufacturer or distributor must be identified. The label must also include a description of the designed usage or purpose of the food. This may describe various life stages, such as puppy, adult, inactive and overweight, or senior. Many foods may also be labeled to be "complete and balanced for all life stages."

The Association of American Feed Control Officials (AAFCO) is an organization that helps to monitor pet foods and establish national standards. Two methods are available to meet these standards. The simplest and most inexpensive method is based on calculations. In this method, the food can be evaluated in the laboratory to arrive at the nutrient content. This analysis is then compared to the nutrient requirement of a pet at a given life stage. The drawback of this method is that palatability and bioavailability of the food are not evaluated. The second method to evaluate the suitability of a pet food is to do feeding trials. This method is more time consuming and expensive to perform, but is considered to be more reliable. The feed trial must follow guidelines established by AAFCO. A statement may be placed on the pet food label stating that feeding trials were performed to evaluate the food. This provides the consumer the ability to compare how foods were

FIGURE 13–4 An example of a pet food label.

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evaluated. Even food trials have certain limitations; they are performed under specific conditions and have a specific trial length. Results may differ if the animal is held under other conditions or when fed this diet for extended periods of time.

Also on the label is the guaranteed analysis of the pet food. The guaranteed analysis does not define the absolute quantity of nutrients, but rather certain minimums and maximums. The label lists the minimum for crude protein and fat. The actual amount may be higher than that listed on the label. Maximum values are listed for moisture and crude fiber. For these nutrients, the actual content may be less than that listed on the label. The minimum and maximum values assure the consumer of a certain quality of the food. The manufacturer can, for example, formulate the food with a higher level of protein. If the quality of the ingredients used in the food declines, the manufacturer is still safe in producing an acceptable product. If the moisture level is over 14% it too must be included on the label.

The label must also include the ingredients, listed in descending order. This can be somewhat confusing, however. Consumers may choose a pet food because it lists meat sources as the first ingredient, but the ingredients are listed based on weight. Although meat products may be listed as the first ingredient, this source may contain much higher water content than the second ingredient, which might be a grain source. Multiple forms of a similar ingredient may also be listed (such as corn grain, flaked corn, corn byproduct, ground corn, and so on). Again this gives the appearance that the grain source is lower in the list. Furthermore, meat by-products may vary significantly in their nutritional content, based on the sources are used.

Many terms are used on the packaging and in the ingredient list. Some terms are legally defined while others are used as a promotion. The complete list of terminology is quite long. A sample of common terms follows.

1. Meat by-products and poultry by-products: These are high-protein sources derived from meat scraps, blood, bone, and other organs such as the heart and liver. This term is often characterized in a negative light in pet food commercials. It is important to recognize that in the wild, carnivores often eat the organs before eating the meat (i.e., skeletal muscle). AAFCO clarifies the use of the term by-products, which does not include feather, hooves, horns, or the intestinal contents.
2. Natural: This term refers to products derived solely from plants, animals, and mineral without being chemically synthesized. These foods may contain synthetic vitamins and often have an added antioxidant to stabilize the fat in the product.
3. Organic: The U.S. Department of Agriculture (USDA) has clear rules defining the production of organic animals and plants. There are specific restrictions on the use of pesticides, herbicides, and antibiotics. More than 95% of the ingredients must be from organic sources to qualify.
4. Premium: Although this term implies a higher level of quality it is not legally defined. Therefore, the term *premium* cannot be used to compare products from different companies.
5. Soybean meal: This is a highly digestible protein source obtained from processed soybeans. Much of the starch and oil is removed in the process, resulting in the high protein concentration.
6. TBHQ (tertiary butyl hydroquinone): This is an antioxidant used to prevent rancidity in the fat.
7. Tocopherols: Chemical terms are often alarming to consumers, but in this instance tocopherols are a natural vitamin E source and function as an antioxidant to prevent fat from becoming rancid.
8. Veterinarian approved: This is another term that is not legally defined.
9. Whole grain: As the term implies a whole grain source includes the entire grain. It is typically processed in some manner, such as grinding. Whole grains provide a significant source of starch but also contain protein, fat, vitamins, and fiber.

In 2007, many pets were sickened by the addition of melamine and cyanuric acid in commercial pet foods. These products were added to artificially raise the protein level in some processed feeds purchased for use in dog food. It took time to isolate the source of the problem and many foods had to be recalled. This had a major impact on pet owners' confidence and trust in commercial pet foods. In response, some people chose to make their own pet's food, ensuring that they know the contents.

A raw food diet is one method of self-preparation. Supporters suggest this is a more natural way to feed pets and also raise concerns that cooking in the preparation of commercial foods decreases the digestibility and destroys important nutrients. It is true that overcooking may decrease the availability of protein but for some plant ingredients the digestibility is actually increased by proper cooking. Additionally, infectious agents (e.g., *Salmonella* and *Escherichia coli*) can be present in raw meats. This contamination has potential risks for both the pet and the owner handling the meat.

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Veterinarians are commonly asked, “How much should I be feeding my pet?” This is a very difficult question to answer completely and directly. The labels on pet foods give an estimate of how much to feed. However, this recommendation needs to be adapted to the individual pet. Variations in the energy requirement of an individual have already been discussed.

The goal of the diet is to provide enough food to maintain an ideal body weight and body condition. *Body condition* is a term that describes the outer appearance of an animal. Body weight is very helpful, but it is important to realize that muscle tissue is more dense than fat. Two animals with the same body weight could have quite different appearances and body composition. Body condition is used in many species to judge the amount of fat on the animal.

In pets, a simple evaluation of body condition is to feel the flesh over the ribs. It should take only gentle pressure to feel the individual ribs. If firm pressure is required to feel the ribs, the animal is becoming too fat. There should be enough flesh over the rib cage that the ribs are not visible. The animal is too thin if the ribs are visible. (It is important to realize that long hair can mask this sign.) Pets should also have a waistline (Figure 13–5). That is, the abdomen should be smaller than the ribs. When the abdomen protrudes beyond the ribs, the animal is becoming too heavy. The dog in Figure 13–6 illustrates a body condition score of 1. This dog has basically no body fat and had been neglected.

Although cats and dogs share a very similar digestive system, they do have distinct differences in their nutritional demands and habits. Several generalizations can be made; however, many exceptions exist. Dogs do not require a change in foods to provide variety. This may actually create a finicky eater. Often the dog can train the owner! When the dog learns to expect feed changes often, it eats poorly for a few days and the owner responds with a new food. It is better to maintain the dog on a consistent diet. If changes do need to be made, it is best to gradually make the transition to the new diet over several days to prevent upsetting the digestive system.

Cats can become very fixed on a particular food type. It is best to provide a diet with multiple protein sources, which makes transitioning to a new diet easier if the need arises. Cats can also be made into finicky eaters by frequent feed changes. Cats often eat small amounts frequently, unlike many dogs that eat large meals. Typically, cats even prefer to eat alone and tend to be erratic in their appetite. One day they may eat a large amount and eat very little the following day.

More important than the behavior involved, cats and dogs have distinct nutritional differences. Cats are true carnivores (meat eaters), whereas dogs fit more

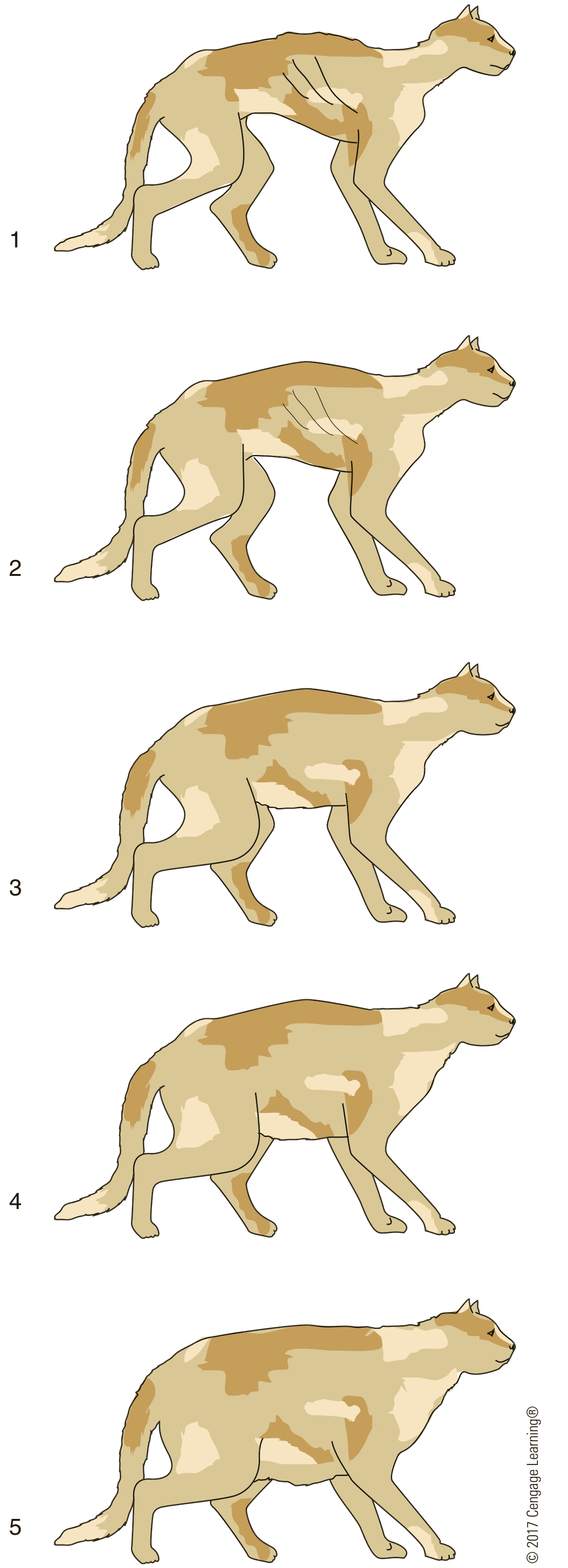

FIGURE 13–5 Evaluating body condition in cats on a scale of 1 to 5. The illustrations show cats ranging from emaciated (1) to obese (5). Number 3 is ideal. This cat will still have a visible waistline, and the ribs can easily be felt but not seen. Long hair can make visual evaluation difficult.

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FIGURE 13–6 A dog with a body condition score of 1. This dog was being neglected and was rescued. Fortunately, the dog recovered very well.

into the omnivore (eating both meat and plant) category. Dog foods are not designed to be nutritionally sound for cats. Cats have a higher demand for protein and require much higher levels of the amino acids arginine and taurine than the dog. Cats cannot convert linoleic acid to arachidonic acid like the dog. Arachidonic acid and taurine are found only in animal tissues and therefore must be included in the cat's diet. Cats cannot survive on a complete vegetarian diet without appropriate supplementation.

Dogs can produce the B vitamin niacin from the amino acid tryptophan and can produce vitamin A from beta-carotene. Cats are unable to make either of these conversions. As a result, the cat's requirements for niacin and vitamin A are much higher than those of the dog.

To ensure proper nutrition for a dog or cat, it is essential to feed a good quality food designed for that animal in that stage of life and activity level. Cat and dog foods are not interchangeable. The volume of food to provide is the amount necessary to keep an animal in good body condition and at ideal body weight and maintain its health. Supplements are generally not needed for healthy animals on a balanced diet.

EQUINE NUTRITION AND FIBER DIGESTION

Objective

- Discuss the Horse's Ability to Digest Fiber and Its Role in Equine Nutrition

The discussion in Chapter 7 has already illustrated the horse's ability to digest fiber. This section reviews the basic structures of the horse's digestive tract and discusses in greater depth the considerations involved in equine nutrition.

Many of the principles basic to the nutrition of dogs and cats also fit in the feeding of horses or any species. The main goal of a nutritional program is to maintain the ideal body weight and condition while maximizing performance. There is a tremendous variation in the demands placed on horses. It is easy to see that a backyard pleasure horse ridden infrequently requires much less energy than a Thoroughbred training for a major race. Likewise, a massive Percheron draft horse plowing all day has a much higher nutritional requirement than a pony giving rides at a party. The nutritional requirements are also influenced by the health, age, condition, and temperament of the horse. Factors such as growth, pregnancy (especially in the last three months), and lactation increase a horse's energy demands. The environment also influences the demands on the animal. A horse kept outside on a wet cold day burns much more energy maintaining its body temperature than a similar sized animal kept in a warm barn.

It is useful to consider a horse in the wild to understand the design of the equine digestive system. Wild horses spend the majority of their day (up to 18 hours) **grazing** (Figure 13–7). The grazing provides a regular input of small meals, delivering new nutrients into the intestinal tract throughout the day. These horses live almost entirely off the leafy portion of grasses or roughages. Horses in the wild have minimal


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FIGURE 13–7 Horses grazing on pasture in early spring.

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grain in their diets. Over the course of a year, the diet does change significantly in quality. One acre of well-managed pasture may support one horse. With drought conditions, it may take three or more acres to adequately support one horse. Typically, horses gain weight, depositing reserves of fat in the spring and early summer. As the seasons progress and the plants mature, the nutritional quality declines. With limited feed availability horses lose much of their fat over the winter. Wild horses' diets must support them in maintenance and provide adequate nutrients to support reproduction.

Our domestic horses do not share many of these challenges. In general, a domestic horse has a consistent diet throughout the year and is often protected from the harsh weather. Many horses have increased nutritional demands due to the work that they are required to do. To compensate for these needs, grain, or **concentrates**, have been added to their diets. Grain feeds have been called concentrates because the nutrients are present in higher concentration in these feeds compared with roughages. Grazing plays a much smaller role in domestic horses than in those in the wild. The diet is controlled by the owner and often comes in larger meals fewer times a day.

An inactive horse or one performing only light work (e.g., the occasional pleasure ride) needs little to no concentrate. As the workload increases, the need for concentrates in the diet also increases. Concentrates are divided into two categories: energy or protein sources. These types can overlap; a high-protein feed may also be high in energy. Grains such as oats, wheat, corn, and barley are all considered energy concentrates, high in carbohydrates. Seeds such as flax, cottonseed, and soybeans are high-protein sources. Often these seeds are processed to remove much of the oil, creating a meal (e.g., soybean meal, cottonseed meal, and linseed meal from flax). Often several ingredients are combined in one concentrate to increase the energy and protein. Molasses, a rich energy source high in sugar, is often added to increase palatability and decrease the dust.

Roughages or forages, such as hay, should comprise at least half the diet for horses. As discussed, horses are designed to digest the fiber found in plant material. Adequate levels of roughage in the diet help to maintain a healthy digestive system. The fiber also causes the full feeling that limits the appetite of the horse. Eating forages is more time consuming than eating grain. This can help to occupy the horse's time, which may be important for confined animals.

On average, feed entering a horse takes about 70 hours to completely pass through the digestive tract. The stomach of an average adult horse is relatively small, able to hold only 2 to 4 gallons. This reflects the natural diet of horses, in which small amounts are taken frequently throughout the day. Grain feeding needs to be limited to less than 3 to 4 pounds at a feeding because of this small stomach size. Feeding larger amounts can force grain into the intestine too early, disrupting the normal fermentation. Colic is just one side effect of excessive grain intake.

Much of the concentrate portion of the diet and a small portion of the roughage are digested and absorbed in the stomach and small intestine. The small intestine averages 60 to 80 feet in length and can hold approximately 10 to 15 gallons. Much of the protein and carbohydrate not bound in fiber is digested and absorbed in this region.

The fiber remaining then passes into the large intestine. This is the site of fiber fermentation. *Fermentation* describes the digestion of the fiber by the large number of bacteria housed in the large intestine. More than 40 species of bacteria have been identified in the gut of the horse. This normal flora (the collection of microorganisms naturally found in an area) varies with the type of diet being fed. A sudden feed change can kill millions of bacteria. It is important to change a diet slowly over the course of a week or 10 days to allow the necessary bacteria to increase.

The first portion of the large intestine is the large blind sac, the cecum. The cecum averages 3 to 4 feet in length and can hold about 6 to 8 gallons of material. The material then flows into the colon, which further allows for fermentation and water absorption. The colon is about 10 to 12 feet in length and can hold up to 25 gallons.

The bacteria are able to break down the beta bonds in the plant fiber. The bacteria utilize the simple sugars and then release volatile fatty acids (VFAs), which are absorbed by the horse. The bacteria gain nutrients from the fermentation process, allowing them to flourish. The horse provides a warm, liquid environment for the bacteria and supplies them with nutrients. In exchange, the bacteria provide nutrients for the horse. This beneficial relationship is called symbiosis.

The VFAs are short-chain fatty acids. The three most common VFAs are acetic, butyric, and propionic acids. These VFAs are absorbed in the cecum and colon. The horse then utilizes them as an energy source. The intestinal bacteria also produce many B vitamins and vitamin C, which are subsequently absorbed by the horse. As the bacteria continue to reproduce, many are passed to the external environment in the feces. It is not clear if the horse is able to utilize any of the bacterial protein created in the large intestine.

Acetic acid	$C_2H_4O_2$
Propionic acid	$C_3H_6O_2$
Butyric acid	$C_4H_8O_2$

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Many common principles exist in feeding horses, just as in dogs and cats. The first is that the ration needs to be adapted to the needs of the horse. This adjustment includes the influence of the size of the horse and the work done. The diet should provide nutrients to optimize the output of the horse but should not result in overconditioning. An overweight horse usually has decreased performance in whatever type of work it performs. The added fat has an insulating effect that creates an increase in body temperature during exercise. The added body size also increases the oxygen and circulatory demands on the heart and lungs. In addition, the excess weight puts more stress on the musculoskeletal system. This can be important as a horse runs and jumps.

Horses are very sensitive to the quality of feed. Moldy feed can contribute to respiratory problems and colic. Concentrates should only be fed based on the horse's need and, equally important, should be fed in small meals. With the small size of the stomach, no more than 3 to 4 pounds should be fed at any one time. At most, concentrates should contribute 50% or less to the total diet. Horses are creatures of habit, and maintaining a consistent feeding schedule can be beneficial.

A horse that becomes too heavy may have problems, but a loss of weight is also of concern. A horse that is extremely excitable may always stay thin. A common problem as a horse ages is that the margins of the molars become very sharp. With the motion of chewing, the teeth wear in such a way that a sharp edge forms. This can cut the cheek or tongue and cause the horse discomfort. When this condition progresses, the horse may drop whole grain out of its mouth as it chews. This problem can be corrected by having the horse's teeth **floated**. In this procedure, a special rasp is used to file down the sharp edges of the teeth (Figure 13–8).

Intestinal parasites are also a common problem in horses. Any grazing animal has a high risk of intestinal parasites. These parasites pass eggs in the feces, which then contaminate the ground and plants. When animals graze, these eggs are ingested and new parasites develop in the intestinal tract. Regular treatment with medications to kill these parasites is very important.

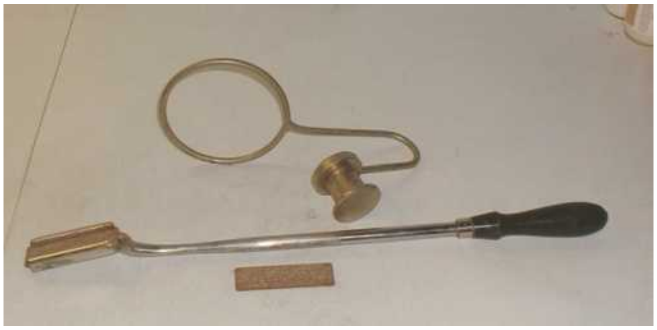

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FIGURE 13–8 A tooth float used to file the teeth of horses. A gag is used to hold the mouth open for the procedure.

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FIGURE 13–9 A horse cribbing. Note the destruction of the board fence.

Any animal losing weight should have its diet evaluated. This is just as true in horses. It is possible that inadequate concentrate is being supplied for the level of work. Another possibility is that the **forage** is of poor quality. As the pasture or hay matures, the feed quality declines. Much of the fiber can become indigestible if the plant is too old.

Horses, especially those confined for long portions of the day, can develop bad habits. **Cribbing**, or wood chewing, is one of those habits (Figure 13–9). The horse stands and chews on the wooden stall for long periods. Another problem occurs when horses eat their own feces. Both habits can be difficult to break. However, some basic principles can be useful in controlling the behaviors. First, it is essential to ensure that the horse is fed a well-balanced diet, with good-quality feed and adequate fiber. Having long-stemmed hay to eat can provide the horse with activity to occupy its time. Maintaining a regular feeding schedule is also helpful. Providing regular exercise can prevent boredom in the horse.

Some horses **bolt** their concentrate; that is, they eat extremely rapidly, with very little chewing. This increases the risk of choking and colic in these horses. Feeding on regular schedules and having adequate fiber in the diet can help keep the horse from becoming extremely hungry at grain-feeding times. In addition, preventing competition among horses is also helpful in avoiding the problem. If the bolting continues, a large,

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smooth stone can be placed in the feed bucket, so that the horse has to eat around it, slowing the ability to consume the grain.

RUMINANT NUTRITION AND FIBER DIGESTION

Objective

- Detail the Ruminant's Ability to Digest Fiber and Its Role in Ruminant Nutrition

Cattle, sheep, and goats are all ruminants. In this section, the cow is used as an example to show the considerations involved in feeding a ruminant. As already discussed in Chapter 7, a ruminant has a large four-compartment stomach containing the rumen, reticulum, omasum, and abomasum. The abomasum is called the true stomach because it functions like that of a monogastric. The large rumen serves as a fermentation vat. It occupies the majority of the left side of the abdomen in adult cattle. The size of the rumen varies with the size of the animal, but on average it can hold 30 to 40 gallons.

Young ruminants actually function as monogastrics, relying on the mothers' milk for their initial nutrition. Over the next few months of life, the rumen begins to develop until the animals become complete ruminants. Cattle initially eat quickly, swallowing forage in relatively large pieces. Just like the symbiotic relationship in the lower intestinal tract of horses, the rumen houses a large number of bacteria and protozoa that are responsible for digesting fiber.

The cow provides the bacteria with warmth, water, and nutrients. In exchange, the bacteria digest fiber, supporting their own replication, but also release VFAs for the cow to utilize. Cattle have a higher efficiency than horses in digesting fiber. In horses, the bacteria use many of the nutrients and eventually are passed in the feces. By having the rumen before the glandular abomasum, bacteria that pass through the rumen are then digested. The large numbers of bacteria that are digested are a significant source of protein for the cow. In designing rations for cattle, we must consider that we are actually feeding the rumen organisms, which in turn feed the cow.

The rumen and reticulum are active stomachs, frequently contracting. On average, healthy cattle have a rumen contraction between one to three times a minute. These contractions can easily be heard with a stethoscope as a rumbling noise on the left side of the abdomen. Evaluating the motility of the rumen is very important in the physical examination of the cow.

The contractions of the rumen keep the contents stirred. The contents in a healthy rumen divide into three layers. On the very bottom lies a very liquid fraction with the finest particles. Above this is a firmer layer with longer fiber particles (Figure 13–10). Floating to the very top is a gas layer. As much as 8 to 10 gallons of gas can be produced every hour by the rumen organisms. The rumen contractions bring this to the appropriate location to allow it to be eructated or belched. If eructation cannot occur, the cow will bloat (a dramatic distention of the rumen with gas). If not corrected, this condition can become life threatening.

The rumen contractions are also responsible for rumination, in which boluses of food are regurgitated into the mouth. The cow at rest spends time chewing this food again, making much smaller pieces. This is called cud chewing. This process has been discussed in detail in Chapter 7. In addition to making the food particles much smaller for bacteria to utilize, cud chewing stimulates the production of saliva. It is estimated that cattle produce between 40 and 50 gallons of saliva every day. This actually contributes a large portion of the liquid in the rumen. In addition, it helps to buffer the pH of the rumen fluid. Maintaining a consistent pH is very important in protecting the large number of rumen microorganisms.

Ruminants rarely vomit. If the ingesta is completely vomited to the outside, it indicates a problem. On many occasions, goat owners have called our clinic concerned because their goats are vomiting. The classic presentation is that the goats were just introduced to a new section of woodland that the owner wanted cleared. When examined more closely, these sections have rhododendron or mountain laurel. Unfortunately, these plants are toxic to ruminants and usually cause vomiting. This can be fatal if the goat ingests enough of the plant.

For the rumen organisms to grow and divide they must be supplied with carbohydrate and protein. Crude protein is commonly measured in a forage analysis. The total nitrogen level multiplied by 6.25 defines the crude protein. (Feed protein averages 16% nitrogen; dividing the nitrogen content by 0.16 determines the protein. Dividing by 0.16 is the same as multiplying by 6.25.) Not all the nitrogen in the plant is found in protein. Urea contains nitrogen and is included in the nitrogen amounts.

When the feed enters the rumen, a portion of the crude protein, especially the urea, enters the liquid portion very quickly. This soluble protein is rapidly available to support the growth of the rumen microbes. Another fraction of protein also dissolves into the rumen fluid but at a slower rate. On average, 60% to 70% of the crude protein is degraded in the rumen and utilized by the rumen microbes. This rumen

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FIGURE 13–10 A. This cow has had a fistula surgically implanted into her rumen. Fluid from the healthy rumen can be transferred to a sick cow to reestablish the microflora. B. Ingesta from the rumen is removed. C. Fluid is squeezed from the ingesta and collected for use in another cow. D. The fiber mat in the rumen is visible through the fistula.

degradable protein (RDP) includes the soluble protein fraction. The remaining 30% to 40% moves into the abomasum to be digested. This is called rumen bypass or rumen undegradable protein (RUP). The vast number of bacteria and protozoa that pass into the abomasum are also digested as a source of protein. The total amount of protein utilized by the cow from the RUP and the digested rumen microbes is called metabolizable protein. Adequate growth of the rumen microbes requires the soluble protein but also the availability of energy. Providing the proper balance of energy, protein, and rumen conditions maximizes the growth of these organisms.

The carbohydrate portion of plants also divides into fragments. A small portion of simple sugars and starch exists, which also rapidly dissolves in the rumen. This provides the energy supply, which organisms need to utilize the soluble protein. A much larger supply of the carbohydrate is found in fiber. Not all the fiber is digestible by the cow or the microorganisms. Cellulose, hemicellulose, and lignin all comprise the plant's fiber. Lignin is indigestible (not able to be used). The older the plant becomes, the higher the level of lignin.

The rumen microbes are able to digest much of the cellulose and hemicellulose. The organisms utilize the energy from the plant fiber and the protein to support their own growth. These organisms release large quantities of VFAs into the rumen fluid, which are then absorbed by the cow. Very little glucose is absorbed in the intestinal tract of the cow. The majority of the simple sugars are utilized in the rumen. The VFAs are the source of energy for the cow.

Acetic acid, propionic acid, and butyric acid are the three major VFAs utilized in the cow. The liver removes most of the propionic acid and converts it to glucose. Acetic acid is used to create energy and is also used in the synthesis of lipids. Butyric acid is used in many tissues throughout the body for energy.

Cows during their dry periods are fed a maintenance diet. In general, dry cows are not expected to gain much weight, and their workload is relatively

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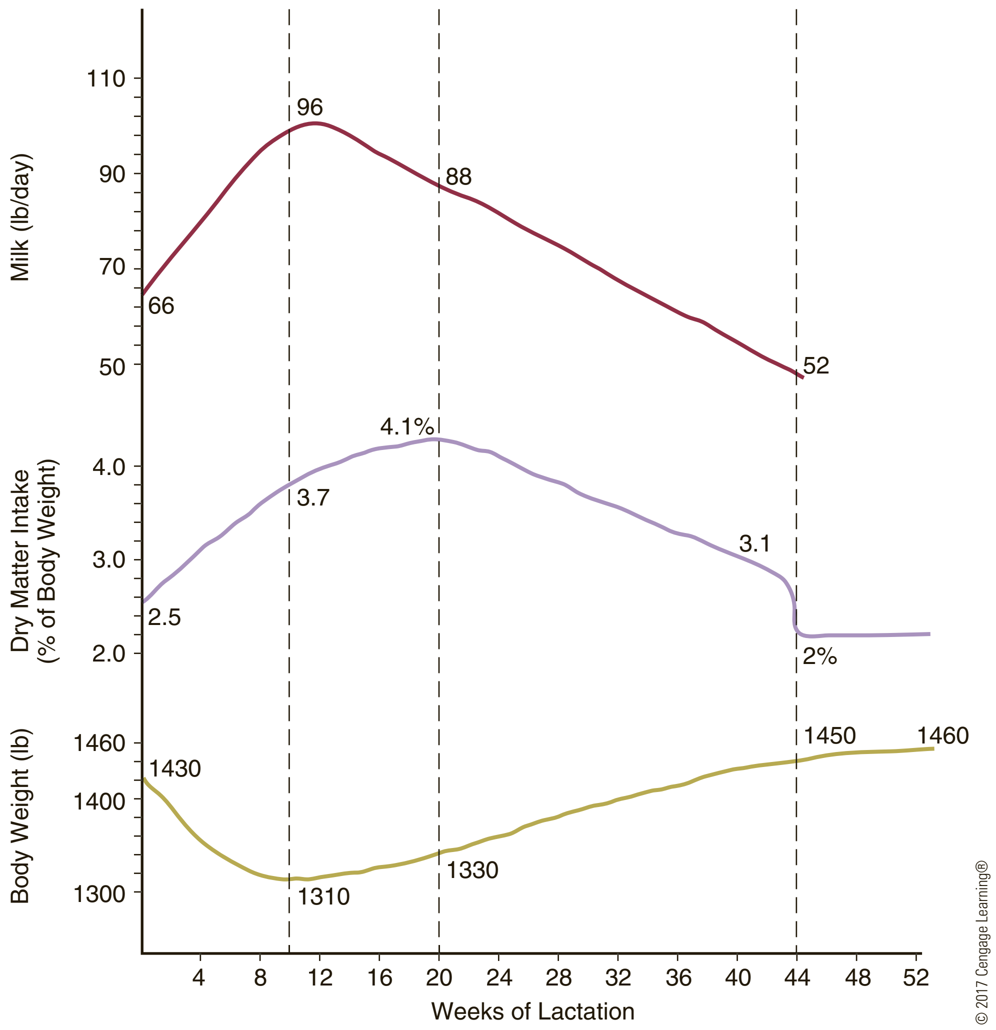

FIGURE 13–11 Graphs illustrating the relationship among dry matter intake, milk production, and body condition over lactation.

low. They need only support themselves and the developing fetus. Following calving, the cows are placed on a diet that is much richer in energy and protein. This diet is designed to supply nutrients to support large amounts of milk production. With time, the rumen develops longer papillae (tiny fingerlike projections) on the lining of the rumen. These papillae are very important in absorption of VFAs.

The formation of these papillae takes several weeks. During that time, the quantity that the cow can eat (dry matter intake [DMI]) gradually increases. Typically, the energy demands for milk production exceed what the cow can consume for the first six to eight weeks. During this time, the cow is in negative energy balance (that is, it is using more energy than it is consuming) and loses weight. Finally, its intake is adequate to meet its needs, and with time, as production declines, the cow is able to gain weight. Figure 13–11 shows graphs describing the relationship among milk production, DMI, and body weight.

A straightforward question might be, "Why not increase the concentrates in the ration to meet the needs?" Feeding excess grain may cause health problems in cattle. The rumen organisms need adequate fiber to survive. The fermentation of the grain creates more VFA production. With less fiber, there is less rumination and less sodium bicarbonate production in the saliva. As a result of increasing grain and decreasing fiber, the pH in the rumen begins to decline. This acidosis can kill millions of microbes. Remember that the organisms are essential to supply energy to the cow and they are a source of protein. Feeding excessive

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FIGURE 13–12 A TMR mixer being loaded with feed.

grain can often make a cow go off feed (have a poor appetite) and actually result in a more negative energy balance.

Even in diets in which normal amounts of grain are fed, feeding too much at one time can cause the same pH changes in the rumen. This is called slug feeding. To prevent this, many farmers feed a **total mixed ration** (TMR). In a TMR, all the feed ingredients are combined in a mixer and blended together (Figure 13–12). The goal of this feeding method is to supply a uniform feed to the cattle throughout the day. With each mouthful, the cow is consuming the proper balance of fiber, protein, and energy.

CLINICAL PRACTICE

Objective

- Link the Clinical Significance of the Academic Material Learned in This Chapter to Veterinary Practice

Obesity is the most common nutritional disorder that veterinarians see in dogs and cats. Certain disease conditions, such as hypothyroidism and hyperadrenocorticism, may contribute to an animal's obesity. However, most cases are associated with an excessive intake of calories relative to the animal's needs. Several factors can contribute to this problem. The animal may be fed too much or fed a diet not designed for its activity level. Many pets confined to a kennel or to the house just do not get enough exercise to utilize all the calories consumed. Most pets will spend a majority of their time resting when there is no interaction with owners. Spaying and neutering also reduce the energy demands of the animal. Additionally, many pets are given too many snacks or treats (both animal treats and table food) that add calories.

Weight regulation in healthy pets requires strong willpower by the owner. Often when treats are taken away or less food is given, the pet begs for food. The owners need to recognize that they are trying to help the dog. Increasing the pet's activity level also requires a significant time commitment by the owner.

Obesity may contribute to or worsen other diseases. A common presentation is an overweight dog that is having difficulty rising or getting around. Many elderly pets develop arthritis, and adding extra weight increases the stress on the joints. As muscles weaken and the arthritis worsens, the extra weight can become quite crippling.

The added weight also puts more stress on the circulatory and respiratory systems. The extra fat puts a higher demand on cardiac output and oxygen usage. This can worsen an existing problem, such as heart failure. These problems also make obese pets more of an anesthesia risk if surgery is required. Obesity may also have a relationship to controlling diabetes. Diabetes is much more readily regulated when weight is brought under control. Recent studies have shown a decreased life span in overweight animals.

As a veterinarian, it is common to hear about the increased variety of food items that pets are fed. Many owners are quite proud when they can say that their pets will eat anything. Unfortunately, many items that humans consume regularly can be toxic to small pets. Chocolate is one such food. Pets often find chocolate very tasty and will consume large quantities if given the opportunities. Chocolate contains theobromine and caffeine, both of which can be toxic when consumed in high levels. These toxic components have effects on the cardiovascular and central nervous systems. Signs of toxicity often begin with increased thirst and urine production, vomiting, diarrhea, and urinary incontinence. If the dosage is high enough, the signs progress to excitability, muscle twitching, seizures, and coma. Chocolate toxicity can be fatal.

The amount of theobromine and caffeine varies among types of chocolate. As a result, the type and amount of chocolate consumed impacts the likelihood of having a toxic reaction. Table 13–1 lists the theobromine and caffeine levels in several common products. Often clinical signs will begin with ingestion at levels of 20 mg/kg of body weight and usually becomes life threatening at 60 mg/kg of body weight.

Cats happen to be very sensitive to a toxin in onions. If consumed in high enough quantities, the onions cause a defect in the red blood cells. The red blood cells break down in the bloodstream, producing hemolytic anemia. These animals develop darkened urine from the free hemoglobin along with a fever. The combination of anemia and damage to the kidneys can result in death if sufficient amounts are eaten.

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Table 13–1 Chocolate

Type of Chocolate	Theobromine (mg/oz)	Caffeine (mg/oz)
Unsweetened cocoa powder	737	70
Baker's chocolate	393	35–47
Chocolate chips	140–240	22
Instant cocoa	135	15–20
Milk chocolate	44–58	22
Oreo cookies	2.4	0.85

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The role of fiber in the nutrition of both horses and ruminants has been emphasized. It is possible to overfeed concentrates and cause digestive disorders. But animals can accidentally gain access to grain and eat extreme amounts in a short period. The result is grain overload. In the horse, grain overload results in a dramatic decline in the pH within the colon. Many of the natural organisms die and are replaced by other bacteria that can survive in those conditions. The death of such a large number of bacteria releases toxins that are absorbed into the bloodstream. In moderate levels, the result is typically diarrhea and anorexia.

In more severe cases, the toxins can have a damaging effect on the blood supply to the hooves. The third phalange (P3) is suspended within the hoof by a tissue rich in blood supply, called laminae. The laminae become inflamed, resulting in a disease called laminitis. With laminitis the horse has a great deal of pain with each step and develops swelling at the top of the hoof. The gait of these horses is often described as "walking on eggshells." An interesting side note is that horses bedded with black walnut shavings may also develop laminitis. The walnut shavings have a toxin that can cause laminitis.

Horses with mild laminitis improve with rest and medications to reduce the inflammation. More severe cases can result in permanent lameness. The disease can be so severe that the point of P3 rotates downward. The laminae are so inflamed that they are unable to suspend the bone. It is possible that the entire hoof can become detached. Many of these horses do not recover.

Nutrition is often used in combination with treatment or as a follow-up to treatment in many diseases. Bladder stones and urinary blockage in cats were discussed in Chapter 6. Diet can play a significant role in preventing recurrences of these diseases. The diet change must be adapted to the specific cause. Many different types of bladder stones may develop. Some are more likely to occur in low pH, whereas others occur in high pH. Each has specific mineral composition. Diets can be adapted to control both the pH and the mineral content of the urine. This modification must be carefully balanced to prevent deficiency and yet restricted enough to minimize crystal formation. Initially these types of diets were sold only by prescription through veterinarians. Now many foods are available over the counter to help control such problems. Many diets are now labeled with the claim of promoting urinary health in cats.

Other diseases that can benefit from attention to nutrition include kidney and heart failure. In kidney failure, nitrogen-containing waste from protein metabolism builds up in the blood. Diets used to control kidney failure contain a very high-quality protein source in limited amounts. Other minerals, such as phosphorus, are also restricted to help limit the accumulation in the blood. In heart failure, the diets often restrict the amount of sodium, which helps prevent excessive blood volume from accumulating.

Earlier it was mentioned that high-producing dairy cattle often have a negative energy balance early in lactation. In response, the cow mobilizes body fat in an attempt to meet the energy demands. Molecules of triacylglycerols are broken down into the component glycerol and three nonesterified fatty acids (NEFAs). NEFAs can be used by the mammary gland to produce milk fat. The liver absorbs much of the NEFAs to capture the energy available in these molecules.

To complete the process of oxidizing NEFAs, the liver needs glucose. Cattle absorb very little glucose directly from the intestinal tract (unlike monogastrics). As a result, cattle must create glucose from VFAs and amino acids (a process called gluconeogenisis). When glucose is in a limited supply, the NEFAs are incompletely oxidized, creating ketones or ketone bodies. As levels increase in the bloodstream, the cow will have a depressed appetite and suppressed milk production. This clinical condition is called ketosis.

Ketones are eliminated by the kidney in the urine and exhaled through the lungs. This excretion produces a "sweet" smell to the breath and urine. (Students may be familiar with the smell of the ketone acetone, found in many fingernail polish removers.) Quick dipstick tests are available to test the urine for those people who are not sensitive to the smell. Treatment of ketosis revolves around providing the cow with glucose or glucose precursors. This allows the cow to completely metabolize the ketones.

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SUMMARY

A review of Chapter 12 will provide information about the six nutrients and their effects on the body. This chapter discussed how to interpret pet labels and differentiate between the nutritional needs of cats and dogs. Also covered were a horse's ability to digest large amounts of fiber and how horses and ruminants differ in the digestion of fiber. Understanding differences in species' digestive tracts gives veterinarians the ability to successfully develop species-specific rations.

REVIEW QUESTIONS

1. Define the following terms:

   free choice diet
   resting energy rate
   maintenance energy requirement
   grazing
   concentrates
   float
   forage
   cribbing
   bolt
   total mixed ration
2. True or False: To develop a diet, a veterinarian first considers the needs of a resting animal in a comfortable environment.
3. True or False: The adult rumen in cattle can hold 40 gallons.
4. The maintenance energy requirement is typically ___ times that of resting energy requirement for an animal.
5. Filing the sharp edges of a horse's teeth is called ___.
6. Does a lactating animal have more or less nutritional needs than when not lactating?
7. Which feeding system can help quiet confined dogs?
8. What type of food do dogs typically prefer?
9. In general, what is the water content of semi-moist pet food?
10. Do horses prefer to graze throughout the day or eat one large meal daily?
11. Where are simple sugars utilized in the cow?
12. Are cats carnivores or omnivores?
13. Where does fiber fermentation occur in the horse's digestive tract?
14. How are ingredients listed on a pet food label?
15. List the three types of feed available for dogs and cats.

ACTIVITIES

Materials needed to complete activities:

samples of canned, moist, and dry pet food
  accompanied by their respective labels
a variety of pet food labels
labels from dog and cat foods

1. Research the Association of American Feed Control Officials (AAFCO). Report on the scope of their oversight.
2. Compute your resting energy rate by multiplying your body weight times 10 (keep in mind that variations will exist, but this simple equation will give a ballpark figure). Example: $155 \times 10 = 1550$ calories. The resulting number gives your RER. List activities that would increase your energy needs. Expected answers could be sports or physical labor. If you have an animal, explain how much feed you provide to the animal and why you chose that amount.
3. Based on the display of pet food samples, guess the percentage of water in each. Suggest an ingredient list for each. Pick a favorite from a pet's perspective.
4. Ms. Goodchef calls your office Saturday evening at 6 PM to tell you that her French poodle, Pierre, just ate 2 oz of chocolate chips that had gotten knocked off the counter. She tells you that Pierre weighs 11 pounds. Ms. Goodchef is very busy preparing a banquet and wonders if she needs to worry. You tell her that you will need to do some calculations and will call her right back.

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a. What is Pierre's weight in kilograms?

b. Using Table 13–1, how much theobromine did Pierre ingest if he ate 2 oz of chocolate chips?

c. How much theobromine would he have to ingest for you to start treatment (using the 20 mg/kg level)?

d. How much theobromine would he have to ingest for you to be concerned that he could have life-threatening problems (using the 60 mg/kg level)?

e. What will you tell Ms. Goodchef when you call her back?

1. You tell her that you hope her meal turns out well and she should check with your office on Monday morning to set up an appointment; or

2. You tell her that you are very concerned about the levels of theobromine that Pierre has ingested and that she should come immediately to your office.

4. Compare and contrast the ingredients found on the dog and cat food labels. Refer to the chapter content to identify the differences.

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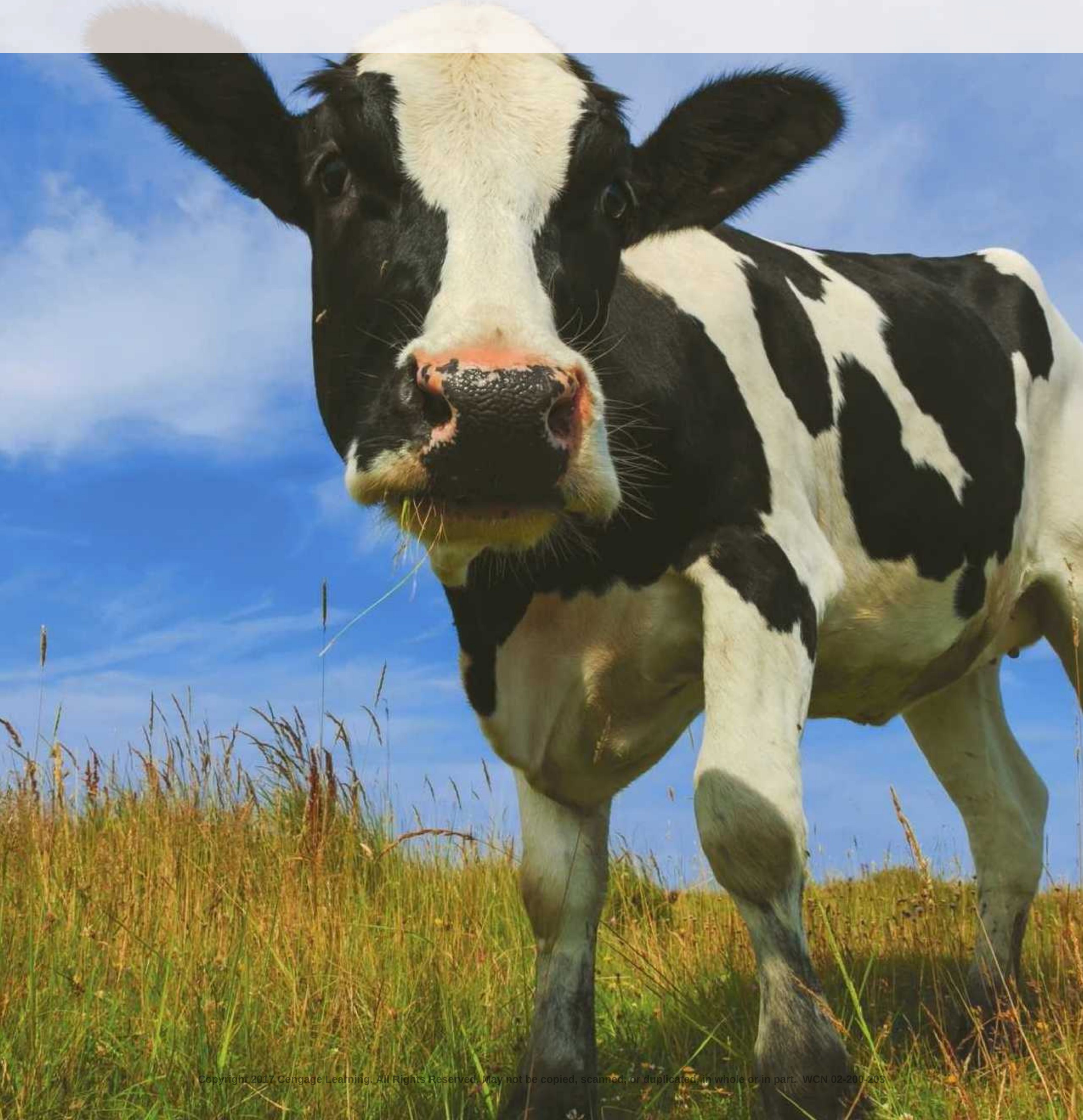
Unit III

Diseases



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CHAPTER 14

Principles of Infectious Disease

Objectives

Upon completion of this chapter, you should be able to:

- Describe Koch's postulates.
- List the important distinguishing features and give examples of major disease agents, and discuss the resulting diseases.
- Relate the academic material learned in this chapter to common presentations.

Key Terms

coliform	fomite	prodromal phase	antimicrobial
botulism	vector	anemia	bacteriostatic
anthrax	eukaryotic	systemic	antiseptics
Koch's postulates	prokaryotic	Lyme disease	disinfectants

Introduction

A disease is a change that occurs in the body and prevents normal function. Some diseases occur as a result of other organisms' invasions. Numerous organisms (e.g., intestinal bacteria) are necessary to keep our bodies functioning normally. Only a small percentage of microorganisms are capable of causing disease.

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A Day in the Life
Sometimes I Worry . . .

While writing, I often come across cases that relate to the text subject matter. Then these cases interfere with my writing progress. Last night one of those situations occurred. I was on call for large animal emergencies, so it was not surprising when the phone rang at 8:30 PM. A young farmer reported that he had a cow down and she was unable to rise. This was not a classic milk fever case, because the cow had calved two months earlier.

I went to the farm and found the down cow to be obviously quite ill. Her eyes appeared sunken, and she had severe diarrhea. I began my physical examination and found that she was running a fever. While checking her milk, I discovered the source of the problem: mastitis. Mastitis is an infection of the udder that causes abnormal milk to be produced. The milk from infected quarters contains a very high number of white blood cells that have migrated into the milk from the blood stream.

This cow had a yellowish, watery secretion from the infected quarters (Figure 14–1). This type of secretion is classic for **coliform** mastitis. The word *coliform* describes a related group of bacteria that cause this specific type of mastitis. Fortunately, the cow responded well to treatment and soon was able to rise. Many cows that reach this degree of severity with coliform mastitis do not respond as positively.

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FIGURE 14–1 Normal white milk is shown in the left tube. Abnormal secretion from a cow with coliform mastitis is shown on the right.

Although it happened many years ago while in veterinary school, I vividly remember a demonstration. A horse was presented for weakness. The veterinarian on the case set a bucket of water in front of the horse. The horse immediately placed its muzzle in the water and apparently began to drink. After several minutes the horse raised its head, and the water level had not changed. The students observing the case were all surprised. It appeared that the horse was trying to drink but was not able. Next the clinician held the horse's head and pulled gently on the tongue. The horse did not resist. Normally, a horse has such strong muscle tone in its tongue that it is difficult to hold. These two tests confirmed the diagnosis that this horse was showing the earliest signs of **botulism**.

It is not unusual for our clinic to get calls from cat owners reporting that their pets have developed swellings. When examined, these cats are usually also feverish. The swellings often occur around the base of the tail or on the head and neck. These swellings typically happen after a cat fight. After clipping the cat's hair, I usually find a small puncture or punctures in the skin caused by the bite or scratch from another animal. These punctures have begun to heal, sealing the opening. Unfortunately, the teeth or claws introduce bacteria under the skin. The bacteria then multiply inside the warmth of the cat. As the body's immune system fights the infection, pus accumulates under the skin. These lumps can break and drain before the cat is presented.

Graduation is a wonderful time for students. It is a relief that all the formal schooling is finally completed. But in the real world, the education continues throughout a career. In 2013, the news came that porcine epidemic diarrhea (PED) had been discovered in the United States. I did not remember learning about PED in vet school and had to do my homework to learn more about this disease.

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KOCH'S POSTULATES

Objective

- Describe Koch's Postulates

In the fall of 2001, current events brought the disease **anthrax** to the forefront. Spores of anthrax were being mailed as a form of bioterrorism. There was fear that large outbreaks of anthrax could develop. Frequent news reports taught us of the skin, intestinal, and inhaled forms of this disease. Nearly 125 years earlier, Dr. Robert Koch, a German physician, was investigating the same disease. At that point, the medical profession was attempting to discover why certain diseases were occurring.

Koch's investigation led to the development of foundational principles about infectious diseases. Koch studied anthrax in cattle in an attempt to prove that an agent was responsible for the disease. This research occurred before bacteria and associated disease conditions were clearly understood. Koch knew that blood taken from an infected cow would cause the same disease in another cow. He was able to isolate the causative bacterium (*Bacillus anthracis*) from the blood.

His work led to the formation of a set of principles that helps to define an infectious disease. These principles have come to be known as **Koch's postulates**. To prove the cause of a disease, he postulated the following requirements:

1. The infectious agent should be detectable in sick animals but not healthy animals.
2. It should be possible to isolate and culture the organism.
3. Organisms taken from the culture and introduced into a healthy animal should cause the same disease.
4. The same organism should be isolated from this second animal as well.

Koch's theory helped to establish germ theory. Physicians finally recognized that infectious agents caused many diseases. To this day, Koch's postulates are helpful in understanding infectious diseases. The basic principles still hold true, although not every disease is so clearly defined. For example, an infectious agent may be isolated from a healthy animal. In other situations, more than one infectious agent can be involved in causing an illness. In certain diseases, the symptoms are caused by a toxin released by the organism. By the time the animal is showing clinical signs the organism may no longer be present.

Infectious diseases are caused by microorganisms that gain entry into the animal's body. Some infectious diseases are also contagious. This means that a healthy animal exposed to a clinically infected animal may also develop the disease. The organism is transmitted from one animal to the next. It is important to realize that not all infectious diseases are contagious. In Chapter 11, tetanus was discussed. This is an infectious disease. The animal picks up the organism from the environment. However, other animals in contact with the infected animal are not at risk of becoming infected from the exposure.

Tetanus is an example of a disease in which the organism is introduced into the body through a wound. For many other diseases, organisms come into contact with a mucous membrane. This can be in the nose, mouth, or eyes, or the respiratory, gastrointestinal, or urinary tracts. The organism must first adhere to the surface of the mucous membrane and then begin to replicate.

The animals may become exposed to organisms from several sources. In contagious diseases, the animal may become sick following exposure to another clinically ill animal. Some animals, following recovery from infectious disease, continue to shed organisms. These carriers may be a source of infection for others.

Although contact with infected animals may be direct, some infectious diseases can be spread through the air. Sneezing and coughing can make the infectious organisms airborne, and other animals subsequently inhale them. The organisms can often be found in high numbers in the secretions of the animal (e.g., nasal discharge, saliva, tears, urine, and feces). These discharges can contaminate inanimate objects, or **fomites**. These fomites can then be a source of infection for other animals. Shared water bowls or feeding utensils are common examples of how this type of contamination may occur. Different organisms can survive for variable periods outside the animal. Survival time is influenced by the outside temperature and the availability of moisture. Extremes of temperature and dryness generally shorten the ability of an organism to survive.

Arthropods such as insects, mites, ticks, and mosquitoes may also play a role in transmitting disease (Figure 14–2). These arthropods are then called

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FIGURE 14–2 A cow suffering from pinkeye. Pinkeye is an infectious disease that is commonly spread between animals by flies.

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vectors. Some diseases actually require the arthropod to be involved. In these diseases, the arthropod serves as a host necessary for the development of the infectious agent. For example, in heartworm disease, the parasite (*Dirofilaria immitis*) undergoes a stage of development in the mosquito before it can be contagious to another dog. In other cases, the arthropod is merely contaminated and serves as a vector to carry the organism to other animals. This is also the case with pinkeye, in which flies feeding on the face of a cow become contaminated with bacteria (*Moraxella bovis*) that are then transferred to the next animal.

Some organisms are commonly found in the soil and require some means of being introduced into the body (again tetanus serves as an example). Food and water also may become contaminated with infectious organisms. Listeriosis is a disease caused by bacteria infecting the brain. Contaminated silage is a common source of this infection in cattle.

DISEASE AGENTS

Objective

- List the Important Distinguishing Features and Give Examples of Major Disease Agents, and Describe the Resulting Diseases

Traditionally, infectious diseases are divided into four classes of agents: bacteria, viruses, fungi, and parasites. However prions have more recently become a major disease agent. Within each class exists tremendous variation. This discussion begins with a description of bacteria.

Until this point, the discussion of cells has been limited to **eukaryotic** cells. These cells have membrane-bound organelles, such as the nucleus, mitochondria, and endoplasmic reticulum. Bacteria are one-celled **prokaryotic** organisms. Prokaryotic cells lack membrane-bound organelles. Each bacterium has a single circular chromosome that is not surrounded by membrane. The chromosome is highly folded within the cell giving it a three-dimensional shape.

Bacteria reproduce through cell division, one cell dividing into two. The process begins with a replication of the chromosome. Cell membrane and cell wall grow across the cell, thus dividing it into two. This process can occur in less than 20 minutes. At this speed, millions of bacteria can be formed in the matter of hours. Replication of bacteria is limited by the availability of nutrients and the accumulation of waste products released by the bacteria. Most bacteria survive best at a pH in the range of 6.5 to 7.5. The waste products from bacteria are often in the form of acid, which decreases the surrounding pH. This decline in pH is often what limits the proliferation of the bacteria.

Bacteria are also affected by the surrounding air, including gases such as oxygen, nitrogen, and carbon dioxide. Bacteria vary considerably in their need for oxygen. Many bacteria, called obligate aerobes, require oxygen to be present in the environment to allow for growth. Other bacteria, such as *Clostridium tetani*, grow only in environments lacking oxygen. These bacteria are termed obligate anaerobes. A third class of bacteria, known as facultative anaerobes, grow in either type of environment. *Escherichia coli*, a bacteria commonly found in the intestinal tract, is a facultative anaerobe. Oxygen is poorly soluble in water but *E. coli* is able to survive with these lower levels of oxygen. The efficiency of energy production by the bacteria is diminished by the decline in oxygen.

Bacteria also have a cell wall that provides a rigid framework and maintains the cell's shape. The cell wall is composed of short polypeptides and sugars combined into one large macromolecule that surrounds the cell. The plasma membrane lies immediately beneath the cell wall. Many bacteria must be able to survive in a hypotonic environment (such as water). A normal animal cell would burst in such an environment, because the osmotic pressure of the cell would draw water into it. The cell wall prevents this flow of water into bacteria.

The cell wall is significant in the classification of bacteria. Differences in the cell wall influence various bacteria's ability to pick up stain. In the late 1800s, Christian Gram, a Danish bacteriologist, developed a staining technique for bacteria in which the sample is treated with the primary stain crystal violet, a purple dye. After being rinsed the slide is treated with iodine, which acts as a mordant, helping to bind the primary stain to the cells. The sample is then treated with alcohol or acetone to remove any free crystal violet. This step washes the primary stain out of certain bacteria and not others. The last step is to use a different colored stain, such as pink safranin. The end result distinguishes different bacteria based on their color, either retaining the crystal violet or the safranin. Gram stain is described as a differential stain because it helps to distinguish classes of bacteria.

In this technique, some bacteria absorb the crystal violet and are stained blue. Another class of bacteria does not retain this stain when decolorized and subsequently are stained red with the safranin. The Gram stain then distinguishes two classes of bacteria. Gram-positive bacteria are stained blue due to the presence of a thicker peptidoglycan layer in the cell wall. They pick up the crystal violet. Gram-negative bacteria have a layer of lipopolysaccharide in their cell wall; therefore, they do not retain the crystal violet and are visible as red or pink under the microscope. This simple fast staining technique can help a veterinarian make important decisions on antibiotic selection before the actual species of bacteria is identified.

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Tuberculosis and Johne's disease are both caused by bacteria in the genus *Mycobacterium*. Bacteria of this genus have a waxy substance in their cell walls. Another differential staining technique, the acid-fast stain, is used to identify this type of bacteria. In this technique the primary stain carbolfuchsin is applied to the slide. After heat treatment, the slide is decolorized with an acid alcohol. Acid-fast bacteria such as *Mycobacterium* retain the red-colored carbolfuchsin. Once again this differential stain is extremely valuable in identifying the class of organism infecting the animal.

Some bacteria have a slime layer or capsule surrounding the cell wall. This additional layer makes it more difficult for phagocytes to capture and engulf them. Other bacteria are mobile with the help of flagella. The flagella have a different structure than those found in eukaryotic cells. Also found on the surface of the cells are small protein filaments projecting from the cell membrane through the cell wall. These pili play a role in the bacteria's abilities to attach to other cells. The pili may also function to transmit DNA material between bacteria.

In addition to the main chromosome, many bacteria have small fragments of DNA called plasmids. The genes carried on the plasmid are not essential for normal function or replication of the bacteria and are typically less than 5% of the size of the main chromosome. The plasmids can replicate independently of the bacteria. Plasmids can provide the genetic code for certain enzymes, for the exchange of genetic material, and for resistance to antibiotics. Resistance to antibiotics is a very serious concern in human and veterinary medicine; therefore it is critical to understand how plasmids can transfer this information between bacteria.

Three methods are available for bacteria to transfer the genetic material found in the plasmid: conjugation, transformation, and transduction. The first method, conjugation, requires direct contact between two bacterial cells. Pili, coded for in the plasmid of the donor cell, come into contact with the recipient's cell membrane and a bridge of cytoplasm forms between the two bacterial cells. A copy of the plasmid DNA then transfers across this cytoplasmic bridge. As a result, both bacterial cells have a copy of the plasmid, which is available for transfer to even more bacteria.

Transformation is another process whereby DNA is exchanged between bacteria. Lysis of the cell wall of a bacterium releases fragments of DNA into the surrounding solution. Other bacteria encountering this free DNA can engulf it and take it into the cell. This DNA fragment is actually incorporated into the chromosome, creating a recombinant cell. This new DNA is then passed along with each cell division. Some of the earliest work on transformation added heat-killed bacteria of a pathogenic strain to a solution of nonpathogenic *Streptococcus pneumoniae*. The pathogenic strain has a capsule that prevents phagocytosis. After the experiment, the nonpathogenic bacteria developed the capsule, proving that genetic material had been transferred.

The final technique, transduction, requires the transmission of the DNA by a virus. Viruses are discussed later in this chapter. In transduction a virus infects a bacterium and utilizes the cell's organelles to produce virus particles. During this process some of the bacterial DNA can become incorporated into the viral DNA. It is then possible for the newly formed virus to infect other bacteria and introduce this new segment of DNA.

When nutrient supplies are scarce or environmental conditions harsh, many bacteria form endospores. Only one endospore is formed from each bacterium; this is not a form of replication. The bacterium loses water and shrinks into a very durable cell. Endospores are capable of surviving very hot and dry conditions or even freezing. When conditions improve, the endospore is capable of becoming active again and functioning as a normal bacterium. *B. anthracis*, the organism responsible for causing anthrax, is capable of forming an endospore.

A tremendous number of bacteria species exist in the world, many of which are normal inhabitants of animals. The importance of bacteria in fiber digestion has already been discussed. The normal bacteria actually compete with invading pathogens, helping to prevent disease. However, a small percentage of bacteria are pathogens that cause disease (Table 14–1).

Only when pathogens are able to compete with the normal flora of bacteria are they able to cause disease. Infectious diseases can be divided into several stages. The first stage, infection, occurs when the organism invades the host animal. The number of bacteria may actually be quite small at this point, and the bacteria must multiply. It is during this incubation phase that the pathogen numbers increase dramatically.

The signs of disease occur only after sufficient numbers of pathogens are present. In the case of bacteria, the signs are a result of toxins released by the bacteria. The effect is quite variable, depending on the toxin. Some organisms, such as in tetanus, release a toxin from the cell. These exotoxins are proteins produced and released by secretion. In the case of tetanus it is a neurotoxin that blocks the neurotransmitter of inhibitory neurons. The result is that all of the muscles become tightly contracted. Initially, the animals will show a "saw horse" stance and a stilted gait (Figure 14–3). Eventually, death occurs as the muscles of respiration stop functioning properly. The toxin can be modified with heat or chemicals to become inactive and the resulting toxoid can be used to vaccinate the animal. The result of the immunization are antibodies that inactivate the toxin.

Endotoxins are the other form of toxin found in bacteria. Endotoxins are the lipopolysaccharide portion of the cell wall of Gram-negative bacteria. These toxins are released only on the death of the bacteria. In these situations, the destruction of large numbers of bacteria by

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Table 14–1 **Common Bacterial Infections**

Disease	Species	Causative Organism	Signs
Anthrax	All	*Bacillus anthracis*	Cutaneous form—painful skin swelling. Inhalant form—difficulty breathing, ataxia, weakness and death
Botulism	All	*Clostridium botulinum*	Muscle paralysis, difficulty in swallowing and chewing, weakness, recumbency, often death
Brucellosis	All	*Brucella* spp.	Abortions, potential human infections
Caseous lymphadenitis	Sheep and goats	*Corynebacterium pseudotuberculosis*	External and internal abscesses, weight loss
Circling disease	Cows, sheep, goats	*Listeria monocytogenes*	Fever, anorexia, begin pressing head against objects, progressing to ataxia and circling in one direction, can be fatal
Contagious equine metritis	Equine	*Haemophilus equigenitalis*	Disease seen in mares, purulent discharge from the vulva, spread by stallions
Contagious mastitis	Cows	*Staphylococcus aureus, Streptococcus agalactiae*	Infection of the mammary gland that can be transmitted between cattle during milking
E. coli diarrhea	All	*Escherichia coli*	Usually young animals less than two weeks old—severe diarrhea, dehydration, anorexia, fever, may cause death (the same organism is one of the causes of coliform mastitis)
Enzootic pneumonia of pigs	Pigs	*Mycoplasma hyopneumoniae*	Often affects young pigs, dry cough, can be chronic, poor weight gain
Erysipelas	Swine	*Erysipelothrix rhusiopathiae*	Acute form can cause sudden death, high fevers, reddened skin progressing to a diamond appearance, arthritis
Foot rot	Cows, sheep, goats	*Fusobacterium necrophorum*	Deep infection between the claws of the hoof, foul odor discharge, lameness
Greasy pig disease	Swine	*Staphylococcus hyicus*	Reddened skin, anorexia, fever early in disease, thickened skin with purulent discharge
Johne's Disease	Cows, sheep, goats	*Mycobacterium paratuberculosis*	Chronic diarrhea, weight loss, anorexia, death
Kennel cough	Canine	*Bordetella bronchiseptica*	Can be secondary to viral infection, causes a dry hacking cough, anorexia
Leptospirosis	All	*Leptospirosis* sp.	Abortions, fever, anemia, jaundice, renal damage
Lockjaw	Horses, cows, sheep, goats	*Clostridium tetani*	Spasms of muscles—jaws held shut tightly, sawhorse stance, stiffness, progressing to recumbency and eventually death
Lyme disease	All	*Borrelia burgdorferi*	Spread by ticks, primarily arthritis, can be chronic and intermittent, may also show lethargy, anorexia
Otitis externa	Dogs, cats	*Pseudomonas aeruginosa*	Infection of external ear canal, also urinary tract infections
Pinkeye	Cows	*Moraxella bovis*	Increased tear production, inflamed conjunctiva, cloudy cornea, pain to eye in bright light

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Table 14–1 *continued*

Disease	Species	Causative Organism	Signs
Pneumonia	Bovine	*Mannheimia haemolytica, Pasteurella multocida*	Respiratory infection, fever, labored breathing
Pneumonia	Equine	*Rhodococcus equi*	Usually affects young horses, fever, nasal discharge, respiratory difficulty, lung damage and inflammation, may spread to joints
Pneumonitis	Cats	*Chlamydia psittaci*	Ocular discharge and inflammation, sneezing, tearing, fever, cough
Rain scald	Horses, cows, sheep, goats	*Dermatophilus congolensis*	Crusting of skin at base of hairs, often on the top of the back, most common in animals housed out of doors in damp conditions
Salmonellosis	All	*Salmonella* sp.	Severe diarrhea, often with blood, high fever, anorexia, dehydration, weakness, may cause death
Strangles	Equine	*Streptococcus equi*	Usually affects young horses, anorexia, fever, nasal discharge, swollen lymph nodes
Swine dysentery	Swine	*Treponema hyodysenteriae*	Diarrhea, often with blood and mucus, dehydration, weakness, anorexia, may cause death
TEME	Cows	*Histophilus somni*	Fever, severe depression, hind limb paralysis when it invades the spinal cord, may cause death
Wooden tongue	Cows, sheep	*Actinobacillus lignieresii*	Severe inflammation of the tongue and local lymph nodes (in sheep usually does not affect tongue)

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Note: This is only a partial list of bacterial diseases commonly found in domestic species. The complete list is well beyond the scope of this text. In general when a bacterial infection is diagnosed, an appropriate antibiotic and supportive treatment are used.

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FIGURE 14–3 A cow suffering from tetanus. She has a wide stance and a very stilted gait.

the immune system causes a release of large quantities of endotoxin. The sudden release of endotoxin is responsible for many of the clinical signs of the disease. The endotoxin release may result in fever, aches, decreased blood pressure, inflammation, and a decline in white blood cell count. The combination of signs of fever and decreased blood pressure secondary to the endotoxin release is called septic shock. This is a life-threatening condition and requires aggressive treatment.

Following the incubation period in which the infectious agent multiplies, the actual illness begins. The first signs of illness occur in what is called the **prodromal phase**. This is a short-lived period and may have such nonspecific signs as fever and muscle aches. The disease quickly progresses into the acute period, when the signs of the disease are maximized. It is hoped the animal's immune system (possibly with the aid of medication) is able to control the infection. The disease then enters the decline period, when the symptoms begin to improve. Finally the animal enters the convalescent phase or recovery period, when it begins to return to normal. During this phase the animal regains strength, begins eating well, and becomes more active. It is possible for an animal to develop an infection and not reach the point of showing clinical signs. This situation is called a subclinical infection. While this animal may not be sick, it is possible for it to shed bacteria or virus and infect others. Evidence of a subclinical infection can be detected with a rise in the antibody titers against this organism.

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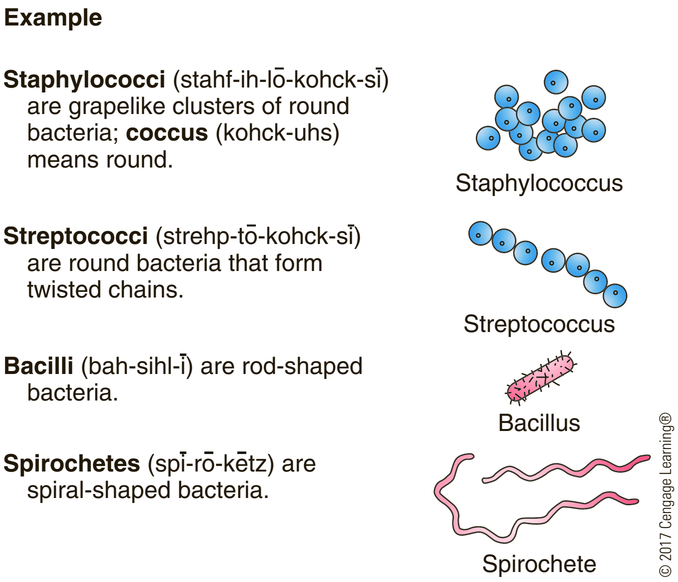

FIGURE 14–4 The shape of bacteria.

If the immune system and any treatment are unsuccessful in clearing the infection, the animal may enter a phase of chronic illness. The length of time for the chronic phase can be extremely variable. Some chronic illnesses can last a lifetime.

In addition to being classified as Gram-positive or Gram-negative, bacteria are classified based on shape (Figure 14–4). Spherical bacteria are called cocci. If the cocci bacteria cluster in groups of two, they are called diplococci. Streptococci are individual cocci bacteria grouped in long chains. Bacteria that are cylindrical are called rods or bacilli. Some bacteria take on a spiral shape. *Spirochete* describes bacteria that have a flexible spiral.

The classification of bacteria is always being evaluated, and at times the names of bacteria are changed. Many more factors are involved in classification, but the Gram stain characteristic and the shape of the bacteria are two important features. It is well beyond the scope of this text to list all the disease-causing bacteria. Only a few examples of each are given.

Gram-positive cocci are one such class. This group includes the *Streptococcus* (they grow in chains) and *Staphylococcus* (clusters of cocci bacteria). Many species in this group infect the mammary gland, causing mastitis. Other species can cause skin infection (*Staphylococcus aureus*) and infection in the respiratory tract of horses (*Streptococcus equi*).

Gram-positive rods include the *Clostridium* organisms and *Bacillus anthracis*. In addition to tetanus, which has already been discussed, *Clostridium* species also cause botulism. *Clostridium botulinum* is a toxin-producing organism that is often found in spoiled food. The same disease can occur in humans who consume improperly canned food. The toxin blocks acetylcholine, which is released by motor neurons. The result is severe muscle weakness. The disease can be fatal if the muscles that control respiration are paralyzed.

The Gram-negative rods include *Escherichia coli*, commonly abbreviated *E. coli*. In mastitis, the Gram-negative rods are grouped as coliforms because of their similarities to *E. coli*. There are a large number of disease-causing Gram-negative rods (such as *Klebsiella*, *Pseudomonas*, *Salmonella*, *Yersinia*, *Pasteurella*, *Mannheimia*, and *Histophilus*). These species commonly cause intestinal, respiratory, and mammary gland infections. The disease-causing spirochetes are also Gram-negative. The most common spirochetes in veterinary medicine are species of *Leptospira*, which can cause damage to the kidneys or abortions as a result of a disease called leptospirosis.

Not all bacteria fit neatly into the Gram-positive and Gram-negative classification. *Mycoplasma* species are some of the smallest bacteria and lack a cell wall. Technically, these organisms are Gram-negative because of the lack of cell wall. However, other staining techniques are necessary to identify these organisms. These organisms commonly cause respiratory, joint, and mammary gland infections in farm animals.

Another class of disease-causing organisms is the viruses (Table 14–2). Viruses are neither eukaryotic nor prokaryotic cells. Viruses have no cell wall, no organelles, and no enzymes capable of producing energy. Viruses are not even able to replicate on their own. Viruses replicate by utilizing the organelles and metabolism of infected cells to produce more virus. The viruses are so simple in form that it has been debated whether they can be considered living things. This replication within the host cells, using the cells' own metabolism, makes antiviral drugs very difficult to develop.

Viruses have a central core of nucleic acid, either RNA or DNA, not both. Surrounding this strand of nucleic acid is a protein coat called the capsid. The capsid is responsible for protecting the nucleic acid (Figure 14–5). In addition, the protein of the capsid determines the kind of cell to which the virus can attach. Once attached, the capsid plays a role in the insertion of the nucleic acid into the infected cell. Some viruses have an envelope surrounding the capsid. Typically this occurs when the virus is released from the host cell and become wrapped in cellular membrane as it is released.

Viruses can be classified as either RNA or DNA. DNA viruses contain a double strand of DNA. Infection begins when the virus locates a host cell and attaches to the plasma membrane at specific receptor sites.. Viruses can be very specific in the type of host and the type of cell to which they can attach. Some viruses may attack only one species, whereas others can infect all mammals. Following the attachment phase, the virus enters the cell. This may occur by pinocytosis where the membrane of the cell wraps around the virus and brings it into the cytoplasm in a small vesicle. For the enveloped viruses entry into the cell may occur via fusion. In this process

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Table 14–2 **Common Viral Infections**

Disease	Species	Causative Organism	Signs
Calicivirus infection	Cats	Calicivirus	Inflamed eyes, ocular discharge, sneezing, pneumonia, ulcers in mouth
Canine distemper	Dogs	Canine distemper virus	Respiratory—fever, nasal and ocular discharge, pneumonia Nervous—seizures, can be fatal
Coronavirus infection	Dogs	Canine coronavirus	Generally a mild case of vomiting and diarrhea, usually self-limiting
Equine encephalomyelitis*	Horses	Togavirus	Fever, mental depression, anorexia, central nervous system signs
Equine influenza	Horses	Equine influenza virus	Coughing, fever, anorexia, tearing, cloudy cornea
Equine infectious anemia	Horses	Retrovirus	Fever, hemolytic anemia, icterus, weight loss
Equine viral arteritis	Horses	Herpesvirus	May attack upper respiratory tract with fever, nasal discharge, coughing or cause abortions
Equine viral rhino-pneumonitis	Horses	Herpesvirus	Fever, cough, inflammation of nose and throat, nasal discharge
Feline infectious peritonitis	Cats	Coronavirus	Wet and dry form, distended abdomen, weight loss, fever, progressive
Feline leukemia	Cats	Retrovirus	Chronic weight loss, anemia, anorexia, tumors
Feline viral rhinotracheitis	Cats	Herpesvirus	Coughing and sneezing, discharge from eyes and nose, fever, anorexia
Foot-and-mouth disease	Cattle and swine	Picornavirus	Fever; blisters in mouth, nose, udder and feet; highly contagious
Infectious canine hepatitis	Dogs	Canine adenovirus	Fever, lethargy, enlarged liver, anorexia, bleeding disorders, enlarged lymph nodes
Kennel cough	Dogs	Adenovirus and parainfluenza	Dry hacking cough, fever, anorexia. Can lead to secondary infection with bacteria (*B. bronchiseptica*)
Panleukopenia	Cats	Feline parvovirus	Young cats, fever, vomiting, diarrhea, anorexia, often fatal, can damage bone marrow
Parvo	Dogs	Canine parvovirus	Usually young animals, severe vomiting, diarrhea, anorexia, fever, often fatal
Pseudorabies	Primarily pigs (can infect many species)	Herpesvirus	Affects the central nervous system, shaking, ataxia, convulsions, seizures, fever, anorexia
Rabies	All	Rhabdovirus	Fatal infection of the central nervous system: quite variable signs, paralysis, inability to swallow (foaming at the mouth), aggression, stupor
Shipping fever complex	Cows	IBR, PI-3, BVD, BRSV	High fevers, nasal discharge, ocular discharge, coughing, severe pneumonia
Sore mouth	Sheep and goats	Contagious ecthyma virus	Sores on lips, mouth, udder, turns to scabs
Swine influenza	Pigs	Influenza type A	Sudden onset, high fever, anorexia, coughing, respiratory distress

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Table 14–2 *continued*

Disease	Species	Causative Organism	Signs
Transmissible gastroenteritis	Swine	Coronavirus	Watery diarrhea, vomiting, dehydration, highly contagious
West Nile disease	Horses, birds	West Nile virus	Neurologic signs, weakness, ataxia, can be fatal

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IBR = infectious bovine rhinotracheitis; PI-3 = parainfluenza 3; BVD = bovine viral diarrhea; BRSV = bovine respiratory syncytial virus.
*Three forms exist: Eastern, Western, and Venezuelan.
Note: This is only a partial list of the viral diseases found in domestic species. The complete list is beyond the scope of this text. In general no specific treatment is available to cure viral infections. Supportive treatment is necessary. Vaccination is critical in preventing viral diseases.

the envelope fuses with the membrane of the cell subsequently releasing the virus into the cytoplasm.

Once the penetration phase is complete, the uncoating process begins and the viral nucleic acids are released from within the capsid into the cytoplasm. Viral DNA will penetrate into the nucleus to be replicated. The genes coded in the virus's DNA use the host cell's ribosomes to produce enzymes (Figure 14–6). These enzymes can actually shut down the host cell's DNA while using the cell to produce multiple copies of the virus's DNA. This replication phase also has the cell producing proteins for the capsid. The cycle then enters the assembly phase, in which the DNA and capsid protein are combined into a new virus. In the release phase, lysosomes are released to destroy the host cell. The assembled viruses are then released, ready to attack new cells. This entire process from the initial attachment to the final destruction of the host cell and release of virus is called the lytic cycle. The enveloped viruses are released without destroying the cell in a process called budding, whereby the virus is wrapped in an enclosure of cell membrane.

RNA viruses have a similar cycle upon infecting host cells. The host cell is once again used to create new strands of RNA and capsid. Compared to the DNA viruses working in the nucleus, the RNA viral synthesis occurs in the cytoplasm. Upon assembly of the virus, the cell can be lysed and new virus released.

Not all viruses result in the death of the cell. The retroviruses actually incorporate genetic material into the host cell's DNA. The feline leukemia virus (FeLV) is a common example of this type. FeLV is an RNA virus that infects the cells of cats. The RNA codes for a strand of DNA that is formed in the host cell. The newly

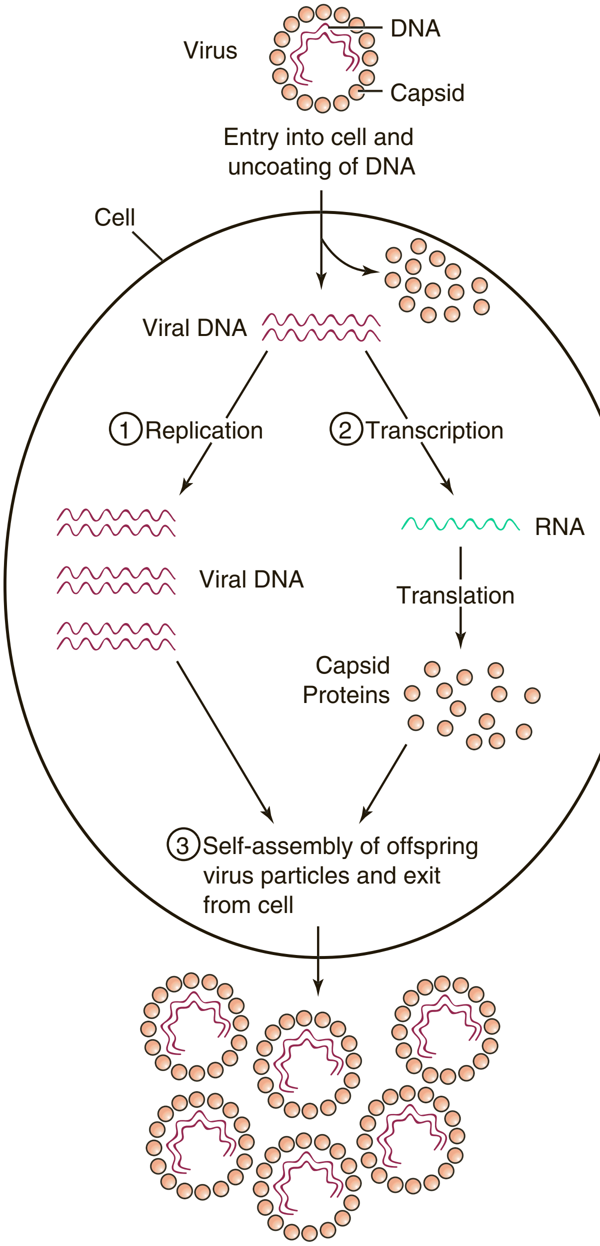

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FIGURE 14–6 Life cycle of virus.

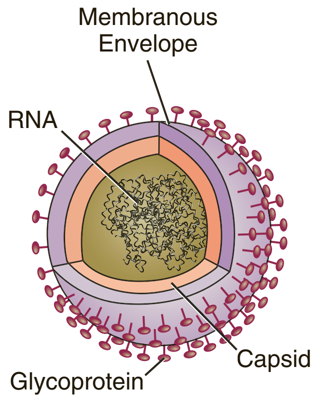

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FIGURE 14–5 Classic virus structure.

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produced DNA inserts into the chromosomes of the host cell. With every division of the cell, the viral genetic material is passed on to the daughter cells. Once the virus has inserted into the host DNA, the infection will last for the life of the animal.

The DNA codes for the production of proteins specific for the virus. Some of these proteins can be detected within the serum of the cat. Enzyme-linked immunosorbent assay (ELISA) tests have been developed to detect these proteins. These tests are available in self-contained kits and can be performed in the practitioner's office.

Feline leukemia virus can eventually result in fatal diseases. Many cats can live for long periods while infected with FeLV. However, the virus can result in a suppressed immune system. As a result, the cats are more susceptible to other bacterial and viral infections. FeLV may also suppress the bone marrow, resulting in **anemia**. Infected cats can also develop tumors of the immune system or bone marrow.

Viruses are classified by several distinguishing features. As already discussed, the type of nucleic acid is the first major classification. Other features include how large a nucleic acid is included, the shape of the capsid, and the type of host that is infected (Figure 14–7). Some viruses require a vector to transmit them between hosts. This characteristic is also included in the classification.

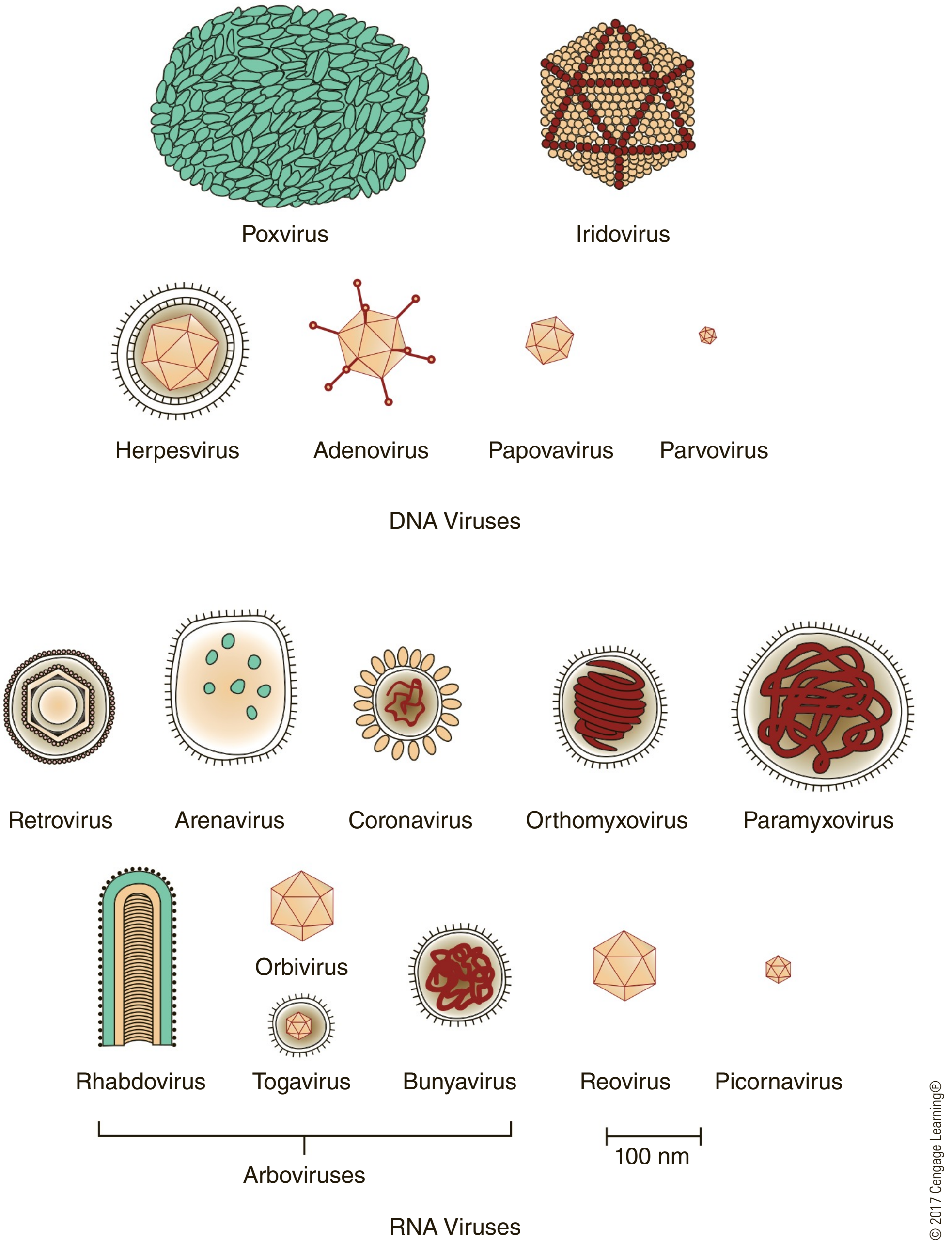

FIGURE 14–7 Examples of the shape of different viruses.

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Porcine epidemic diarrhea (PED) was first confirmed in the United States in 2013 and became a disease to which the swine industry had to react. This disease had been identified as early as 1971 for the first time in the United Kingdom. PED is caused by a coronavirus. The disease spreads rapidly and will often infect a very high percentage of piglets in naïve herds. Clinical signs include severe watery diarrhea along with vomiting, resulting in dehydration. In suckling piglets the death rate or mortality can approach 100%. The mortality is not as high in older animals.

One of the challenges when PED was initially encountered is that the clinical signs mimic another coronavirus-caused disease called transmissible gastroenteritis (TGE). The two diseases can only be distinguished with laboratory identification of the virus. Although there are vaccines for TGE initially none were available for PED. By June of 2014 the U.S. Department of Agriculture (USDA) issued a conditional license for a PED vaccine. This quick response was designed to help protect the swine industry. The effectiveness and safety of the vaccine will be evaluated before a final license is issued.

The third class of infectious microorganisms is called fungi (singular is fungus). Fungi have eukaryotic cells. They have cell walls, as do plants. Fungi, however, do not have chlorophyll, the substance that plants use to capture the energy from the sun (Figure 14–8). Fungi gain their nutrition by absorbing nutrients from the surroundings. Fungi can use inorganic nitrogen to create protein.

Most fungi are spore producers. The spores provide the ability to spread the organism to other areas and also to survive harsh conditions. Fungi have an appearance of filaments. Each filament is called a hypha (plural is hyphae). Cells from the end of the hyphae produce an asexual spore. The spore in this case is a cell budding off the end of the filament. These spores are very resistant to drying. Once adequate moisture is present, these spores germinate into an active growing fungus. Sexual spores can also be produced when two specialized hyphae fuse and combine the genetic material of two cells that had undergone meiosis. The sexual spores tend to be much more resistant to heat than are the asexual spores.

Fungi can affect the health of animals in several ways (Table 14–3). *Mycosis* is the term used to describe any fungal infection (mycoses is plural). Ringworm is a common fungal infection. It is important to realize that ringworm is caused by a fungus that infects skin, hair, nails, and claws and has nothing to do with worms! The infection often appears in a circle and expands outward. In humans, ringworm appears as a red circle. It is this presentation that gave the disease its name. In animals, ringworm often has a very crusty, flaky appearance (Figure 14–9).

Several different fungi are capable of causing ringworm (e.g., species of *Microsporum* and *Trichophyton*). These fungi are often introduced into the skin through abrasions. They invade the outer layers of the skin and work into the hair follicles. Damage to the hair follicles results in loss of hair in the infected region. A special culture medium is available to detect ringworm. Hair from infected regions is placed on the medium. The fungus absorbs nutrients from the medium and grows. A color reaction occurs to help provide the diagnosis of ringworm (Figure 14–10).

Fungi can also infect the internal organs. The fungi can enter through the respiratory or the intestinal tracts.

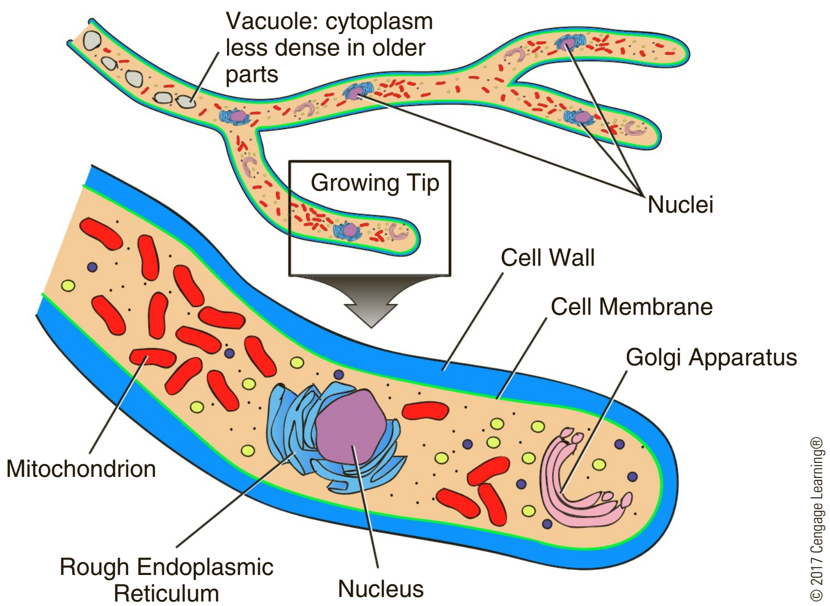

FIGURE 14–8 Illustration of a fungus.

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Table 14–3 Common Fungal Infections

Disease	Species	Causative Organism	Signs
Blastomycosis	Dogs	*Blastomyces dermatitidis*	General signs of anorexia, fever, weight loss, usually begins with a severe pneumonia and may spread to lymphatics, eyes, bone
Cryptococcosis	Dogs, cats	*Cryptococcus neoformans*	More common in cats, may affect upper airways with sneezing and discharge, open mass in skin, also affects eyes
Histoplasmosis	Dogs, cats	*Histoplasma capsulatum*	Often begins as respiratory infection with dyspnea, weight loss, and anorexia; may also invade intestinal tract with diarrhea and weight loss
Ringworm	All	*Microsporum* sp. and *Trichophyton* sp.	Superficial infection of skin, areas of hair loss, with crusting and flaking
Sporotrichosis	Dogs, cats	*Sporothrix schenckii*	Usually introduced into skin by trauma, causing nodules, these lumps in skin often drain
Valley fever	Dogs, cats	*Coccidioides immitis*	Most prevalent in Southwest United States, may infect the skin with lumps and abscesses, also infects lungs, eyes and bone

Note: This is only a partial listing of fungal diseases found in domestic species. A complete list is beyond the scope of this text.

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The infection can begin in those areas, but it is then possible for it to spread to other regions. Any organ system can become involved. The skin, eyes, bones, and lymph tissue are all common sites of infection. These **systemic** (affecting the entire body) infections are much more common in animals with suppressed immune systems. The same occurs in human medicine in patients who are immunosuppressed following organ transplantation or as a result of diseases such as acquired immunodeficiency syndrome (AIDS).

Other fungi that do not directly infect animals may also cause diseases. Fungi can grow on poorly stored feeds. Some of these fungi can produce toxins (mycotoxins) that are harmful to the animals consuming these feeds. In very high levels, these mycotoxins can result in sudden illness and even death. Often the problems result from smaller levels over long periods. One toxin (zearalenone) can mimic the hormone estrogen. Swine are quite sensitive to this toxin. Affected pigs have swollen vulvas, enlarged mammary glands, and decreased fertility.

Prions are a poorly understood class of infectious agents. Prion is short for proteinaceous infectious particle. Only the abnormally shaped protein molecule has been discovered within prions. To date no nucleic acid material has been found. The manner of replication within the host is not well understood. Prions are extremely resistant to heat and do not stimulate an immune response from the infected animal.

Prions cause a class of diseases called transmissible spongiform encephalopathies (TSE). *Encephalopathy* is a general term describing a disease of the brain. Spongiform describes the microscopic holes creating a spongelike appearance of the diseased brain. Scrapie, mad cow disease, and Creutzfeldt-Jakob disease are three of the most notable TSEs.

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FIGURE 14–10 A culture for ringworm. Note the fuzzy growth of fungus on the culture media.

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FIGURE 14–9 A Holstein heifer with ringworm.

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Mad cow disease, or bovine spongiform encephalopathy (BSE), is a progressive disease in cattle. An incubation period is the time it takes from the animal being exposed to an infectious agent to the point when clinical signs of the disease develop. Organisms such as bacteria and viruses often have an incubation period measured in days to weeks. The incubation period of prions is measured in years or decades. In cattle, the incubation period for BSE is generally considered to be in the range of two to eight years.

The first sign in cattle is often a change in behavior. Infected animals often become restless, nervous, and agitated. Many become aggressive and even small noises can cause a very serious reaction. As the disease progresses, the cattle begin to lose coordination and eventually become unable to rise. Generally after a period of a few weeks to months from the onset of clinical signs, the animal dies or has to be destroyed.

While BSE has been discovered in the United States, the largest number of cases has been diagnosed in the United Kingdom. It is generally believed that the high incidence occurred as a result of feeding meat and bone meal of ruminants as a protein source for cattle. Prions can be found within the central nervous tissue of infected animals and are present even before the animal shows clinical signs. It is believed that prions contaminated the meat by-products and directly infected the cattle consuming these products. The USDA banned the use of these protein sources in the feeding of cattle in the United States in 1997.

Creutzfeldt-Jakob disease, a TSE in humans, has many of the same characteristics of mad cow disease. A sporadic form of this disease occurs in humans and generally affects people in their 60s or older. A variant of Creutzfeldt-Jakob disease (vCJD) has been linked to BSE. Individuals with vCJD are much younger than those who develop the sporadic form. The disease in people also attacks the central nervous system and is slowly progressive. The disease is fatal, with the progression often occurring over the course of a year. The association between the two diseases has made control and monitoring a very high priority.

The final class of infective organisms is parasites. There are many different types of parasites. Parasites may be single-celled organisms or much larger arthropods that are visible with the naked eye. Parasites may be within the body (endoparasites) or on the surface of the body (ectoparasites). In general, parasites use the host animal as their sources of nutrients and protection. This description may sound very much like the symbiotic relationship that describes the rumen bacteria and the cow. The difference is that the host is actually harmed by the parasite (Table 14–4).

Parasites can damage the host in several ways. Some parasites actually compete for nutrients. These parasites living in the intestinal tract can utilize the nutrients before the host has the opportunity to absorb them. The parasites can also damage the intestinal mucosa, hindering the ability of the host to absorb nutrients. Certain intestinal worms and external parasites

Table 14–4 Common Internal Parasitic Infections

Roundworms of dogs and cats
CAUSED BY: *Toxocara canis, Toxocara cati, and Toxascaris leonina*
CLINICAL SIGNS: diarrhea, vomiting, pot-bellied appearance, dull coat, poor weight gain, coughing.
LIFE CYCLE: Ingested eggs develop into larvae in the intestinal tract. The larvae migrate through the liver and lungs. Eventually migrate up the trachea and are swallowed to develop into adults. Eggs are then shed in the feces. Four means of transmission exist: 1. Larvae can cross from the mother to the fetus through the placenta. (*Toxocara canis*) 2. Larvae can pass through the milk to infect newborns. 3. Animal can ingest the eggs with feces contamination of food. 4. Ingestion of certain animals carrying the larvae (e.g., rodents, rabbits).
Hookworms of dogs and cats
CAUSED BY: *Ancylostoma* sp. *and Uncinaria* sp.
CLINICAL SIGNS: diarrhea, anemia, anorexia, weight loss, may cause death.
LIFE CYCLE: Four means of transmission exist: 1. Ingestion of larvae. 2. Across the placenta. 3. Through the milk 4. Larvae may penetrate through the skin of the foot pads to enter the host. The larvae enter the intestinal tract and develop into adults. The adults attach to the lining of the intestines and suck blood from the host. Adult hookworms produce eggs which are passed in the feces. These eggs develop into larvae, which are then infective to new hosts.

continues

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Table 14–4 *continued*

Whipworms of dogs

Caused by: *Trichuris vulpis*

Clinical signs: chronic diarrhea often with blood or mucus, weight loss, dehydration.

Life cycle: Eggs are passed in the feces. Larvae develop within the eggs, which are then ingested. The larvae hatch out of the egg and develop infection in the intestines. Adults then shed eggs.

Tapeworms of dogs and cats

Caused by: *Dipylidium caninum, Taenia pisiformis, Taenia taeniaeformis*

Clinical signs: usually minimal, severe infections may cause weight loss or low blood sugar in small young animals. Often a concern to owners because the segments are visible.

Life cycle: Requires an intermediate host (*Dipylidium*—flea, *Taenia*—rabbits, rodents).

The intermediate host eats the eggs, the definitive host (dog or cat) eats the intermediate to ingest larvae. The larvae establish infection in the intestines. The adult tapeworm forms, segments or eggs are passed in the feces. These are consumed by the flea or rodent.

Heartworm of dogs

Caused by: *Dirofilaria immitis*

Clinical signs: coughing, exercise intolerance, fluid accumulation in abdomen (ascites), cardiac or respiratory failure.

Life cycle: Adult worms live in the major vessels close to and in the heart chambers. Adult worms produce larvae (called microfilariae) that travel in the bloodstream. A mosquito picks up the larvae when consuming a blood meal from the dog. The larvae mature in the mosquito (the intermediate host). At this stage if the mosquito bites another dog, the larvae are introduced. The larvae finish their development in the dog, a process requiring up to five months. Adult worms then mate and produce more microfilariae. The entire cycle requires six to seven months for microfilariae to be detectable in the blood.

Diagnosis of heartworm disease requires a blood test. Tests are available to detect the microfilariae, or antigens released from the adult worms.

Strongylosis of horses

Caused by: *Strongylus* sp. (numerous species exist)

Clinical signs: colic, weight loss, diarrhea.

Life cycle: Eggs passed in the feces develop into larvae. The larvae crawl up blades of grass, which are then ingested by grazing horses. The larvae migrate through the bloodstream of the horse. Damage done to the blood vessels can result in colic. At a stage in their development the larvae enter the large intestines and mature into adults. The adults then pass eggs in the feces.

Roundworm infection of horses

Caused by: *Parascaris equorum*

Clinical signs: coughing, anorexia, poor weight gain, large numbers can cause impaction and obstruction of the intestines.

Life cycle: The horse ingests eggs, which then release a developing larva. The larvae migrate through the liver and lungs. Eventually the larvae are swallowed, where they develop into adults in the small intestine.

Bot infection in horses

Caused by: *Gasterophilus intestinalis* and *Gasterophilus nasalis*

Clinical signs: mild stomach irritation, often no clinical signs.

Life cycle: see text portion of this chapter.

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Table 14–4 *continued*

Trichostrongyles of ruminants
CAUSED BY: species of *Haemonchus, Ostertagia, Trichostrongylus, Cooperia, Bunostomum*
CLINICAL SIGNS: diarrhea, weight loss, low blood protein resulting in fluid accumulation under the skin (e.g., bottle jaw—the accumulation of fluid, edema, under the jaw).
LIFE CYCLE: These parasites have a direct life cycle. Eggs passed in the feces contaminate pastures and are then consumed. The larvae mature in the intestines and eventually produce adults that release eggs into the environment. The larvae of different species migrate into tissues to varying degrees.
All of the developing larvae have the ability to enter a stage of arrested development when conditions are bad (e.g., during winter). The larvae halt development until conditions improve (e.g., spring) and then mature into adults.
Coccidiosis in ruminants
CAUSED BY: numerous species of protozoa, many *Eimeria* sp.
CLINICAL SIGNS: chronic diarrhea, rough hair coat, poor weight gain.
LIFE CYCLE: An egg, called an oocyst, is passed in the feces. The oocyst is consumed by another animal. Immature stages are released from the oocyst. These immature stages penetrate the lining of the intestine and go through several stages of development. Each step damages lining cells of the intestines and is responsible for the clinical signs. Once mature, the coccidia release more oocysts to continue the life cycle.
Liver fluke in ruminants (Trematode)
CAUSED BY: *Fasciola hepatica*
CLINICAL SIGNS: may reduce liver function, creates abscesses in liver and may cause death in severe cases.
LIFE CYCLE: The adult parasite lives in the bile ducts. Egg is passed through the bile duct into the intestine and to the environment in the feces. The eggs will only hatch in water and then infect a snail. Larvae develop in the snail and eventually leave to form a cyst on plants above the water level. The cyst in ingested. Larvae hatch in the small intestine and then penetrate the intestinal wall and migrate to the liver. The larvae migrate until they find a bile duct and then mature into an adult.

Note: This is only a partial listing of the parasitic infections found in domestic species. The complete list is beyond the scope of this text.

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actually consume the blood of the host. If the number of parasites is excessive, they can consume such a large amount of blood that the host becomes anemic. Parasites may also have stages that migrate through the body, resulting in further tissue damage.

Many parasites have complex life cycles that allow them to survive and infect other animals. In many instances, this requires more than one host to complete the life cycle. The animal that carries the adult form of the parasite is called the definitive host. If another animal is required to transmit the immature stages of the parasite, it is called the intermediate host.

The tapeworm (*Dipylidium caninum*) in dogs and cats offers an example of a life cycle requiring an intermediate host. The tapeworm is a flatworm joined together in small segments (Figure 14–11A). The head of the worm attaches to the lining of the intestine. Over time, individual segments containing eggs are passed in the feces. Owners often see these segments on the hair coat around the anus of the animal. The individual segments are flat, often moving, and the size of a rice grain.

These segments rupture, releasing the eggs. The larvae (immature stages) of a flea consume these eggs. As the flea matures, it jumps onto the skin of another animal. As this animal grooms itself or bites at the skin, the flea is consumed. The tapeworm is released from the flea and establishes itself in the new host. In this life cycle, the dog or cat is the definitive host and the flea is the intermediate host. The definitive host contains the stage in which the parasite is sexually mature and able to produce eggs to infect others. The intermediate host is infected with larval stages.

Taenia taeniaeformis is another example of a tapeworm that requires an intermediate host. The life cycle is very similar to that of *Dipylidium* except that the intermediate host is a rodent. The rodent, such as a mouse or rat, eats the eggs and subsequently develops a cyst in its internal tissues. When a cat ingests the rodent, the parasite is released and develops into an adult form in the cat (Figure 14–11B). In this example the cat is the definitive host and the rodent is the intermediate host.

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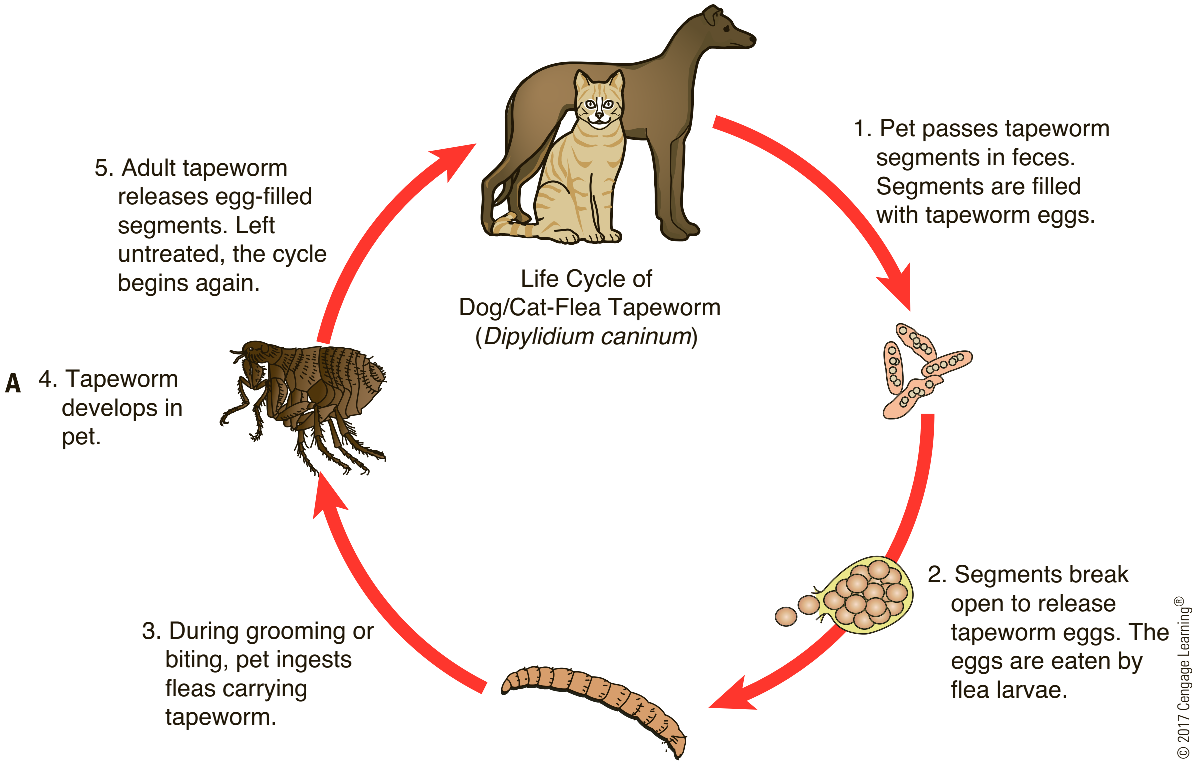

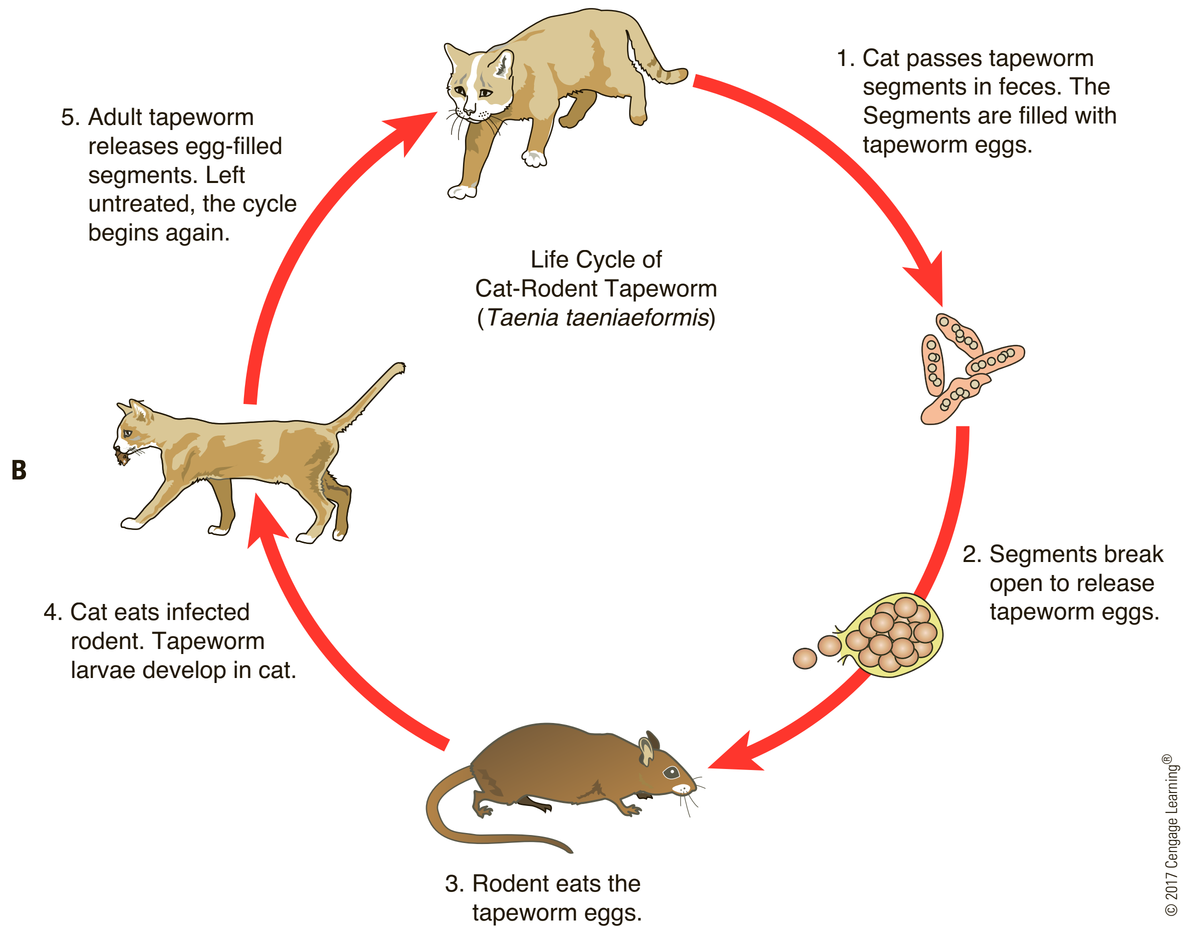

FIGURE 14–11 The life cycle of two tapeworms that commonly infect dogs and cats. A. *Dipylidium caninum*, or dog/cat-flea tapeworm. Any pet with fleas could potentially become infected with this tapeworm species. B. *Taenia taeniaeformis*, or cat-rodent tapeworm.

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The tapeworm is just one example of the flat-segmented parasitic worms (cestodes) that infest animals. Another type of flatworm is not segmented (trematodes). These worms are also called flukes. Many flukes leave the intestinal tract to invade the liver or lungs. A third type of worm is the roundworm (nematodes). Roundworms commonly invade the intestinal tract. In dogs, the heartworm is a roundworm that invades the bloodstream. This parasite requires a mosquito as the intermediate host. The mosquito ingests blood from one dog and then infects another dog with a subsequent bite.

Another common parasite is a single-celled organism called a protozoan. Protozoa lack a cell wall and obtain their food through phagocytosis. Many types of protozoa are parasites in the intestine or blood of animals. Intestinal protozoa often form a cyst, a structure that is resistant to dry conditions. The cyst is usually passed in the feces, which can then be consumed by other animals.

In general, intestinal parasites pass an infective form from the host in the feces. These may be eggs, cysts, or an immature stage of the worm (larva). To carry the infection to other animals, the parasite relies on an intermediate host (such as the tapeworm) or some means of fecal contamination that is ingested by another host.

In grazing animals (e.g., horses, cows, sheep, and goats) it is obvious how easily an infection can be spread. Eggs passed in the feces of an infected animal contaminate the ground and plants on the pasture. Rain can contribute to spreading the eggs to new areas. The next host then consumes the egg by eating contaminated plants. Dogs and cats are also infected in similar ways. The pet walking on contaminated soil gets eggs on the skin or footpads. As the pet grooms itself, it can become infected as well. It is important to note that some intestinal parasites of dogs and cats can cause infections in humans. Young children who place things in their mouths are at highest risks. Children playing in contaminated soil can also develop infections of these parasites. This risk emphasizes the importance of controlling parasites in pets.

Animals are susceptible to external parasites as well. These external parasites are all arthropods. Arthropods are the class of organisms that includes insects and spiders. There are a tremendous number of arthropods in the world. They constitute the largest group of organisms. Only a relatively small number are parasites in domestic species. These external parasites include ticks, fleas, mites, lice, mosquitoes, and biting flies (Figure 14–12). As already mentioned, these parasites

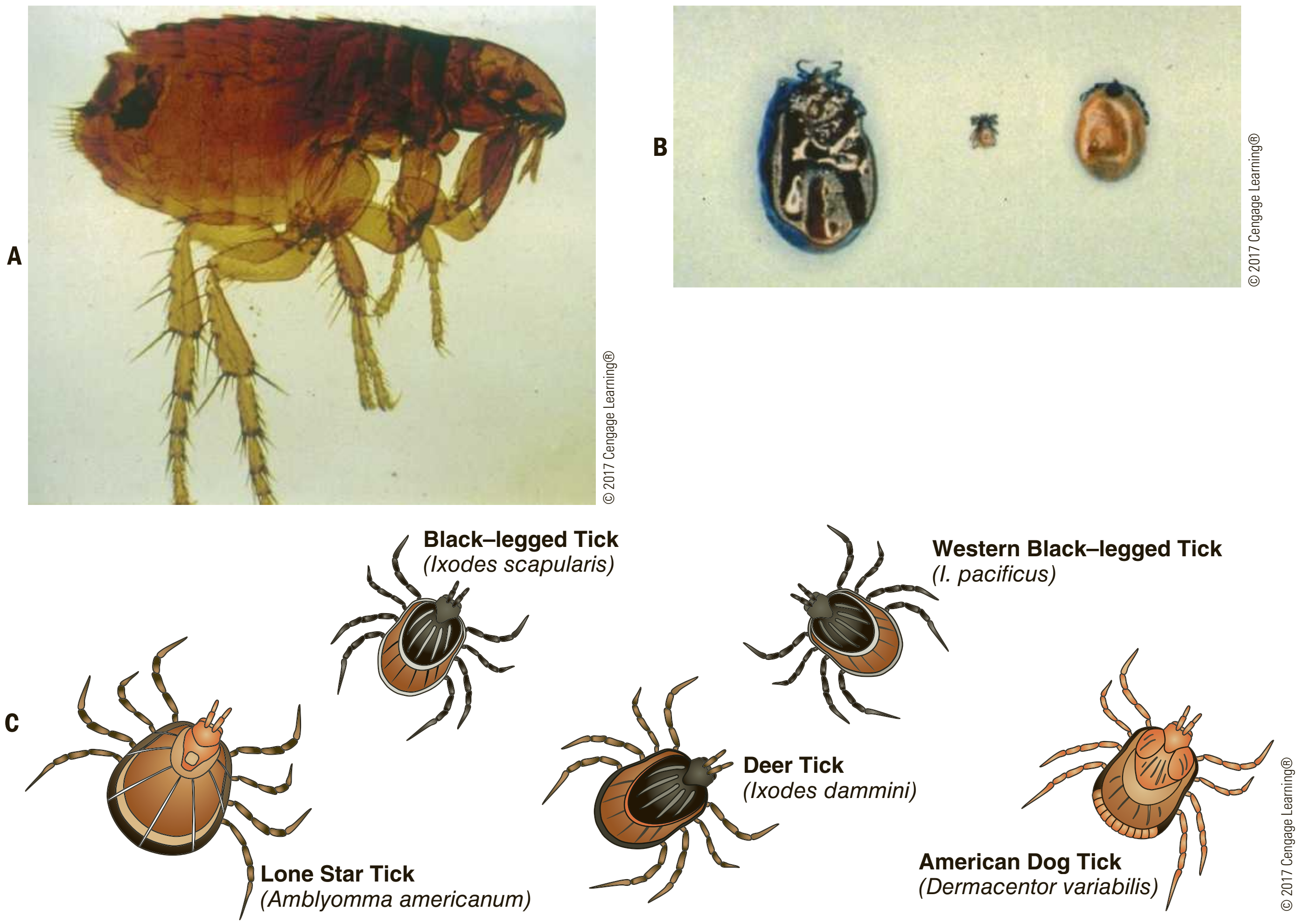

FIGURE 14–12 A. Flea. B. Tick. C. Several species of ticks.

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FIGURE 14–13 Larvae of the horse botfly *(Gastrophilus)* attached to the stomach lining of a horse.

can be responsible for transmitting other parasites and diseases.

One insect, the botfly, is also the source of an internal parasite. The botfly lays eggs on the legs of horses. As the horse licks these eggs, larvae hatch and penetrate into the gums and tongue of the horse. As development continues the next stage of larvae move down the esophagus and enter the stomach. Large numbers of these larvae may develop in the stomach, causing irritation to the lining (Figure 14–13). Each larva can be up to 20 mm in length. The larvae develop in the horse for 10 to 12 months and then pass in the feces, usually in the spring. The larvae then develop into the botfly, which lays eggs to continue the life cycle.

Fleas may be the most common external parasite seen in veterinary medicine. The flea is a blood-sucking insect that can cause significant skin irritation, transmit tapeworms, and cause anemia. Small kittens and puppies may develop a life-threatening anemia when infested with a large number of fleas. The eggs of fleas develop in the environment, off the infected animal. This makes control difficult, because eliminating all the fleas from the animal does not prevent reinfection.

Flea shampoos can be very useful in ridding the animal of existing fleas. The effect of the shampoo is eliminated once the animal is rinsed. If fleas exist in the environment, they will quickly reinfest the animal. Many forms of insecticides exist to kill fleas. Flea sprays, dips, collars, and powders have all been helpful in controlling flea infestations. Unfortunately, the treatment has to be consistent to prevent reinfection. Advances have provided treatments that can be effective for a month or longer. These products have been very useful in controlling flea problems.

Many pets are allergic to fleabites. As the flea sucks blood from the animal, some of its saliva enters the skin. If the pet is allergic to the saliva, scratching, biting, and skin irritation result. The animals often lose hair in these areas, and the skin can develop a bacterial infection. Large numbers of bacteria live on the surface of healthy skin. Once the skin becomes irritated, the bacteria can enter and establish an infection. The infection in this situation is not what started the problem, but it does make it worse. The flea is the primary problem and must be controlled. The bacterial infection is called a secondary infection.

Ticks are blood-sucking external parasites. Ticks have gained notoriety for transmitting **Lyme disease** in humans. Lyme disease is a bacterial infection that can result in many disease symptoms in humans, including fatigue and joint pain. The same disease may infect pets as well. In addition, ticks can transmit a number of bacterial, viral, and protozoal diseases. It is concerns about these other diseases that makes control of ticks so important.

Numerous insecticides are available for controlling ticks. Just as in fleas, long-lasting products have been developed. The tick attaches to the skin for long periods, engorging itself with blood. Once full, the tick detaches and falls from the animal. It is during attachment that diseases can be transmitted. Even with some of the long-lasting control products, it is still possible to find ticks on the animal (the product kills the tick but does not repel it). The important benefit of these products is that the tick is killed before it has time to transmit the disease.

Many chemicals exist that hinder the growth or kill microorganisms. **Antimicrobial** is the general term for these types of agents. A natural antimicrobial is called an antibiotic. The suffix *-cidal* describes antimicrobials that kill microorganisms, whereas *-static* describes those that slow the rate of growth of microorganisms. For example, a germicide is capable of killing a variety of microorganisms. An antibiotic that only slows the rate of growth of bacteria is called **bacteriostatic**.

Antiseptics and **disinfectants** are two types of germicides. Antiseptics are germicides that may be used on the skin of animals. These products are not mild enough to be taken orally. Disinfectants may be too harsh to be used safely on the skin and are used as germicides on inanimate objects. An antiseptic soap is used to kill organisms on the skin, whereas a disinfectant would be used to clean the examination table in the veterinarian's office. For all of these products contact time is important to kill microorganisms. For example, many of the alcohol-based hand sanitizers require 15 to 30 seconds of contact time to be effective.

Antibiotics are products produced by one microorganism that kill or slow the growth of another microorganism. (Modern technology has allowed for the production or synthesis of new antibiotics without the need for a microorganism.) Penicillin was one of the first antibiotics discovered. Dr. Alexander Fleming, a

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physician doing research in London, first wrote about penicillin in 1929. Fleming noticed that bacteria failed to grow around a mold that had accidentally contaminated his cultures. Fleming was able to isolate a product produced by the *Penicillium* fungus, which he called penicillin. Fleming showed how penicillin was able to kill many bacteria. It was almost 10 years until penicillin was produced in quantities capable of being used to treat humans and animals. Penicillin is credited with saving many lives of soldiers wounded in World War II.

Antibiotics are capable of killing bacteria but not viruses. Many antibiotics are effective only on a limited range of bacteria. For example, penicillin is most effective for the Gram-positive bacteria. Penicillin blocks the formation of units of the cell wall that are specific for Gram-positive organisms. *Broad spectrum* describes an antibiotic that is effective against a large variety of bacteria. Broad-spectrum antibiotics are effective against many Gram-positive and Gram-negative organisms. No antibiotic has been found that can kill all the different bacteria. Selection of the appropriate antibiotic is important in treating infectious diseases.


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FIGURE 14–14 A transtracheal wash is being performed on a dog. The catheter inserted into the trachea is used to deliver and recover a small amount of saline. This fluid can then be cultured.

CLINICAL PRACTICE

Objective

- Relate the Academic Material Learned in This Chapter to Common Presentations

Culturing is the technique used to isolate and identify microorganisms causing infectious diseases. Because microorganisms are prevalent in the environment, it is important that proper sampling and handling techniques be used to isolate the actual organism causing the disease. For example, milk is often cultured to identify the bacteria causing mastitis. The skin of the teat must be thoroughly cleaned before obtaining the milk sample. Otherwise bacteria present on the skin will contaminate the sample. Many different bacteria will grow from contaminated samples in the culture and the actual disease-causing organism may be missed.

It is not practical to swab the nose of a horse with pneumonia to identify the source of the infection. Many bacteria that normally inhabit that region would be detected. The sample must be obtained from deep in the trachea or bronchi. A transtracheal wash is often used to obtain these samples. In this procedure a special catheter (the catheter has a needle and a long plastic tubing that can be threaded into the trachea) is slipped between the rings of the trachea (Figure 14–14). The tubing is passed into the trachea, and a small amount of saline (0.9% sodium chloride in water) is pushed through the catheter. The liquid is then drawn back into a syringe. This saline is used as the source for the culture.

The sample is added to a medium (solid or liquid) that provides all the necessary nutrients to allow for the growth of bacteria. Agar, a thickening agent derived from alga, is commonly used in foods such as jelly. The agar provides a solid medium that bacteria do not degrade. The nutrients include sugars, amino acids, vitamins, and minerals. Culturing anaerobes requires that oxygen be eliminated from the surrounding air by adding other gases such as carbon dioxide. Many different media exist. Differences in the nutrients added allow for specific organisms to grow. Selective media favor the growth of one type of organism and suppress the growth of others. By using a selective medium, an organism that is typically found in small numbers can be isolated by slowing the growth of the predominant bacteria. For example, *Salmonella* bacteria can cause a serious diarrhea in animals and humans. Feces have a tremendous number and variety of normal bacteria. By culturing feces on a selective media, disease-causing organisms such as *Salmonella* can be isolated.

Once the sample is applied to the culture medium, it is incubated at 37°C. When using a solid medium, the sample is streaked across the surface. The goal is to distribute individual bacteria on the medium (Figure 14–15). Each bacterium can then replicate, using the nutrients supplied. A single bacterium can divide to such an extent that within 12 to 24 hours, it has produced a colony that is visible to the naked eye (usually about the size of a pin head). Some bacteria are much slower growing and require much longer culture

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FIGURE 14–15 A bacterial culture on a plate with three selective media. The growth pattern helps to identify the type of bacteria present. The other plate shows the organism being tested for antibiotic sensitivity. A clear zone appears around the small disks when the organism is sensitive to the antibiotic on the disk.

times. The appearance of the colony is distinct for each type of bacteria. When applying a specific amount of sample (e.g., 0.01 ml), the number of colonies can provide an estimate of the concentration of bacteria within the sample. For example, if seven colonies develop from the 0.01 ml sample, the plate count would be 700 colony-forming units (CFUs):

$$100 \times 0.01 \text{ ml} \times 7 \text{ colonies} = 700 \text{ CFUs/ml}$$

Once a specific bacterium is isolated, antibiotic sensitivity testing can be performed. The goal of this testing is to identify the appropriate antibiotic for this strain of bacteria. Again *Salmonella* offers an excellent example of why sensitivity testing is performed. Although the same organism is causing the disease on two different farms, it does not mean that the same antibiotic will be effective in each case.

Small disks saturated with antibiotics are placed on a culture plate coated with bacteria. The antibiotic within the disk diffuses out into the culture medium. If the antibiotic is effective, a ring will develop where there is no bacterial growth. The size of this ring is influenced by several factors: the sensitivity of the organism, the concentration of the antibiotic, and how it diffuses on the culture medium. Because other factors exist, it is important to interpret the size of the ring based on the specific antibiotic in question (i.e., a disk with a small ring may be the most effective because it diffuses poorly and is being used at a very low concentration).

Choosing the appropriate antibiotic is important in the success of treatment. Plasmids within bacteria can carry the genetic code that provides the resistance to a given antibiotic. Treating with an inappropriate antibiotic will destroy many bacteria, leaving the resistant bacteria to thrive. This can make subsequent treatment even more difficult. The plasmids can also be exchanged between other bacteria, creating even more resistant strains.

For treatment to be successful, several important factors must be considered. Choosing the correct antibiotic is only the first step. In addition, the antibiotic must be used at a dosage that delivers adequate amounts of the drug to the affected tissue. For example, antibiotics often do not penetrate into bone tissue very easily. In cases of bone infection, the dosage of antibiotic is often much higher than if the same infection was present in the skin. A third factor is the length of time that the antibiotic is used. Some bacteria may be only slightly resistant to the antibiotic and can be destroyed by treating for long enough time periods. If treatment is stopped too soon, the mildly resistant organisms can survive and continue the infection. The next time treatment is required, this infection may be more difficult to cure, because it stemmed from these resistant organisms.

Proper usage of antibiotics and client cooperation is a very important issue in veterinary and human medicine. It is not unusual for clients to see significant improvement in their pet's condition and stop giving the antibiotic. The infection can then return. It is emphasized to clients that they must use the entire course of antibiotics that is prescribed.

Antibiotics are not effective against viral infections. Administering antibiotics to animals with viral infections may destroy many of the normal bacteria and allow resistant bacteria to survive. This inappropriate use of antibiotics can create strains of bacteria that are becoming more difficult to cure. An excellent example is actually the common cold in human medicine. A virus causes the common cold, and antibiotics will not alter the course of the disease. Physicians should not prescribe antibiotics for this type of condition. The challenge arises because a bacterial infection can develop secondary to the virus. Veterinarians and physicians must attempt to determine if an antibiotic is necessary.

Many intestinal worms shed eggs or larvae in the feces. The presence of these eggs is necessary to identify infected animals. The simplest technique is to smear a small amount of feces on a microscope slide and examine it under the microscope. The drawback of this technique is that only a small amount of feces is used and eggs can easily be missed. Other techniques exist that concentrate the eggs, making a diagnosis more likely. Fecal flotation is a concentration technique that uses the differences in specific gravity between the egg and other fecal material.

Specific gravity is basically a measure of how particles will float. Parasite eggs will not float in tap water. Various salts or sugars (e.g., table sugar, sodium nitrate, and zinc sulfate) are added to the water to raise the specific gravity of the solution to a point that the

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eggs will float. Particles in the feces remain too heavy to float and settle to the bottom. Kits are available to make this procedure quick and convenient.

Feces are placed in the container, and the salt solution is added (Figure 14–16). The feces are stirred, and the container is completely filled with solution. Enough solution is added that it actually domes above the surface of the container (Figure 14–17). A microscope coverslip is placed on top of the solution. Over the next 5 to 20 minutes, the eggs float to the surface and adhere to the coverslip. The eggs are being concentrated from the larger sample into one small region. The coverslip is lifted and placed on a microscope slide. The slide is then examined for the presence of parasite eggs or larvae (Figure 14–18).

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FIGURE 14–16 The steps in doing a fecal flotation on a stool sample: (1) Feces is added to the sample container. (2) A sleeve is slid over the container to hold solution. (3) Flotation solution is added, and a sieve is placed to trap large particles. (4) The tube is filled completely, and a cover slip is placed on top of the solution. With time the eggs float to the surface and adhere to the coverslip. The coverslip is examined under a microscope.

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FIGURE 14–17 This photograph illustrates the raised meniscus of fecal flotation solution prior to placing a coverslip.

The sensitivity of fecal flotation can be raised by using a centrifuge. Similar to the prior procedure, the fecal sample is mixed with the flotation solution. Large particles are filtered either before putting the solution in a tube or with a filter in the tube. The fluid level is raised with a meniscus above the top of the tube and a coverslip is placed on the fluid. The tube is spun in a centrifuge for five minutes. The parasite eggs will float to the top and adhere to the coverslip. The coverslip is carefully lifted and placed on a microscope slide. The slide can be examined just as in the prior procedure.

It is the egg that is passed from the adult worm that allows for a diagnosis. The period when the animal has developed an infection, but adults have not yet developed, is called the prepatent period. This is significant because there are times when clinical judgment allows us to treat an animal for the potential of having a parasitic infection, even though a positive diagnosis cannot easily be made.

In sheep and goats, a group of nematodes has clinical significance. One of the most common and devastating of these parasites is *Haemonchus contortus*. *H. contortus* has also been called the barber pole worm because of its appearance when detected during necropsy. Blood ingested by the worm creates a striped appearance resembling a barber pole. Each adult female worm can produce thousands of eggs, which pass in the feces to contaminate pasture. The prepatent period of *H. contortus* is about three weeks. Because these worms consume blood, the animal can lose a high volume of blood, becoming anemic and low in blood protein. Infected animals often have poor weight gain, depressed appetites, and anemia. Severely infected animals can also develop bottle jaw. This is an accumulation of fluid under the jaw due to low blood protein and the resulting decrease in osmotic pressure of the blood.

As in many diseases, the young and debilitated are the most susceptible to parasites. Although not complete, animals do develop a certain level of immunity to intestinal parasites. While the parasites are not completely eliminated the immunity can keep the level of parasitism at a moderate level and minimize the clinical signs.

H. contortus and many of the intestinal nematodes enter a dormant period when environmental conditions are not favorable for completion of the life cycle outside the animal. This period of dormancy, called hypobiosis, occurs over the winter months in those regions with cold winters. In the spring, which often coincides with the lambing and kidding, the larvae enter a much more active period and mature into adults. The adults then begin to produce large number of eggs that go on to contaminate the pastures. *Periparturient*

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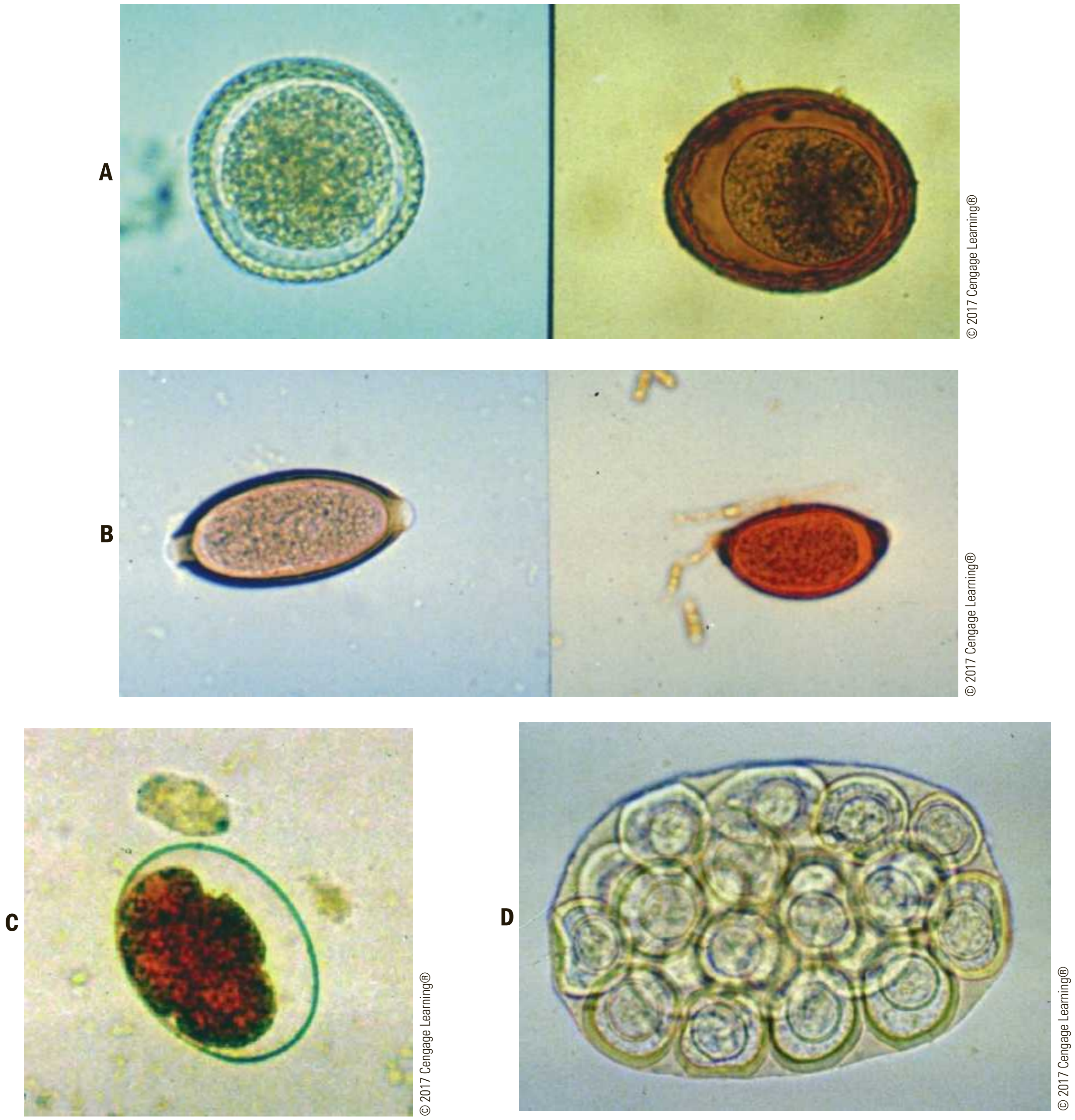

FIGURE 14–18 Parasite eggs commonly found on fecal flotation. These eggs are used to diagnose an infection. A. Roundworm eggs (*Toxocara canis*, left; *Toxascaris leonina*, right). B. Whipworm, left (*Trichuris vulpis*); lungworm, right (*Capillaria aerophila*). C. Hookworm (*Ancylostoma*). D. Tapeworm (*Dipylidium caninum*).

rise describes this dramatic increase in fecal egg count. The increasing pasture contamination occurs at a time when the very susceptible young are beginning to graze.

While antibiotics are medications used to treat bacterial infections, anthelmintics are used to treat parasitic infections. Previously, anthelmintics were used to keep parasite numbers at very low levels because of the impact on weight gain and performance. With this strategy, any worms resistant to treatment were left to replicate. In the recent past, concern has risen over the development of parasites resistant to the currently available anthelmintics. This has required development of new worming strategies.

Rather than treating every animal frequently, a current strategy is to treat the animals showing the most significant effect of parasitism. *H. contortus* can create a severe anemia and low protein levels or hypoproteinemia in parasitized animals. One strategy for targeting the anthelmintic treatment is called FAMACHA, after the founder of the system. In this protocol, each animal is evaluated for the color of its mucous membranes. A color chart is compared to the color of the conjunctiva of the eyes. Only animals with the palest mucous

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membranes are then treated. This system is labor intensive and does require some training to properly conduct the evaluation. It is important to realize that this system is effective only for *H. contortus*, which creates anemia. This would not be effective for other nematodes that do not consume blood from the host. By treating only clinically affected animals, there is less selective pressure for creating resistant parasites.

The cow from the introduction, suffering from coliform mastitis, was showing severe signs secondary to a bacterial infection in the udder. The bacteria gain entrance into the udder through the teat canal and begin to rapidly divide, using the milk as a source of nutrients. The cow's immune system attacks the bacteria, and many begin to die. Coliform mastitis is caused by Gram-negative bacteria, which contain endotoxins in their cell walls. The sudden death of large numbers of bacteria releases a large amount of endotoxin.

The endotoxin causes many signs in animals. Typically, the cow shows signs of fever, rapid heart rate, diarrhea, and an inactive rumen. Treatment usually includes fluid therapy and medications that block the effects of the endotoxins. A very useful technique in treating cows with coliform mastitis is frequent milking of the infected quarter. By removing the milk every one to two hours, much of the endotoxin is eliminated before it can be absorbed into the bloodstream. In addition, many bacteria are physically removed. The combination of frequent milking and treating the effects of the endotoxins keeps the animal supported until its immune system can eliminate the infection.

Botulism, on the other hand, is the result of an exotoxin. With botulism, the animal is not infected by the bacteria but ingests the exotoxin that is produced. Spores of *C. botulinum* are commonly present in the soil. Often the source of the toxin is a decomposing animal carcass that is caught in the animal's hay. The carcass provides an environment in which the spore can germinate and begin dividing. Exotoxin is produced and released into the carcass and surrounding hay.

When ingested, the botulism toxin blocks the release of acetylcholine at the nerve muscle synapse. The result is the profound muscle weakness. In horses, the earliest signs are muscle weakness and difficulty chewing and swallowing. When examined, these animals have very weak tongue tone. If not caught early, the weakness becomes generalized and so severe that the animal is unable to rise.

When botulism is this severe, the horse may die from dehydration or from paralysis of the respiratory muscles. Beginning treatment early in the disease is very important in improving the outcome. The specific treatment is botulism antitoxin (antibodies specific against the toxin). The antitoxin is extremely effective against any circulating toxin but does not reverse the effect of any toxin that has already bound at the synapse. Therefore, the more quickly the treatment is initiated, the better the results.

Supportive treatment is also essential. Supplementing water and feed is necessary in those horses that cannot eat. Fluids can be given intravenously through a catheter. A slurry of protein-rich food can be pumped into the stomach through a tube passed through the nose and esophagus. Down horses must also be rolled side to side to prevent pressure damage in the muscles and nerves from lying too long.

Cats that spend a portion of their time outdoors have the potential to encounter other cats. Often this can result in a fight between or among animals. This is especially true of male cats that are fighting to protect their territory. A bite can introduce bacteria that are common in the mouth of cats or introduce bacteria that are present on the skin and hair of the bitten animal.

An abscess, the accumulation of a pocket of pus, is a common result. *Pasteurella multocida* is a very common organism that causes these catfight abscesses. This type of interaction can also introduce viruses (e.g., feline leukemia virus). The viruses do not contribute to the abscess but can result in a more serious infection. Treatment of the abscess does generally include antibiotic therapy. A number of antibiotics are effective for the common bacteria found in abscesses. Recovery is also speeded by draining the pus from the abscess. This may be done through the initial bite wound or by making a new incision.

In large abscesses, a drain may be placed. A Penrose drain is soft rubber tubing that is placed in the abscess cavity and exits through the skin. The purpose of the drain is to keep the opening from healing too quickly. As more pus accumulates, it is able to drain out of the hole kept open by the Penrose drain. As the amount of discharge declines, the drain can be removed.

SUMMARY

Koch's postulates lay the foundation for investigation of infectious disease. The following four statements paraphrase these postulates: (1) The infectious agent should be detectable in sick animals but not healthy animals. (2) It should be possible to isolate and culture the organism. (3) Organisms taken from the culture and introduced into a healthy animal should cause the same disease. (4) The same organism should be isolated from this second animal as well. Knowing these postulates and possessing understanding of the four major infectious disease agents (bacteria, virus, fungi, and parasites) help veterinarians identify, prevent, and treat infectious diseases.

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REVIEW QUESTIONS

1. Define any 10 of the following terms:

   coliform
   botulism
   anthrax
   Koch's postulates
   fomite
   vector
   eukaryotic
   prokaryotic
   prodromal phase
   anemia
   systemic
   Lyme disease
   antimicrobial
   bacteriostatic
   antiseptics
   disinfectants

2. True or False: Horses typically have poor muscle tone in their tongues.
3. True or False: Bacteria are multicelled organisms.
4. True or False: Fungi contain chlorophyll.
5. Transduction requires the transmission of bacterial DNA by a ________.
6. The suffix *cidal* means the antimicrobials that ________ microorganisms.
7. A Gram-________ bacterium causes coliform mastitis.
8. How many principles are found in Koch's postulates?
9. Give an example of an arthropod.
10. What causes ringworm?
11. What external parasite transmits Lyme disease?
12. Is botulism the result of an endotoxin or an exotoxin?
13. Who developed the commonly used bacteria-staining technique?
14. List the three types of anthrax.
15. List the four major classes of infectious disease-causing agents.
16. What is the goal of antibiotic sensitivity testing?
17. Describe the process of sensitivity testing an antibiotic for specific bacteria.
18. List the steps for performing a fecal flotation.
19. What test must be performed to identify microfilariae in a dog?

ACTIVITIES

Materials needed for completion of activities:

tryptic soy agar media plates
sterile cotton-tipped applicators
incubator at 37°C (local veterinarians may be able to incubate the plates)
assorted disinfectants
hole punch
tweezers
filter paper
marker or wax pencil
incubated cultures from step 1 or 2 or prepared bacterial cultures (allow for a known Gram-positive or Gram-negative organism to be used)
microscope (with oil immersion lens)
immersion oil
sterile swabs
microscope slides
Gram stain kit
Bunsen burner
tongs for holding slides
latex or vinyl gloves
protective eyewear

1. This experiment is designed to culture bacteria from humans and the natural environment. Take a sterile, cotton-tipped applicator and swab the area being investigated. The swab should be wet when swabbing dry surfaces. Potential surfaces include skin, mouth, under the fingernails, desktops, soil, and soles of shoes, or other surfaces if approved by the instructor. Use the swab to inoculate the surface of the culture media. The swab should be held at approximately a 45-degree angle and placed gently against the media. Too much pressure will cut the surface of the media. The swab should be taken in a zigzag fashion across one half of the plate. This swab should then be discarded (Figure 14–19).

   A new sterile swab should then be taken across the already inoculated section one time. Inoculate the remaining half of the plate with this swab in

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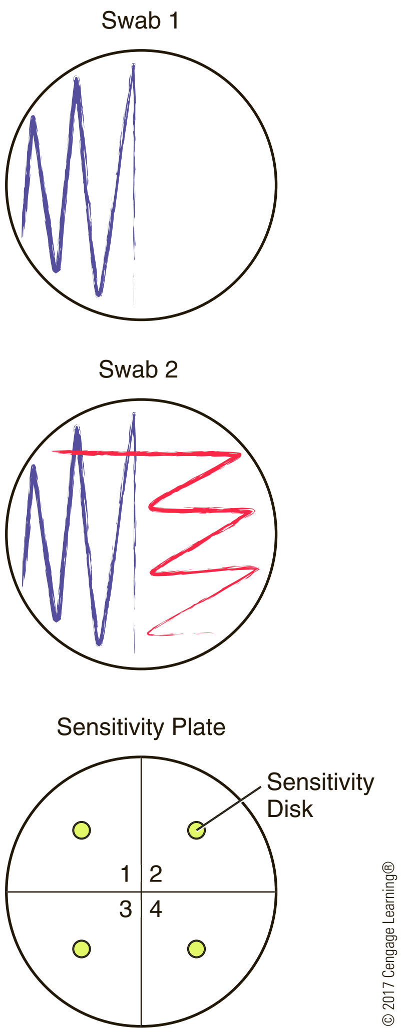

FIGURE 14–19 The proper technique for streaking a culture plate.

a zigzag manner. By using the second swab, the number of bacteria in the second half will be significantly lower. The goal is to spread the bacteria, so that an individual cell can produce a colony. If the tested surface is highly contaminated, the colonies may grow too close to identify individual types.

When a single bacterium produces a colony, it will have a distinct appearance. The colony will be consistent for each type of bacteria. Colonies can be judged on size (tiny or pinpoint, small, medium, large, or very large), shape (round, irregular, spreading), color (white, yellow, creamy, red, metallic), and cross-sectional view (flat-topped, domed, concave).

The plates should be labeled with your name and the surface tested. The plates are turned upside down (culture media on the top) and placed in an incubator at 37°C. The media plates can be left at room temperature; however, results may be inconsistent and growth may be poor. The culture plates should be examined at 24 and 48 hours for growth of microbial colonies.

For each surface tested, answer the following questions:

- How many different colony types can be identified?
- Describe the shape, color, and size of each type of colony. Sketch each type of colony.
- Compare the different media plates. Which surfaces seemed to have the largest number of bacteria? Which surfaces seemed to have the largest variety of bacterial types (i.e., different colonies)?

2. Individual colonies from question 1 can be used in this experiment to evaluate the effectiveness of various antiseptics. Gather various antiseptics and disinfectants from home. (This may include items such as mouthwash, liquid soap, topical wound sprays, and household cleansers listed as disinfectants.)

Identify a single isolated colony from one of the cultures performed in question 1. Take a new sterile swab through this colony. Be careful to touch only one colony. Take this swab and cover the entire surface of a new culture plate. Turn the plate approximately 60 degrees and repeat the swabbing using the same swab. Turn another 60 degrees and repeat. The goal is to evenly distribute the bacteria over the entire surface of the culture plate.

Using a standard hole punch, make numerous circles or disks from a piece of filter paper.

Using tweezers, dip a circle of filter paper in a disinfectant or antiseptic. Hold until all excess has dripped from the paper. Place the filter paper disk on the surface of the newly streaked culture plate. Distribute a number of circles around the perimeter of the culture plate. It is important to divide the bottom of the plate into sections with a marker or wax pencil. Place a number in each section. Make a key to identify each number with the product used (for example, 1 = mouthwash, 2 = hand soap, and so on).

Gently press each disk against the culture media with a probe. Invert the plate and incubate for 24 hours. If the disks do not stick to the surface of the media, the plate can be cultured with the media on the bottom. If incubated in this fashion, it is important to check frequently because the media will dry out quickly in this position.

Examine the plate for bacterial growth. Observe for any clear zone surrounding the individual

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disks, where no bacteria have grown. Measure each zone and record.

- Were any of the disinfectants or antiseptics effective in preventing growth of bacteria?
- Which product produced the largest zone of inhibition?
- Were the products consistent with all different bacteria?

3. Perform the Gram stain. Take a sterile swab and lightly touch a colony of bacteria. Place a drop of distilled water on a slide. Smear the surface of the slide with the swab. Allow to dry completely. The bacteria must be fixed to the surface of the slide. This is accomplished by holding the slide with the tongs and passing the slide (bacteria side up) through the flame of the Bunsen burner two to three times. This prevents the bacteria from being washed off the surface of the slide.

   Stain the slide following the Gram stain procedure. Specific times and techniques will vary with the stain purchased. The basic procedures are to saturate the surface of the slide with the stain and rinse with water between steps. One step is to decolorize the initial stain. This is what distinguishes Gram-negative from Gram-positive bacteria. Following the staining, examine the slides under a microscope.

   - Are the bacteria Gram negative (pink) or Gram positive (blue)?
   - Are the bacteria cocci or rods?

   When dealing with bacterial cultures, wear latex or vinyl gloves and protective eyewear. Wash your hands thoroughly following each procedure, and thoroughly clean laboratory equipment and tables as well.

4. The USDA Animal and Plant Health Inspection Service (APHIS) provides a comprehensive listing of animal diseases as well as status updates on eradication programs. Also, details of the APHIS traceability programming can be found at the USDA APHIS website. Traceability allows for the identification of the origin of infected livestock, which in turn can aide in disease control. After reviewing the APHIS material, report on the protocol of interstate transport of livestock.
5. Research a disease and answer the following questions in your report:
   - What are the features of the causative organism (such as Gram stain characteristics, type of virus [RNA or DNA])?
   - How is the disease transmitted? Is it contagious? How long is the incubation period or life cycle?
   - How is the disease diagnosed?
   - What is the treatment for the disease? Is it often fatal?
   - How can it be prevented?
   - Is it a threat to humans?
6. Research parasites. Create a table listing types of parasites (internal or external; bacterial, fungal, viral, or protozoal). Within the table, provide the common name, the scientific name, and a brief description of how the parasites are transmitted and their effects on the hosts.
7. Research the diseases presented in this chapter. Create a table listing the diseases. Within the table, identify the agent causing the disease (bacteria, virus, fungus, or parasite) as well as the treatment for the diseases.

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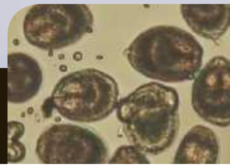
CHAPTER 15



Disease Prevention

Objectives

Upon completion of this chapter, you should be able to:

- Name the basic components of disease prevention.
- Describe the types of vaccines available and their roles in disease prevention.
- Link the clinical significance of the academic material learned in this chapter to veterinary practice.

Key Terms

antioxidant
ventilation
tunnel ventilation
wet dewlap
biosecurity
equine infectious anemia
bio-contaminant
quarantine
metaphylaxis
fibrosarcoma

Introduction

Treating infectious diseases is a critical part of a veterinarian's life. However, the goal of the profession is to prevent disease. With prevention, the animal and owners are not faced with the losses associated with disease. Many factors must be considered in preventing disease.

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A Day in the Life
Here We Go Again . . .

Over the years I have seen similar cases too many times. The scenario begins when I receive a call from a farmer reporting several cows being off feed. During the visit, it is obvious a respiratory infection outbreak is spreading through the herd. Often, a quarter to half of the cattle show clinical signs. These animals cough, breath heavily, and have nasal discharge. Typically, they present with high fevers and very poor appetites (Figure 15–1).

The classic history reveals that a few animals were purchased recently and introduced to the herd. These new cattle do not show any clinical signs of disease. Additionally, the herd has not been recently vaccinated. The purchased animals are typically healthy, but with the stress of transport and a new environment they shed bacteria or viruses. However, they have adequate immunity because of prior exposure and therefore remain healthy. Unfortunately, the existing herd is not immune and the disease spreads rapidly.

In any herd with such problems, the economic costs can be quite staggering. Expenses include veterinarian examinations, treatment (medication costs can be very high for large animals), death loss, and a decrease in productivity as afflicted animals produce little milk or gain little weight.

Fortunately, not all of my work is treating the animals after they are sick. Many producers understand the concept of disease prevention and ask for advice before purchasing cattle. For example, a large dairy that I service planned to purchase a group of 40 dairy cows. The dairyman, the seller, and I worked together on a plan. We recognized that there are always risks associated with purchasing cattle, but the right approach would help to minimize the risk. We screened the incoming cattle for several diseases and were able to somewhat isolate them for several weeks after arrival. Thankfully, all of the tests were clear and there was no evidence of disease problems.

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FIGURE 15–1 Heifer suffering from pneumonia. This heifer has a thick nasal discharge and labored breathing.

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FIGURE 15–2 An anesthetized dog with a large number of porcupine quills.

Many kennels require visiting dogs to be current on all their vaccines, including kennel cough. The kennel cough vaccine is not one that I recommend for every animal. When many dogs are combined in a confined area such as a kennel, however, the risk increases for kennel cough, and this is why kennel owners require the use of the vaccine.

As I do my preparation for writing a chapter, my job often leads me to important information to include in the book. My practice is in a rural area and many of the pets have access to the outdoors. Unfortunately this puts the pets at risk of being struck by a car, bitten, or even shot. One day, I had two dogs that tangled with a porcupine. I had to anesthetize the dogs and carefully pull each quill (Figure 15–2). I can only imagine how painful it was for the poor dogs to have hundreds of quills in their mouths and skin.

I remember graduating from veterinary school. For the first time, I heard the word *doctor* in front of my name. All the years of hard work had finally paid off. Actually, there was one more step. In addition to obtaining a doctorate, veterinarians must meet additional licensing requirements before practicing medicine.

I had already passed the National Board Examination. The majority of states require a minimum standard

continues

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A Day in the Life continued

on this test before permitting the veterinarian to enter practice. Many states have additional requirements beyond the National Board Examination. When I graduated, Pennsylvania required the successful completion of an oral comprehensive examination for all new veterinarians. The candidate entered a room and sat before four veterinarians on the licensing board. The candidate could be asked anything about veterinary medicine by this group.

While waiting for my turn to enter the examination, I felt like I was being sent into an interrogation. My mind raced with the thought of bright lights shining into my eyes, sweat beading on my forehead, and the interrogators prying answers from me. The entire process was quite intimidating. Over the four years of veterinary school, a tremendous amount of information was covered. I wondered what they were going to ask.

When I finally entered the room, the group was quite nice. They welcomed me and told me to make myself comfortable. The honest truth was that I was not going to be comfortable until I knew if I had passed. My entire career had come down to the next few questions.

The first question concerned a condition called gastric torsion in dogs. In this situation the dog's stomach twists, trapping gas inside. This is a life-threatening problem, requiring surgical and medical treatment. I had just been through the emergency service rotation, and this disease and its treatment were fresh in my mind. At this point, I was feeling quite smug. Maybe this oral exam was not so tough after all.

The next question burned in my mind. I was asked to discuss the causes and treatment of wool eating, wet dewlap, and cannibalism in rabbits. My jaw dropped and heart stopped. I'm sure the panel immediately knew I was in trouble from the expression on my face. Exotic animals were not a significant part of the core veterinary school curriculum. Plenty of opportunity existed for studying this kind of information, but it was elective, and up until that moment, I did not have a lot of interest in the subject.

I honestly could not remember hearing of these diseases before that moment, and I surely did not know any specifics. But one thing that veterinary school does teach is how to use the knowledge that you do have. After a few seconds of stuttering, I began to discuss some very important principles in disease prevention. I discussed in general terms proper nutrition, proper sanitation, and minimizing stress. They asked me to explain a few other points about the topics before moving to the next question. (Fortunately, the remaining questions related to familiar material and I was granted a license!)

As I left the room, I did not know if I had passed. I just had to investigate the unfamiliar diseases. Even though I had not learned about these specific diseases, I had learned the important principles of disease prevention. My answers, although more general than the board may have wanted, were quite correct. In this chapter, the discussion centers on important principles in preventing infectious diseases.

DISEASE PREVENTION

Objective

- Name the Basic Components of Disease Prevention

Many factors contribute to an animal's resistance to disease, such as immunity and nutrition, which have already been discussed in depth in previous chapters. A healthy animal remains resistant to most diseases. The skin and mucous membranes serve to prevent invasion of pathogens. The normal bacterial flora plays a role in maintaining the health of an animal. These bacteria secrete substances that inhibit the growth of other organisms. In addition, pathogens must compete for adhesion sites. The pathogen must adhere to the animal's cells before an infection can begin.

It is an obvious conclusion that maintaining the normal bacterial flora helps to maintain the health of an animal. Stress, nutrition, medications, and other diseases influence the normal bacteria. Humans can think of factors that produce stress (e.g., a major examination pending). In animals, stress does not require conscious thought. Stress is any factor considered a threat by the animal. An animal under stress releases higher levels of epinephrine and cortisol (see Chapter 10). In addition, stress increases the activity of the sympathetic nervous system.

A wide range of factors can contribute to stress. Examples include overcrowding, competition for feed, extremes of weather, rough handling, noise, and transport (Figure 15–3). Environmental conditions also have a significant impact on health risk. Wet conditions, manure accumulation on hair coat, and poor air quality (dust, smoke, and ammonia) can all increase the stress and demands on an animal. Commingling animals from multiple sources also adds to the stress as the animals establish their social hierarchy. Some factors that are designed to help an animal can also contribute to stress. Hospitalization and surgery both stress the animal. Following major surgery, an animal can be more susceptible to contagious diseases.

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FIGURE 15–3 These individually tied cows have feed delivered directly to them. This feeding method greatly decreases competition.

The increase of cortisol in response to stress has specific benefits. Cortisol helps to increase carbohydrate metabolism and shifts glucose to the brain. The cortisol also minimizes inflammation in damaged tissue. As a side effect, the elevated cortisol suppresses the immune system, increases the risk of diabetes, and weakens muscle tissue. These signs are quite evident in hyperadrenocorticism (Cushing's disease), where cortisol levels remain chronically elevated.

Nutritional problems can also be considered a stress, or may have a direct effect on diminishing the immune response. Many vitamins and minerals (such as vitamin E and selenium) are crucial in maintaining a healthy immune system. All the **antioxidants**, oxidation-inhibiting vitamins and minerals, play a role in the animal's immune system. Other deficiencies may weaken the defense of the animal in more general ways. For example, a protein and energy deficiency may weaken the skin and mucous membranes, increasing the likelihood that pathogens will invade.

Sudden changes in diet are also an important stressor in animals. A major effect of diet changes is the decline in the normal bacterial flora in the intestinal tract. This greatly increases the risk of pathogen invasion and consequential disease. Medications, primarily antibiotics, pose the same threat to the animal's defense system. When treating a bacterial infection, antibiotics also cause a decline in the normal flora—a particularly high risk if the pathogen has resistance to that antibiotic. This is another key reason why antibiotics should be used only in situations in which they are actually required.

Some factors that increase the animal's stress also contribute to increasing exposure to pathogens. Overcrowding was mentioned as a stressor. Overcrowding increases the competition for feed and comfort, in addition to increasing the contact between animals, which aids in the spread of contagious diseases. The high density of animals typically increases fecal and urine contamination in the environment as well. Humidity is often higher in confined areas, which aids in the survival of pathogens outside the body. Pathogens that are spread through the air physically have less distance to travel when contacting another susceptible individual.

Ventilation describes the exchange of air from within a building to the outside. As animals exhale, they add moisture, heat, and potential pathogens to the air. Ammonia and hydrogen sulfide are also released from the urine and feces in the building. Excess of these toxic gases can cause irritation to the mucous membranes and lower the respiratory defense mechanisms, increasing the risk of a pathogen's invasion of the respiratory tract. Most organisms require some degree of moisture to survive, so exhaled moisture contributes to the success of pathogens. The activity of animals in a barn also creates airborne dust particles. These particles can help to carry pathogens and damage the protective ability of the respiratory tract.

To help prevent disease, fresh air from the outside needs to be brought into the building and the stale air exhausted. This helps to lower the moisture, heat, ammonia, and pathogen load in the air. Some facilities are built to allow for natural airflow to make this exchange (Figure 15–4). Other buildings rely on fans to move the air efficiently. **Tunnel ventilation** has become quite popular (Figure 15–5). In tunnel ventilation, the fans are placed at one end of the barn, and all the air inlets are on the opposite end. With the fans running, the air is brought into the barn over a broad area and an even flow of air is swept over the animals. In warm weather, enough air is exchanged to produce a breeze of 3 to 5 miles per hour.

In cold weather, less air can be exchanged. In these conditions, enough body heat must be maintained to

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FIGURE 15–4 A free stall barn with comfortable cows. Note the high open side walls and the large number of fans.

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FIGURE 15–5 Barn equipped with tunnel ventilation.

prevent freezing within the barn. Even in the coldest weather, at least four air exchanges per hour should be accomplished. This means that the exhausted air should be equivalent to four times the amount of air contained within the building. Unfortunately, in many barns there are areas that do not completely exchange air. These areas can be regions where confined animals are at a higher risk for disease. In the heat of the summer, up to 30 air exchanges per hour may be needed to maintain appropriate conditions.

In summary, proper ventilation helps to protect the animal in several ways. It maintains appropriate temperature and humidity levels in the barn. It also minimizes the accumulation of irritating gases as well as lowers dust levels. Removing the already breathed air also physically removes infectious agents that have become airborne through exhalation and coughing. Properly designed ventilation also minimizes dead air space and drafts. Considerable emphasis is put into ventilation design in new construction. Modifying existing barns to provide proper air flow can be more difficult.

In general, older animals have a higher level of immunity than the very young. They have been exposed to more organisms and vaccines over the years. They also have a higher likelihood of being carriers for pathogens. Therefore, when designing animal facilities, it is important for the airflow to move from the youngest to the oldest. In this way, the young animals are not exposed to the pathogens that could be exhaled from the mature animals. It is ideal that young animals do not commingle with adults for the same reasons. Having separate areas of confinement is very helpful.

Urine and feces not only release ammonia into the air but also contribute pathogens. Establishing proper sanitation and providing clean, dry bedding are extremely important in reducing pathogen load. Physically, these steps help to lower the number of organisms in the environment. In addition, they help to keep the animal's hair clean and dry. Hair has a very important role in insulating the animal and conserving body heat in cold weather. When the hair coat becomes wet and matted with feces, the animal loses higher levels of heat. In addition, prolonged exposure to moisture, urine, and feces increases the risk of developing skin disorders (such as **wet dewlap** in rabbits, an infection in the skin of the lower neck).

VACCINES

Objective

- Describe the Types of Vaccines Available and Their Roles in Disease Prevention

The previous details discussed are designed to minimize the exposure of the animal to pathogens and to limit any factors that decrease the animal's resistance to disease. Another component of disease prevention is to increase the animal's immunity with vaccination. Much has been discussed about vaccines in Chapter 11. Many factors are involved in determining a vaccination program.

The goals of a vaccination program vary with the type of animal and the disease. Most vaccines do not offer complete disease protection. Properly vaccinated animals can still become ill when overwhelmed with exposure to a pathogen. Therefore, vaccination programs must be established with realistic goals in mind. Successful vaccination requires that an effective vaccine

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be given to an animal that is capable of responding well. In addition, the vaccine must be given long enough before exposure to allow immunity to develop.

Consideration must be given as to which vaccines should be included in the program. The risk of acquiring an infection is one important factor. Certain organisms have a specific geographic location. Therefore, vaccination is not considered in areas where the organism is not found. Other factors such as age, sex, and functional purpose of the animal must also be evaluated. Some diseases may be common only in young animals, and some infections are associated with reproductive problems that require females to be vaccinated. Certain diseases are spread from bulls to cows during natural breeding. Artificial insemination and the use of semen from bulls free of these diseases prevent the need for vaccination against these organisms.

The severity of the disease must also be evaluated in terms of medical and economic impact. A very mild and self-limiting disease usually does not require vaccination. Diseases such as distemper in dogs and panleukopenia in cats are so deadly that they are included in all vaccination programs for these species. In food-producing animals, a disease may be self-limiting, but if it attacks a large percentage of animals, it may still be a very costly disease, due to loss of production. This type of disease may be included in the vaccination program.

Vaccines vary considerably in how effective they are at preventing disease. Some vaccines provide only a short-lived immunity. Others may decrease the incidence only slightly or may lessen the severity of the disease. The success must be evaluated against the cost of the vaccine. A costly vaccine that has only limited success may not be used. A vaccine may also have adverse effects (such as suppressed milk production in dairy cattle), which is another factor considered in establishing a program.

In companion animals, vaccination programs are established with the goal of preventing the disease in every animal vaccinated. The emotional attachment to pets makes the individual animal of extreme significance. The vaccines are given at frequent intervals in young pets with the goal of developing immunity as the maternal antibodies decline. Even the most thorough program may not prevent every case.

Experts in organizations such as the American Animal Hospital Association and the American Association of Feline Practitioners have developed guidelines to help practitioners in making vaccination decisions. Certain organisms are considered so important that they are recommended to be included in all vaccination programs. These core vaccines include distemper, adenovirus, parvovirus, and rabies for all dogs. In cats the vaccines for panleukopenia, herpes virus, calicivirus, and rabies are also considered core. Decisions on noncore vaccines are then made based on particular risk factors for the individual pet. For example, a Lyme vaccine may be recommended for a hunting dog in an endemic area but not included in a program for a dog in a large city in a nonendemic area.

In the farm setting, vaccination programs help establish herd immunity. These vaccination programs are designed to decrease the number of susceptible animals in an attempt to prevent a herd outbreak. Ideally, every animal would develop complete immunity. However, it is quite possible for an individual to develop clinical disease. If herd immunity is established, the disease will not spread throughout the remainder of the animals. In addition, even if disease occurs in a vaccinated animal, the severity may be much less and recovery much quicker when compared to an unvaccinated animal.

Herd immunity is maximized when all the at-risk animals are vaccinated. The vaccination programs are established to minimize the potential losses experienced with an outbreak of clinical disease. Producers also attempt to keep the cost of the program as low as possible. Therefore, only animals with a reasonable threat of exposure are vaccinated, and they are vaccinated only as often as is necessary to maintain immunity.

Timing of vaccinations is also critical to the success of a program. Vaccinations need to be administered early enough that an immune response can be mounted prior to exposure to the disease. Vaccinating a dog for kennel cough after it has arrived at a kennel would not be protective. Likewise, vaccinating cattle in the presence of a pneumonia outbreak will not prevent clinical disease in cattle already incubating the disease. Vaccines may also be scheduled to maximize protection at particular times of the year or production cycle. In some facilities, pneumonia may be more likely in the winter when the cattle are housed, rather than when grazing on an open pasture. Vaccinating these animals in the fall allows for an appropriate immune response to be mounted prior to the high-risk time. Certain vaccines may also be used to improve colostrum quality. In this case, timing the vaccination a month or two prior to the end of gestation can maximize the benefit of the vaccine.

In review, immunity may be active or passive. Passive immunity is acquired with the transfer of antibodies. This may occur with the ingestion of colostrum by a newborn. A well-vaccinated mother generally has better-quality colostrum. The higher quality of colostrum improves the amount of antibody absorbed by the newborn. The volume and how quickly after birth the colostrum is delivered directly influence the passive transfer.

Certain vaccines also provide passive immunity by supplying antibodies. The immunity is only temporary, and therefore the timing of the vaccination is

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critical. An example is tetanus antitoxin, which may be administered at a time when an animal is at high risk. This may include a horse with a deep puncture wound or an animal that is being castrated. If the animal was not vaccinated previously for tetanus, these antitoxins have the distinct advantage of delivering immediate immunity.

For an animal to develop active immunity, a vaccine must be administered that allows the animal to produce its own antibodies. Natural infections also create an active immunity. Natural infections often provide the strongest and longest lasting immunity. Vaccines must provide enough antigens to stimulate the immune system. The two major types are killed (commonly virus or bacteria) and modified live vaccines (typically virus). In a killed vaccine, enough antigens are provided for the immune stimulation. The organism within the vaccine is completely inactivated.

With killed products, a primary vaccination initiates the immune response. A booster dose must be given in three to four weeks to stimulate the memory response. It is only after this second dose that effective levels of antibodies develop. Relative to modified live vaccines, the killed products provide a short immunity. Periodic boosters are then required to maintain immunity (which typically ranges from several months to a year).

Modified live virus vaccines (MLVs) stimulate both antibody production and cell-mediated immunity. Initially, MLVs deliver a small amount of antigen. The virus then undergoes replication once injected into the animal. The amount of antigen then increases to a level adequate to stimulate the immune response. The virus has been modified so it can replicate without causing clinical disease. In general, an MLV provides a higher level and longer-lasting immunity than do killed products. Many MLVs do not require a booster vaccination in the three- to four-week period, as the killed products do. The immunity may not be indefinite, however, and a booster is required every one to three years.

Numerous factors can lead to a failure of a vaccination program. Modified live vaccines require very careful handling to ensure that the organism will replicate once injected. These products come as a dehydrated powder and a liquid to mix with it (Figure 15–6). Once rehydrated, the vaccine should be used immediately. The organism can be killed by extremes of temperature, direct sunlight, and exposure to many disinfectants. Proper storage at controlled refrigerated temperatures is essential. (These factors may also damage killed products.) If the organism does not replicate, not enough antigen will be present to stimulate an immune response.

With killed vaccines, failure to give a booster dose also prevents acceptable levels of immunity. The timing of the booster is also important. Administering the booster in less than two or more than eight weeks

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FIGURE 15–6 Examples of vaccine selection (clockwise from lower left): (1) Modified live vaccine. The freeze-dried powder must be reconstituted with liquid before usage. (2) An oral vaccine (bolus) used to provide passive immunity to newborn calves. (3) A modified live vaccine administered intranasally. The white nasal canula shown in front of the bottles is applied to the end of a syringe to administer the vaccine into the nasal passages. (4) A killed vaccine that is ready to be administered.

greatly decreases the level of immunity developed. It is essential to remember that immunity only develops following the vaccination with either type of product. Failure may occur if the animal is exposed before or shortly after the vaccination.

The animal must be able to respond to the vaccine. Very young animals may have levels of maternal antibody that prevent the immune system from responding. The maternal antibodies quickly bind to the antigen and therefore prevent the need for the immune system to respond. Animals that are under stress or are ill may not be able to mount an effective response. Poor nutrition or certain medications also decrease the level of immunity.

Even a well-vaccinated animal with a good level of immunity can be overwhelmed if exposed to high levels of pathogens. In effect, poor management can defeat a good vaccination program. Any failure in management (such as poor sanitation, poor ventilation, or overcrowding) can result in the animal being exposed to such high numbers of pathogenic organisms that the immune system cannot defeat them.

CLINICAL PRACTICE

Objective

- Link the Clinical Significance of the Academic Material Learned in This Chapter to Veterinary Practice

Kennel cough in dogs represents an excellent example of how vaccination programs are adapted. Several different viruses or the bacteria *Bordetella bronchiseptica*

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may cause kennel cough. Dogs with kennel cough typically present with a severe, dry hacking cough. Dogs that develop kennel cough generally respond to medication (cough suppressants and possibly antibiotics) and improve within one to two weeks.

Because the disease is generally self-limiting and the incidence of kennel cough is quite low in the average house pet, routine vaccination is not always required. Kennel cough is highly contagious and is able to be spread through the air or by direct contact. Therefore, dogs that are housed in close quarters with others are at a higher risk. This is especially true in a boarding kennel, where dogs from multiple households are brought into close confinement. Because the risk is higher in these situations and the disease can spread so rapidly, vaccination for kennel cough is often required before boarding.

Biosecurity is a term used to describe practices that protect the health of the animals on a farm by preventing the introduction of pathogens (Figure 15–7). Ideally, these practices prevent the introduction of disease into the herd. For example, horses are often screened for **equine infectious anemia** (EIA) prior to a show or purchase. EIA is a viral disease causing fever, an anemia from the breakdown of red blood cells, depression, and weight loss. Some horses die from EIA; others develop a chronic infection and become carriers of the virus. These horses may appear normal but when under stress may shed the virus. They can then be a source of infection for other animals on the farm. The testing of animals for infectious diseases before introducing them onto a new farm is an important biosecurity practice.

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FIGURE 15–7 This farm has implemented biosecurity measures to limit the risk of disease entering the farm.

As discussed biosecurity begins at the farm level, but it is also very important on regional and national levels. For example, individual states develop specific requirements for animals being transported from other states. National guidelines are in place to prevent the importation of disease into the United States.

Bio-containment is the practice used to minimize the spread of disease if it is introduced onto the farm. The previously mentioned dairy herd with the outbreak of respiratory infection emphasizes the importance of biosecurity. The farm in this case had poor biosecurity. The purchased cattle represented a real threat to the health of the existing herd. The purchased animals had not been screened for any infectious diseases, and the existing herd was not well vaccinated. By recognizing that the purchased cattle were a potential threat to introduce infectious respiratory diseases, the farmer should have vaccinated the herd. Even with proper vaccination, a small number of cases may have developed. The goal of the vaccination program is to establish herd immunity and minimize the spread of the disease.

Diseases can be introduced onto a farm by many vectors. Visitors, trucks (feed, livestock), rodents, birds, and water supply are all potential sources for new diseases. Even veterinarians represent visitors to a farm. Veterinarians take precautions by sanitizing boots and hands between farm visits.

The greatest risk of new disease is introducing new livestock. The newcomers have the greatest potential to introduce large enough numbers of pathogens in close contact to the existing animals. An excellent procedure for minimizing this risk is **quarantine**. Quarantine confines the animal in a location that prevents contact with the existing herd. A separate set of utensils (e.g., pitchforks and feed buckets) should be used in the quarantine area. Proper sanitation in water troughs and feed troughs is also an important aspect of bio-containment.

The goal of quarantining is to ensure that the purchased animals are not incubating a disease. The new additions may appear perfectly healthy at the time of purchase but be in the earliest stage of infection. Separating the animals for two to four weeks helps to minimize this risk. Unfortunately, many farms do not have facilities to keep animals completely separated.

Many farms eliminate the need for quarantining by practicing an all-in all-out system. All the animals leave the farm, the barn is cleaned and sanitized, and then the next group of animals is brought onto the farm. Ideally, all of these animals come from one source, minimizing the threat of animals becoming exposed to new pathogens.

Some farms are not able to practice an all-in all-out system and on others the animals may have to come from multiple sources. The risk of a disease outbreak is highest in the first days to weeks after the animals

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arrive on the farm. This is a result of the stress of transport and the exposure to new pathogens from the other animals. **Metaphylaxis** describes the prophylactic use of antibiotics in these times of high risk. For example, calves arriving at a stocker operation may be given a long-acting antibiotic injection at the time of arrival. The goal is to minimize the number of cases, limit the severity of cases that do develop, and increase the overall weight gain of the animals arriving. Numerous studies have shown improvements in average daily gain, dry matter intakes, and feed conversion ratios with metaphylaxis. Metaphylaxis does not replace a proper vaccination program but merely works in concert with it.

Vaccination programs are developed to maximize protection of the animal. However, consideration must be given to the cost of the vaccine and the potential for side effects. In farm animals the cost of the vaccine is balanced against the potential for loss if the disease occurs. The effectiveness of the vaccine must also be considered.

Any vaccine has the potential to cause side effects. Soreness and swelling at the site of injection are very common. Many animals also develop mild fevers, lethargy, and poor appetites. In general, these side effects are short lived and disappear without treatment. Some vaccines may increase the risk of abortion in pregnant animals. The most serious side effect is anaphylaxis. This allergic reaction may be so severe that it is life threatening. Prompt treatment with epinephrine is essential to reverse the allergic response.

In companion animals, vaccination programs generally begin with a series of vaccines in the young. Recommendations vary significantly, but vaccination often begins in dogs and cats at six to eight weeks of age. Booster vaccinations are given at three- to four-week intervals until there is confidence that maternal antibodies have declined to a level that allows the pet to respond (recommendations vary from 12 to 18 weeks of age). The long-held standard is that the pets are then given yearly booster vaccinations to maintain a high level of immunity.

It has been discovered that certain vaccines may increase the risk of developing a cancerous tumor of connective tissue (**fibrosarcoma**) in cats. There is also evidence that certain immune-mediated diseases may be increased as a result of frequent vaccination. This discovery has raised significant controversy relating to vaccination recommendations. New protocols based on disease exposure are being developed and tested in which vaccines are not repeated as frequently. In addition, testing may be done to measure antibody levels to see if vaccination protection is still present. With the development of new vaccine technology and an understanding of the science of immunology, strategies for properly vaccinating animals will continue to evolve.

SUMMARY

Disease prevention begins with sound biosecurity practices such as maintaining a sanitary environment. Employing a comprehensive vaccination program tailored for each client's needs also helps prevent the spread of disease. Ultimately, disease prevention proves cost effective for both the large-scale producer and the pet owner alike.

REVIEW QUESTIONS

1. Define the following terms:

   antioxidant
   ventilation
   tunnel ventilation
   wet dewlap
   biosecurity
   equine infectious anemia
   bio-containment
   quarantine
   metaphylaxis
   fibrosarcoma

2. True or False: All vaccinations offer complete protection from the intended disease.
3. A ___ dose must be given a month or so after administration of a killed vaccine to elicit a memory response.
4. Which have higher immunity levels, young or older animals?
5. How long should a new animal be quarantined when brought home?
6. Name a common side effect of vaccination.
7. Does stress in animals require conscious thought?
8. Does a vaccine exist for distemper in dogs?
9. Can a vaccine affect milk production?

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10. Should a modified live vaccine be refrigerated?
11. How does allowing an animal's hair coat to become wet and matted contribute to disease conditions?
12. Describe the cough in kennel cough.
13. Name two types of immunity.
14. List at least two factors used in developing a vaccination program.
15. List the symptoms of equine infectious anemia.

ACTIVITIES

1. Low stress levels in cattle increase milk production. Many companies are designing low-stress facilities for dairy cattle. Do a Web search to investigate such items. Share information with the class.
2. Interview a livestock producer and a pet owner regarding their vaccination protocols. Compare and contrast the responses. Report findings to the class.
3. Contact a contract large-scale swine or poultry operation. If such businesses are not present locally, an Internet search can be helpful. Try to obtain a biosecurity plan from the business.
4. Pretend to be a livestock producer of one specific species. Using the information collected in the above activity, develop a biosecurity plan for your intended farm.
5. Learn how a scoring system can be used to detect respiratory disease in calves by searching the Web for a calf respiratory scoring chart.

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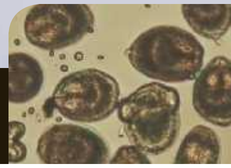
CHAPTER 16



Classification of Diseases

Objectives

Upon completion of this chapter, you should be able to:

- Classify diseases, match them with the domestic species in which they occur, and discuss their clinical significance.

Key Terms

schistosomus reflexus	arthritis	peritonitis	neoplasm
congenital	pneumothorax	idiopathic	metastasis
hemophilia			

Introduction

In the most general terms, a disease is any disorder that creates a problem in the normal function of the body. During the discussion of the individual organ systems, a variety of diseases have been introduced. This chapter discusses the major classifications of diseases and the underlying causes.

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A Day in the Life
All I Want is a Full Night's Sleep . . .

A common part of the job is to be called in the middle of the night. With the first ring, I begin to wonder what the call is going to concern. The calls vary—they could be anything from someone canceling an appointment to a distraught owner whose five dogs have porcupine quills in their mouths. When awakening from a deep sleep, it takes me a few minutes to pull my thoughts together. I find it difficult to think clearly when people begin to immediately ask questions.

One particular call really caught me off guard. It was 2:47 AM when the phone rang. On the other end was a woman who was quite upset. She immediately began to talk; the conversation went something like this (my thoughts are in parentheses):

"Hello, Dr. Lawhead, my husband and I are getting ready to go on vacation. (Well, thanks for calling to tell me.) My dog is on heartworm preventative (Oh no, she is out of medication and needs some more. But at this hour?), and I laid out his pill along with my husband's heart medication. Unfortunately, my husband took the dog's pill. Will it hurt him?"

At this point I crawled from bed and went to look through my pharmacology text. I tried to think about what potential problems could develop. I just could not remember what effects it had in humans. Finally, it struck me—had the dog taken the husband's medication, I could help. But I was not qualified to give human medical advice. I referred her to a poison control hotline. This call was quite unusual. However, we do receive many calls from owners whose pets have ingested items they should not have.

Most cows are able to calve on their own. When there is difficulty, a majority of farmers are capable of assisting in the delivery. When that fails, they call the veterinarian for help. I vividly remember one notable calving. The farmer told me that she had reached into the cow in an attempt to determine the problem. She told me that she was confused because all she felt was this *thing*.

Now I was confused. Her description of a "thing" did nothing to tell me what she was feeling. I drove to the farm, wondering what I was going to find. Even someone with limited experience is able to tell me if they can feel a hoof or a nose. She did not recognize what she was feeling. I cleaned the cow and reached through the vulva and into the uterus. I have attended thousands of calvings, so I was confident that I was going to explain to her what was occurring. As my hand finally reached the calf, my first impression was exactly the same—all I felt was this *thing*.

Photograph courtesy Jeff and Joanne Walker.

FIGURE 16–1 A deformed calf (schistosomus reflexus). This calf developed inside out along the length of its spine.

She was right; it did not feel like a hoof, a nose, a rump, or a back. I had to investigate more thoroughly. Reaching in as far as my arm could go, I was able to feel more parts. Unfortunately, I now knew what was occurring, but I also knew that I was in for a lot of work. I was finally able to feel a leg, but I also felt loops of intestine and a heart! When I felt the heart, I knew that the calf was inside-out. This calf had a condition called **schistosomus reflexus** (a good gravy-splasher to try!) (Figure 16–1).

The deformity of the calf prevented a natural delivery. With the assistance of the farmers, I performed a cesarean section, surgical removal of the calf from the cow. We removed the calf through a large surgical incision on the left side of the cow (Figure 16–2). The cow stood through the entire procedure. It is difficult to visualize what the calf looked like. The calf was basically turned inside out, lengthwise. Instead of the legs pointing downward from the spine, they were pointing upward. The skin was folded upward as well, and the internal organs were all exposed. The calf was dead at birth, but the cow did well and actually had a normal calf the next lactation.

Traumatic diseases are often the easiest to diagnose. I received a call from an owner who was obviously quite shaken. The neighbor's dog had just attacked her dog. She was concerned with how badly the dog was still bleeding, so I asked her to bring the dog to my office. Lady, a 40-lb mixed-breed dog, had obviously tangled with a much larger dog. The dog had multiple bite wounds over her neck, face, and ears.

Making the diagnosis was no problem in this case. The challenge then came as my partner and I tried to

continues

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A Day in the Life continued

Photograph courtesy Jeff and Joanne Walker.

FIGURE 16–2 Dr. Lawhead in the process of a c-section. The surgery is performed with the cow standing and with the use of a local anesthetic.

repair the damage. The punctures on the neck were quite deep, with extensive muscle damage. The skin had been torn loose from the underlying muscle tissue. We sutured many of the wounds and placed a drain to allow the tissue fluid to escape. These wounds were severe, but we hoped that Lady would make a full recovery.

In clinical practice, I see a number of fantastic pets. Unfortunately, I often do not experience their true personalities. The pets are often nervous when in the clinic. They are not in their normal environments and are being poked and prodded. Further, I typically only see them for short periods of time. But, there are some animals that have shining personalities even in the clinical setting. Often these animals have conditions that require extended stays at the office or repeated visits, both of which allow me to get to know the animals much better.

Katie, a two-year-old Labrador retriever mix, came to the office as an emergency. Katie had escaped through a fence and been hit by a car. She was in very critical condition. My initial assessment showed that she was in shock, and radiographs showed that she had a pneumothorax. The trauma had ruptured a hole in her lungs and the free air had accumulated in the chest cavity. As if that was not bad enough, Katie had broken the humerus in her right leg and her ulna at the level of the elbow joint in her left leg.

Katie was a champ; throughout this entire trauma she never complained, growled, or tried to bite. She was a very sweet dog and would wag her tail every time that I checked on her. Before we could consider surgery on her broken legs, we had to stabilize the shock and, in this case, allow the pneumothorax to resolve. Katie was coming along well and I offered her a bowl of canned food. Having two broken front legs made movement difficult for her and lying on her side just wasn't practical for eating. I was amazed when Katie, without using her front legs, pulled herself up into a sitting position (picture a begging dog pose). I held the bowl and she ate for me. I was just totally impressed at her spirit, her gentleness, and her will to live. Surgery went well on Katie, although our biggest challenge was keeping her calm and quiet during the recovery period.

DISEASE IN CLINICAL PRACTICE

Objective

- Classify Diseases, Match Them with Domestic Species in Which They Occur, and Discuss Their Clinical Significance

Diseases can be divided into several major classes. The letters of the words *MAD TIN* will help the student to remember the major classes (Table 16–1), but not every disease fits neatly into one class. For example, an infectious agent or toxin may cause a **congenital** (birth) defect. Nutritional problems can result in many metabolic diseases. Diseases are grouped in classes to help aid the veterinarian in considering a diagnosis when examining a sick animal. Although the classification may appear somewhat arbitrary, it is designed to help in the diagnostic process.

Typically, the clinical signs that an animal presents could be the result of several different diseases. Following the physical examination, the veterinarian

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Table 16–1 Major Classifications of Diseases

M–	Metabolic
A–	Anomalies (birth defects)
D–	Degenerative
T–	Trauma Toxins
I–	Infectious Immune Iatrogenic Idiopathic
N–	Neoplasm Nutrition

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considers a list of different diagnoses. This list includes all the diseases that may result in those clinical signs. By considering each class, the veterinarian can efficiently consider a wide range of diseases. The veterinarian attempts to list the most likely diseases first. This list helps to guide the diagnostic tests that will be performed. The goal is to make a definitive diagnosis in an efficient and cost-effective manner.

An example may help to illustrate how this thought process occurs. Benji, a 25-lb, 10-year-old mixed-breed dog, was brought to the clinic by his owner because he was no longer sleeping through the night. Benji was a house dog and went outside only while on a leash. He ate only dry dog food and never got table scraps. While giving the history, the owner explained that Benji had to get up several times during the night to urinate. She also explained that he has been drinking more water than he ever had before. She mentioned that his appetite had declined over the past few days. The physical examination showed that Benji had lost 3 lb but did not provide any further clues to help in the diagnosis.

These signs are quite common, and a large number of diseases may fit this presentation. Each class of disease can be evaluated. Although many diseases can be eliminated, many must be considered:

- Anomalies: Such problems are very unlikely given the age of the dog.
- Trauma: The history helps to rule this out.
- Infection: A kidney or bladder infection is a possibility.
- Nutrition: Benji's diet had not changed, so this is not a likely problem.
- Toxin: Toxins such as antifreeze can cause signs like this, but the history helps to rule out the possibility.
- Neoplasm: A tumor must be considered. In general, the risk of tumors increases with age. Benji's age increases this possibility.
- Metabolic: Diabetes and kidney failure are very likely with this history and clinical presentation.

Following consideration of these possibilities (the complete list is actually much longer), the list of differential diagnoses would include:

- Kidney failure
- Diabetes
- Tumor
- Bladder infection

By preparing this list, the veterinarian can then plan to confirm a diagnosis. In this case, a blood chemistry, complete blood count, and urinalysis would be very reasonable diagnostic tests. The blood chemistry would clearly evaluate the blood sugar level and the function of the kidney. The white blood cell count is very valuable in determining if there is a generalized infection. The urinalysis would provide evidence on how concentrated the urine is and if there were abnormal levels of red or white blood cells. Subsequently abdominal radiographs might be advisable depending on the findings of the initial testing.

Metabolism describes all the processes occurring within the animal. This includes the chemical reactions occurring within the cell and all the functions of the body, such as urine production and hormone control. *Metabolic* diseases occur when there is a disruption in this natural process.

Many metabolic diseases have already been discussed throughout this text. All the endocrine diseases are considered metabolic disorders. Diabetes, hypothyroidism, and hyperadrenocorticism are just a few examples. Milk fever, the low blood calcium that occurs in cows at calving, is also a metabolic disease. Failure of organs, such as the liver or kidney, disrupts the normal metabolism of the animal. These diseases are also included in this class. The complete list of metabolic diseases is very long.

Pregnancy toxemia is a metabolic disorder common in sheep and goats in the last month of pregnancy. Typically, this occurs in animals carrying multiple fetuses. These animals become weak, depressed, and anorexic. As the disease progresses, the animal is unable to rise and eventually dies if left untreated.

The multiple fetuses take up a large space in the abdomen. This limits the size of the stomach and how much feed the animal can eat. In addition, the multiple fetuses increase the demand on the mother. If inadequate nutrients are consumed, the animal mobilizes fat to produce energy. As lipids are broken down, small molecules called ketones are produced. A series of chemical reactions occur in the liver, using the ketones

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in combination with simple sugars to produce energy. In pregnancy toxemia the carbohydrate metabolism is disrupted, and the ketones cannot be fully utilized so they accumulate in the bloodstream. The elevated ketone level causes appetite suppression.

Acetone is one of three major ketones. Acetone (commonly found in many fingernail polish removers) has a distinct odor. The ketones accumulate in the blood but also pass into the milk and urine and are exhaled from the lungs. The breath of animals with pregnancy toxemia develops a sweet smell, which is diagnostic for these ketones. Not all people are sensitive to the smell of ketones. Ketones can be detected in urine with a simple color reaction test strip. (Tip: Many sheep can be stimulated to urinate by holding their nostrils closed!)

Treatment for pregnancy toxemia includes replenishing the energy supply and decreasing the energy demand on the animal. Energy can be delivered by giving intravenous glucose or drenching with an oral product (propylene glycol) that increases the blood sugar. The fetuses continue to be a demand on the mother. A complete cure often requires that the fetuses be removed from the mother. This may be accomplished by inducing labor or by performing a cesarean section (surgical removal of the fetuses). Preventing pregnancy toxemia is not always possible, but proper nutrition is essential for minimizing the number of cases. Although pregnancy toxemia is a metabolic disease, it can be induced by a nutritional problem.

Seizures in dogs can be a result of liver disease. Ammonia that is absorbed from the intestines is removed from the bloodstream by the liver. In liver disease, the ammonia and certain other toxins accumulate in the blood. These products are toxic to the central nervous system and can produce seizures.

This type of liver disease, a metabolic disease, may occur in animals as they age. However, the same symptoms can be a result of an anomaly or birth defect. This anomaly may be a portocaval shunt in which blood from the intestinal tract is diverted around the liver. (Review Chapter 8 and the material on fetal circulation.) This shunt, a normal structure in the fetus, should close shortly after birth. If it remains open, neurologic signs may develop early in life. The age of the animal is significant in determining the differential diagnoses in many disease conditions.

A wide range of *anomalies* can occur. In general, anomalies are detectable in young animals. Some defects may be so severe that abortions and stillbirths are a result (Figure 16–3). Other defects may never cause clinical problems in the animal (e.g., six toes on a foot of a cat, or a short tail). Clinical signs may not be present at birth but may develop as an animal grows. The demands on the body increase rapidly with the growth of the young animal. It is the increasing demand that brings on the clinical signs. An example is a heart murmur in a dog. The animal may be able to grow and crawl as a young pup. As it matures and becomes active, the heart may not be able to compensate for the increased demands that come with greater size and activity. Therefore, a condition that was present at birth may not produce signs until the animal is six months old.

Photograph courtesy John Lynn.

FIGURE 16–3 A calf born with a portion of two heads. The calf was born alive but did not survive.

Anomalies can be inherited; that is, a chromosome has a defect, resulting in the abnormality. A classic example of an inherited disease is **hemophilia**. In this disease, a genetic defect results in a deficiency of one of the clotting factors. As a result, the animal is at high risk for serious bleeding problems. This problem may not be evident at birth, and may only become obvious when there is significant trauma or during surgery.

Other anomalies are a result of a defect in the development of the fetus. One of the most common defects found is an umbilical hernia. The umbilicus (belly button) is where the vessels from the placenta enter the fetus. Following birth, the umbilical vessels begin to shrink and the ring of muscle surrounding them closes. With an umbilical hernia, the ring does not close and connective tissue or intestines push out through the opening (typically the contents remain under the skin).

Often animals live with an umbilical hernia without any complications. The risk is that a loop of intestine will slip through the hole and become twisted. The twisting will cut off the blood supply and trap gas within the intestinal loop. This causes a painful swelling and is called a strangulated hernia. If left untreated, the loop of intestine can die due to a lack of blood supply. A strangulated hernia requires immediate surgical correction. Many hernias are repaired to prevent this occurrence.

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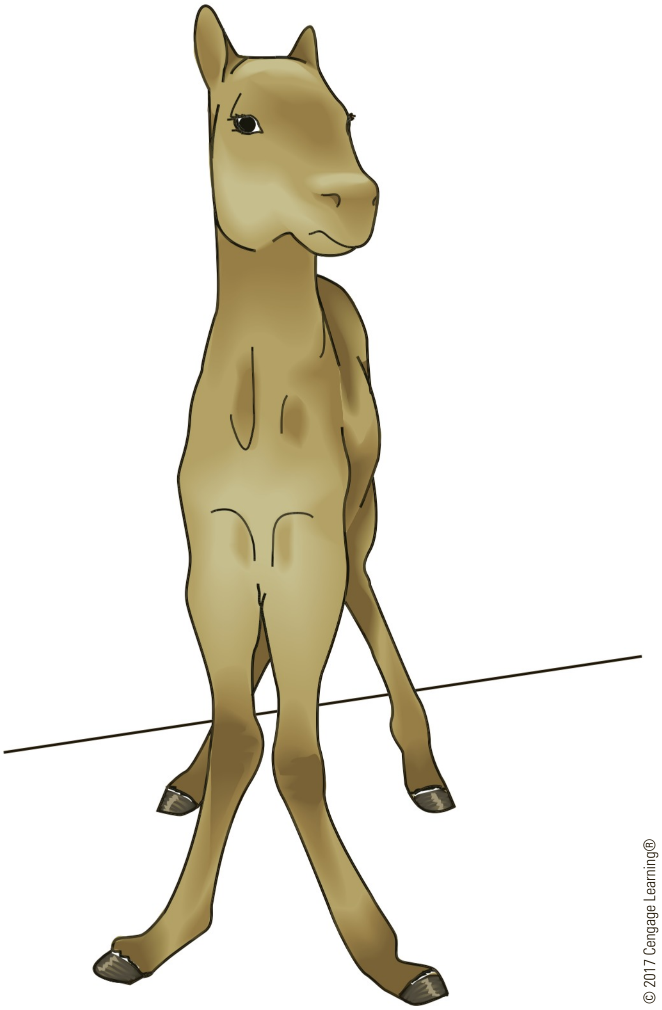

FIGURE 16–4 The legs of a foal with angular limb deformity.

Angular limb deformity is a very obvious defect that can occur in foals (Figure 16–4). When observed from the front, these foals' legs have a deviation (often at the carpus) either to the outside or the inside. This can occur because of positioning within the uterus, weak ligaments, or a failure of normal bone to form.

In mild cases, keeping the foal confined with controlled exercise can be very helpful. This protects the animal as the muscles and ligaments around the joint strengthen. In more severe cases, splints and even surgery may be required. Some cases may be too severe to correct.

Degenerative diseases are often associated with aging. These can occur with the normal wear and tear that occurs to the body over the years. Musculoskeletal problems are often degenerative. **Arthritis** and disk disease are two examples of degenerative diseases. In arthritis, the normally smooth cartilage that lines the joints becomes rough and irregular. Bony spicules are deposited around the joint in response to chronic irritation. The end result is pain and restricted movement in the affected joint.

In disk disease, the disk deteriorates with age and eventually protrudes from the normal site between the vertebrae. Pain and paralysis may result from the disk applying pressure to the nerves or spinal cord. All the clinical signs are secondary to the degeneration of the disk.

Trauma and *toxic diseases* can be some of the easiest conditions to diagnose and treat. Trauma often damages specific regions, and the effect can be quite localized. The veterinarian's attention is directed to one location. Also, many animals present with clinical signs that could have been a result of trauma, but it is unknown if any such event even occurred.

Trauma cases are very common in veterinary practice. The range of severity of the trauma varies dramatically, from two pets playing roughly to gunshot wounds to being hit by a car (Figure 16–5). The treatment obviously depends on the type and location of the resulting injuries. For many mild cases, merely restricting activity for a period of hours or days allows the animal to recover fully. Medication designed to decrease pain and inflammation may also be used.

In many cases, standard first aid is very helpful. The same principles that are used in humans also apply to pets. In cases in which there is bleeding from open wounds, applying a clean pressure bandage is helpful. Even with serious lacerations, maintaining pressure on the site can often control the bleeding.

Unfortunately, the lacerations are not always in a location where this can be accomplished. Several months ago, I received a call from a panicked owner. She had been trimming her dog's nails, and the dog tried to lick its foot at the same time the owner clipped

FIGURE 16–5 Radiograph of a dog with a fractured humerus. The bone has been shattered by a bullet (seen as dense white regions on the radiograph).

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FIGURE 16–6 A selection of bandage material and splints.

a nail. Not only was the nail trimmed, but also a piece of tongue had been removed. The tongue, rich in blood vessels, was bleeding steadily. In addition, saliva made the volume look much larger. The dog did not cooperate with having direct pressure applied to its tongue. This dog was anesthetized, and the tongue sutured.

Trauma can also be severe enough to fracture bones. Again, depending on location, splints can be applied to stabilize the leg. The splint may not be the final treatment, but it prevents further damage to the bone and soft tissue in the area. Without the splint, the bone end might puncture through the skin, adding bacterial contamination to the bone. This can prevent normal healing if an infection is established in the bone.

Applying a pressure bandage is an important technique in first aid. Bandages can be used to stop bleeding and to protect open wounds from further damage and contamination. Adding a rigid support within the bandage can be used to support a leg with bone or joint damage (Figure 16–6). Many variations are possible in bandaging. The location, type, and extent of the injury influence the type of bandage that is used.

Certain principles exist for all types of bandages. For example, the bandage should be kept clean and dry. A bandage that becomes wet and contaminated increases the risk for infection. The bandage itself can damage the underlying skin if it is too tight. If the bandage applied to a limb is too tight, it may also hinder the circulation to the lower portion of the leg. This may cause the animal discomfort and increase the likelihood that it will chew at the bandage. If the foot or toes are exposed, they can be checked to determine if the bandage is too tight. If the foot begins to swell or the toes become cold, the bandage needs to be loosened immediately.

Nondisplaced fractures on the lower leg of a dog or cat can often be stabilized with a splint. In fracture repair, the goal is to immobilize the joint above and below the site of the fracture. For example, a radius fracture requires the splint to stabilize the carpus and the elbow. The basic steps in applying a splint are:

1. Stirrups: Strips of tape are applied to the sides of the legs and an equal length beyond the foot (Figure 16–7A).
2. Cast padding: A thin, cotton padding is applied evenly over the leg. This layer allows the splint to apply even pressure over the entire leg, preventing pressure sores under the bandage (Figure 16–7B).
3. Splint: A rigid support (often plastic) prevents the bandage from bending (Figure 16–7C).
4. Gauze: Wrapped snugly around the splint, gauze provides good stabilization of the leg. This must be applied tightly enough to keep the leg from moving and loosely enough to allow normal circulation. The ends of the stirrups are turned onto the bandage. This ties them into the bandage to help keep it from sliding off the end of the leg.
5. Tape: This is applied to keep the entire bandage together (Figure 16–7D).

This basic technique is used in many bandages. This same technique, without the rigid splint, produces an excellent pressure bandage. On open wounds, a nonadherent pad is placed over the area to prevent the healing wound from sticking to the bandage. These bandages should be changed if discharge begins to soak through the padding or if the bandage appears to slide down the leg.

More severe trauma can also damage internal organs. At times, this may require emergency surgery and treatment. Animals that have been hit by a car may have ruptured a major organ, such as the spleen or liver, resulting in severe internal bleeding. This may require an exploratory surgery to find the site and correct the damage. Such trauma can also damage the lungs to the extent that air leaks from the tissue. The air becomes trapped between the lungs and the chest wall (a condition called **pneumothorax**). This air can be drawn out of the chest through a chest tube that enters through the skin and then penetrates through the muscles between the ribs. Suction is applied to the external end of the tube. In this way, air or fluid can be drained from the chest cavity (Figure 16–8). In more severe cases, the lungs may need to be repaired surgically.

Not all damage is immediately evident following the trauma. If an animal has a full urinary bladder when a car strikes it, the bladder may rupture. The tear may actually be small enough to allow the animal to urinate even though small amounts of urine are leaking into the abdomen. These animals may appear normal immediately following the trauma but become very sick over the next 1 to 2 days. The urine causes a chemical irritation in the abdomen, and the waste products

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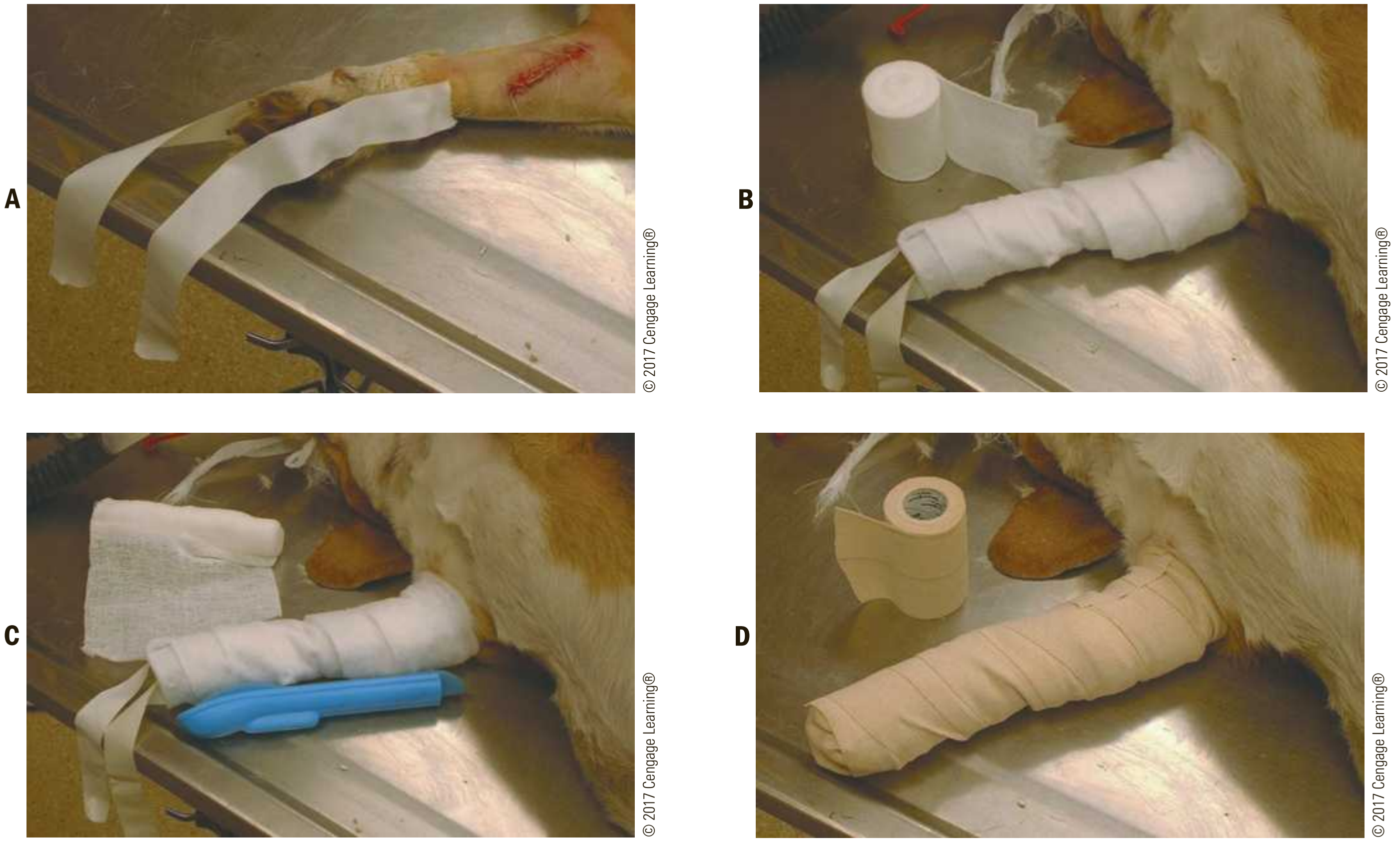

FIGURE 16–7 Applying a splint. A. Stirrups of tape are added on both sides of the leg. This helps to prevent the bandage from slipping. B. A layer of padding is added to the leg. C. At this stage a splint can be included in the bandage and secured with gauze. D. The stirrups are folded into the bandage and an elastic tape has been used to cover the bandage.

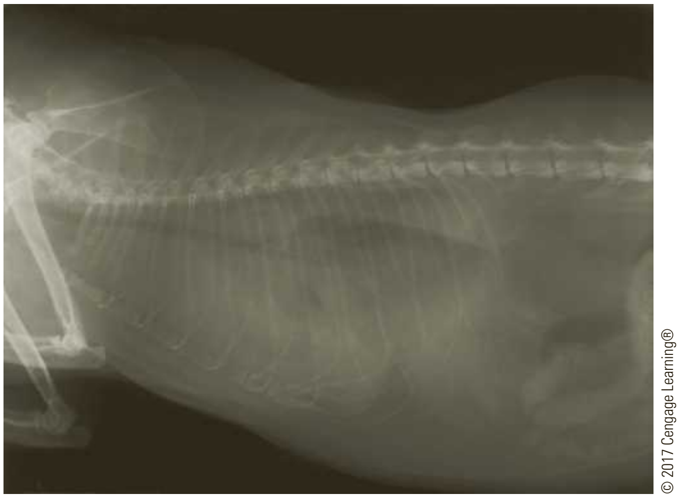

FIGURE 16–8 Radiograph of a cat with a large amount of fluid in its chest. Treatment might include a chest tube to drain the fluid from the chest.

are reabsorbed. The end result is called **peritonitis**, an inflammation throughout the abdomen. The bladder must be surgically repaired in these cases.

Parturition can cause trauma to the mother. During a difficult delivery, tears may occur in the uterus, cervix, and vagina. A tear in the uterus results in a leakage of fluid, which often contains bacteria, into the abdomen. Again the result can be peritonitis. It is also possible that a major vessel is torn and the animal can die from internal bleeding.

Recently, I worked on a cow that had a prolapsed uterus. At some point, the uterus was torn. I was not able to tell if this occurred during the delivery or following prolapse. I sutured the tear before correcting the prolapse and began treating this animal with an antibiotic because of the contamination of the internal organs. The cow was doing fine initially but was at a high risk for peritonitis.

Toxins are a common cause of illness in animals. If the toxin is known, a specific antidote or treatment can be administered. Difficulty arises when the toxin is unknown, making diagnosis and treatment difficult.

Animals may be exposed to toxins by ingestion, inhalation, or contact. With contact, the product may be toxic only in particular locations, such as the cornea or mucous membranes. Some of these toxins cause irritation to the surface of the skin or mucous membranes. However, other toxins are absorbed into the animal through the skin. The signs of the toxin are often related to the route of entry (e.g., skin irritation with contact toxins, vomiting and diarrhea with

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ingested toxins, and breathing difficulties with inhaled toxins). However, many toxins affect other organ systems once they gain entry into the body.

Veterinarians are often presented with a sick pet whose owners are concerned that the animal may have been poisoned. The history shows that the animal is free to roam and is now sick. I am often asked if I can do a blood test to see if the animal has been poisoned. Many tests are available to detect poisons in the blood or urine, but there are thousands of poisons and many cause identical clinical signs. To do proper testing, the veterinarian must have some idea of what the animal may have ingested.

In other situations, owners discover what the animal has ingested. They may catch the animal in the act or discover the empty container. With toxins, the length of time that the animal is exposed is very important in determining the treatment. Initiating treatment before large amounts of the toxin have been absorbed can be lifesaving.

The list of products that can be toxic is extensive. Many everyday products found around the house are potentially toxic to pets (Figure 16–9). Even products designed for pets can become toxic when the animal is exposed to large amounts or to a product designed for a different species. Cats are much more sensitive to certain insecticides than dogs. Owners may mistakenly use a topical flea product designed for dogs on their cat and produce life-threatening complications. Many pet medications are now produced in a flavored form to ease the administration. Unfortunately pets may find them extremely palatable and eat large quantities if they gain access to the package.

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FIGURE 16–9 Many products commonly found in households can be toxic to pets.

Toxins can also include household cleaners, over-the-counter or prescription medications, plants, and certain animals. (For example, some toads have toxins in their skin that irritate the mouths of dogs that bite them.) Even food that we consume without thought has the potential for toxicity in pets. Grapes and raisins have the potential to cause kidney failure in dogs. Xylitol is a sweetener used in many foods, including chewing gum and baked goods. If ingested by dogs, Xylitol can cause extremely low blood sugar levels and necrosis of liver cells. Onions and garlic have the potential to cause damage to red blood cells in pets. The list of potential toxins is long and therefore it is important to control what companion animals ingest.

Problems can result when animals gain access to illicit drugs. In these situations, the owners are often reluctant to admit the potential exposure. A complete and accurate history is necessary for the veterinarian to be successful. As with many toxins, rapid intervention in these cases is often necessary to save the animal.

Table 16–2 lists a number of plants that are capable of causing toxicity in animals. Geographic location is important in the discussion of toxic plants. Certain plants grow only in specific regions. Knowledge of the plants common to a given area is necessary. Not every part of these plants is toxic. For example, an apple is not toxic, but a large quantity of apple seeds is. A goat consuming cherry leaves from a live tree does not become sick. However, the wilted leaves from a fallen cherry tree can contain cyanide, which can be extremely toxic.

Proving exposure to toxic plants may also be difficult. One spring day an 11-month-old kitten presented for lethargy and vomiting. This kitten was strictly a house pet, which provided important history information that eliminated a large number of problems such as being hit by car or ingesting antifreeze. The kitten had been extremely active and healthy until symptoms started the previous evening. Blood work showed evidence of dehydration and a dramatically increased level of both blood urea nitrogen and creatinine (Table 16–3). While the possibilities still existed for some sort of developmental or infectious problem, the history questions turned toward any possible toxin. Unfortunately an Easter lily had been recently introduced into the house and the cat had been seen chewing on the plant. The history provided all of the information needed to confirm the diagnosis that the ingestion of the Easter lily had caused the acute kidney failure.

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Table 16–2 Common Toxic Plants

Type	Plant	Clinical Signs
Trees	Oaks	Anorexia, weakness, icterus, dehydration, may cause death
	Cherry (wilted leaves)	Respiratory distress, death
	Apple (seeds)	Vomiting, salivation, respiratory distress
	Black walnut	Laminitis in horses bedded with shavings
	Red maple	Hemolytic anemia
Houseplants	Oleander	Vomiting, diarrhea, pain
	Mistletoe	Irritation of stomach and intestines, shock
	Dumbcane	Irritation of mouth and throat
	Caladium	Irritation of mouth and throat
	Philodendron	Irritation of mouth and throat
Flower garden	Foxglove	Irregular heartbeat
	Lily of the valley	Stimulation of heart, dizziness
	Daffodil	Vomiting, trembling
	Hyacinth	Diarrhea
	Iris	Respiratory distress
	Autumn crocus	Stomatitis
Vegetable garden	Tomato (leaves)	Vomiting, diarrhea
	Rhubarb (leaves)	Vomiting, weakness, cramps
	Onion	Hemolytic anemia
Ornamental	Mountain laurel, rhododendron, azalea	Salivation, pain, vomiting
	Japanese yew	Sudden death
	Wisteria	Vomiting, pain, diarrhea
	Holly	Diarrhea
	Juniper	Vomiting, diarrhea
Forests	Bracken fern	Fever, anemia, respiratory distress
	Mayapple	Vomiting and diarrhea
	Jack-in-the-pulpit	Irritation of mouth
	Dutchman's breeches	Salivation, diarrhea, incoordination
Wetlands	Water hemlock	Salivation, twitching, seizures
	Skunk cabbage	Irritation of mouth and throat
	Fox tail, horse tail	Incoordination, weakness
Fields	Nightshade	Diarrhea, weakness, convulsions, coma
	Jimsonweed	Restlessness, twitching, paralysis
	Poison hemlock	Weakness, recumbency
	Belladonna, deadly nightshade	Dry mouth, difficulty swallowing, rapid heart rate, urine retention
	Pokeweed	Pain, vomiting, diarrhea
	Milkweed	Convulsions, coma
	Buttercup	Stomach irritation, pain, diarrhea, twitching
	Curly dock	Respiratory distress, death, abortions
	Red-berried elder	Vomiting, diarrhea
	Lamb's quarters	Respiratory distress, death, abortions

continues

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Table 16–2 *continued*

Type	Plant	Clinical Signs
Western dry range and grasslands	Halogeton, barilla	Low calcium, kidney damage
	Greasewood	Low calcium, kidney damage
	Crazyweed, locoweed, milkvetch	Irritable, incoordination
	Groundsel	Liver damage
	St. John's wort	Skin becomes sensitive to sunlight, blisters, scabs
	Ergot (fungus on grasses)	Lameness, sloughing of skin
	Tansy ragwort	Liver damage
	Yellow star thistle	Involuntary chewing
	Johnson grass, sudan grass, sorghum	Cyanide toxicity, sudden death
	Bitterweed	Weakness, salivation, vomiting and diarrhea
Mountain	False hellebore	Salivation, convulsions, weakness, vomiting
	Larkspur	Affects nervous system, convulsions, collapse
	Monkshood	Vomiting, diarrhea, paralysis
	Lupine	Vomiting, pain, ataxia, muscle paralysis

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Table 16–3 Blood Results for a Kitten with Easter Lily Toxicity*

Test	Result	Reference Range
Hematocrit (%)	54.3	30–45
Hemoglobin (g/dl)	18.3	9–15.1
Red blood cells (M/μl)	13.34	5–10
White blood cells (K/μl)	19.92	5.5–19.5
Albumin (g/dl)	3.8	2.2–4
Blood urea nitrogen (mg/dl)	> 130	16–36
Creatinine (mg/dl)	> 8.4	0.8–2.4
Calcium (mg/dl)	9.8	7.8–11.3
Globulin (g/dl)	5.1	2.8–5.1
Phosphorus (mg/dl)	> 16.1	3.1–7.5
Total Protein (g/dl)	8.9	5.7–8.9

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*Eleven-month-old female spayed domestic shorthair cat.
Numbers highlighted in red are above the normal reference range. Elevated levels of hematocrit, hemoglobin, and red blood cells are consistent with dehydration. Extremely high levels of blood urea nitrogen, creatinine, and phosphorus are evidence of severe kidney damage.

Pastures used by grazing animals often harbor toxic plants. In general, the animals do not consume large enough amounts to become sick. Problems are often worse in drought conditions. Many of these toxic plants are commonly found along stream banks. As dry weather decreases normal pasture grasses, grazing animals may eat more of the fresh green plants close to the stream. In these conditions, the animals may consume enough to become ill. Providing an adequate supply of good quality forage and controlling weeds can greatly minimize the risk of grazing animals ingesting poisonous plants.

Cattle ingesting certain plants can develop a condition called photosensitization. In this condition the plants may contain compounds that are distributed into the tissues through the bloodstream. When exposed to the ultraviolet rays of sunshine, the compounds react and release energy to damage the surrounding tissues. Typically this occurs in areas with a thin hair coat or white haired regions (Figure 16–10). Removing cattle

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FIGURE 16–10 Cattle ingesting certain plants can develop a condition called photosensitization.

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FIGURE 16–11 An azalea bush. Many ornamental plants can be toxic if ingested.

from pasture to stop ingestion and protecting them from sunlight is often curative.

Rhododendron, mountain laurel, and azalea bushes are common causes of plant toxicity in goats (Figure 16–11). Often owners will purchase a few goats to clear a section of ground. Goats having ingested plants in this class often have severe gastrointestinal disturbances. The goats will often drool, have nausea, and most notably will vomit profusely. Ingestion of large amounts can be fatal. Once again, knowledge of the plants in the animals' environment can lead to the diagnosis, or could allow prevention more effectively.

Table 16–4 lists a number of common products and medications that can cause toxic effects in animals. From this list, it is obvious that many common products can be damaging to companion animals. Prevention is so important in toxic diseases. These diseases are completely preventable by eliminating access of the animals to these products.

When an animal is exposed to a toxin, beginning treatment as soon as possible can often make the difference between success and failure. The odds of success are much higher when the animal is first exposed than when clinical signs have already developed. The first goal of treatment is to minimize the amount absorbed. When the animal has skin exposure, bathing can be very effective at minimizing the exposure.

The rate at which ingested toxins are absorbed is quite variable. When the ingestion is detected quickly (less than two hours), induction of vomiting can be considered. When the animal vomits, much of the toxin can be eliminated from the animal, greatly decreasing the amount absorbed. Several different products are available to induce vomiting.

Vomiting should be considered only under the guidance of a professional. With certain toxins and conditions, vomiting can be hazardous to the animal. Animals exposed to caustic or irritating toxins should not be induced to vomit. When vomited, these types of toxins can cause further damage to the esophagus and mouth. When an animal is showing certain clinical signs, vomiting can also be dangerous. If the animal is seizing, is having difficulty breathing or swallowing, or is extremely weak, vomiting should not be induced.

Following vomiting, toxin may still remain in the intestinal tract. Activated charcoal is given orally to bind or adsorb the toxin still remaining. Weak chemical bonds attach the toxin to the activated charcoal. The charcoal is not absorbed from the intestines, so the toxin is effectively removed from the animal in the feces. Note that the feces of a treated animal will appear black from the charcoal treatment. Activated

Table 16–4 Common Toxins

Substance	Clinical Signs
Acetaminophen	Facial swelling, vomiting, anemia
Alcohol	Ataxia, depression, coma, death
Anticoagulant rodenticides	Bleeding disorder caused by inhibiting vitamin K
Chocolate	Vomiting, diarrhea, seizures, coma
Copper	Sheep very sensitive, weakness, anorexia, hemolytic anemia
Ethylene glycol (antifreeze)	Vomiting, ataxia, seizures, coma, death
Lead	May be found in old paint, used motor oil, batteries Causes anemia, brain damage
Nicotine	Excitement, diarrhea, vomiting, depression, muscle weakness
Organophosphate insecticides	Blocks acetylcholinesterase in the nervous system SLUD—salivation, lacrimation (tearing), urination, defecation; also vomiting, diarrhea, respiratory difficulty
Zinc	Can occur after ingestion of pennies (minted after 1983) and galvanized metal, causes hemolytic anemia
Over-the-counter anti-inflammatory drugs (e.g., aspirin, ibuprofen, naproxen)	Vomiting, abdominal pain, renal failure

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charcoal can bind a large number of different toxins (but not every toxin).

When possible, a specific antidote can be administered following exposure. For example, many mouse and rat poisons cause bleeding by inactivating vitamin K. Administration of vitamin K by injection or orally is a specific antidote. Antifreeze, ethylene glycol, becomes toxic only when the liver metabolizes it. An antidote can be administered that prevents this metabolism, allowing it to be excreted by the kidney without damage. Many toxins have no antidote available.

Once clinical signs of toxins have begun, supportive treatment is provided. Treatment varies considerably with each type of toxin. The treatment is directed at the specific organ systems affected. For example, if an animal is in respiratory distress, oxygen can be supplemented. If seizures occur as a result of the toxin, medications such as phenobarbital can be used to control them until the toxin is eliminated from the body. Intravenous fluids are valuable in many cases to help maintain blood pressure and increase urine production.

Many references are available to help veterinarians understand the principles of toxins and the treatments available. When unable to find information on a product, several hotlines are available with large databanks of information:

ASPCA National Animal Poison Control Center (Allied Agency of the University of Illinois College of Veterinary Medicine), 1-888-426-4435

Animal Poison Hotline (Sponsored by the North Shore Animal League America in New York City and PROSAR International Animal Poison Center), 1-888-232-8870

These services charge a fee to support their operation.

The *I* in the MAD TIN mnemonic covers an array of diseases. The *I* can stand for infectious, immune, *iatrogenic*, or **idiopathic**. Infectious and immune diseases have been covered to a large extent in previous chapters and will not be reviewed.

Iatrogenic diseases describe those conditions that develop as a result of treatment. Hyperadrenocorticism can be iatrogenic. Many pets have chronic allergy problems, which may require frequent treatment with cortisone. Certain autoimmune diseases may also require high dosages of cortisone. Treating a pet with cortisone for long periods or with high dosages can cause all the signs of naturally occurring hyperadrenocorticism. Pets are monitored for signs consistent with this disease when they are on such treatment.

When on high levels of cortisone, the animal produces less of its own. The medication provides the negative feedback, keeping natural production low. If the medication is removed suddenly, hypoadrenocorticism can be created. This again is an iatrogenic disease.

Surgery is another source of iatrogenic diseases. Surgical excision of the thyroid glands is a standard treatment for hyperthyroidism. The parathyroid glands are closely associated with the thyroid glands. Sometimes during surgery it is impossible to identify the parathyroid glands. Consequently, the parathyroid glands are often removed with the thyroid glands. When this occurs, the animal will have iatrogenic hypoparathyroidism. This problem must be anticipated and can be treated.

Idiopathic describes a condition in which current medical knowledge cannot explain an underlying cause. In horses a number of diseases can cause severe bleeding into the urine. Among the possible causes are cancer or a tract that opens from an artery into the ureter. When no underlying cause is detected, the disease is called idiopathic renal hematuria (*heme* refers to blood; *uria* refers to urine).

Neoplasm and *nutrition* represent the *N* in MAD TIN. Many nutritional diseases have already been discussed. Nutritional diseases often overlap with certain metabolic diseases. The distinction between the two classes is not always clear. The important point is that these classes of disease be considered in the differential diagnosis list.

A neoplasm or tumor develops with growth of cells in an uncontrolled manner. When examined microscopically, a neoplasm has cells that appear similar to the type of tissue from which it arises but usually no organized structure. (Chapter 1 includes a more detailed description of the cell structure in neoplasms.) Neoplasms have no useful function. In the case of endocrine tissues, the neoplasm may actively secrete hormone, but without the normal control or feedback.

Neoplasms are divided into two major classes, benign and malignant. As the cells of a neoplasm continue to divide without control, they may expand just in the local area or actually invade the surrounding tissue. Benign tumors expand only locally, without invading the surrounding tissue. In general, benign neoplasms are much slower growing than malignancies. Benign tumors generally have a well-defined border. *Encapsulated* describes this property whereby the edges of the tumor are clearly defined.

Malignant neoplasms are very destructive and invade the surrounding tissues (Figure 16–12). *Cancer* is generally used to refer to malignant tumors. (In some writings, cancer may be used to describe any tumor, benign or malignant.) The edges of the tumor are often not clearly defined. The cells of the tumor may extend beyond the edge that can be seen and felt.

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A

B

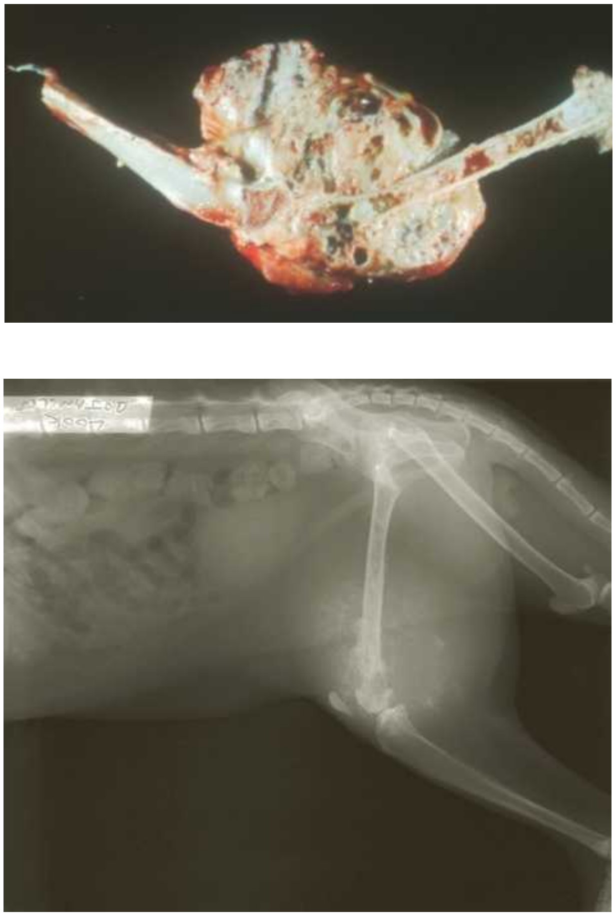

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FIGURE 16–12 A. An osteosarcoma, a malignant bone tumor. B. Radiograph of an osteosarcoma.

Malignant neoplasms have the potential to spread to other locations within the body, a process called **metastasis**. Tumor cells can be spread through the bloodstream or lymphatic system. Individual tumor cells invade these vessels, become detached, and then are carried to distant locations (Figures 16–13 and 16–14). With lymphatic spread, the new tumor is often detected in the regional lymph node that drains that area. When it spreads into the bloodstream, the secondary location may not be as predictable. The lungs, liver, and spleen have a high incidence as the site of metastasis. The extensive blood supply in these organs increases their risk for developing one of these secondary tumors.

Benign tumors can also be quite damaging, even though they do not spread. A benign tumor growing on or under the skin is usually not damaging or harmful to an animal. However, if the benign tumor is located close to a vital area, the effect can be quite devastating. Benign brain tumors are an example. A benign brain tumor located in a vital area can cause severe signs due only to the local expanse of the growth.

Photo by Anne E. Chauvet, DVM, University of Wisconsin School of Medicine.

FIGURE 16–13 Radiograph of a dog with a tumor in its chest. The tumor had spread, or metastasized, from another tumor.

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FIGURE 16–14 Intraoperative photograph showing numerous dark red tumors in the omentum of a dog with a splenic tumor. The tumors had also spread to the liver.

The terminology used to describe tumors is descriptive of the originating tumor. The suffix added to the term helps to classify the tumor as benign or malignant. The suffix *-oma* is added to terms for benign tumors. The suffix *-sarcoma* is used for malignancies arising from connective tissue. The term *carcinoma* is used for malignant tumors arising from epithelial

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tissues. (Other terminology exists for even more tumor types.) Examples include:

Cell Type	Benign	Malignant
Fat	Lipoma	Liposarcoma
Fibrous tissue	Fibroma	Fibrosarcoma
Bone	Osteoma	Osteosarcoma
Squamous epithelium	Squamous cell papilloma	Squamous cell carcinoma
Duct or gland	Adenoma	Adenocarcinoma

A dog presenting with a history of seizures provides an excellent case to review the significance of disease classification. As with all cases, the veterinarian must develop a list of differential diagnoses. The thought process covers all the classes of disease, but the list typically does not have a cause from every class. There is a long list of possible causes for seizures. The veterinarian works to evaluate the most common ones first. Table 16–5 provides a partial list of differential diagnoses for three different cases of dogs with a history of seizures. Although the primary presenting complaint is the same for all three dogs, the age and environmental conditions for the animal change the most likely differential diagnoses for each case.

Table 16–5 **Case Comparison of Seizing Dogs**

CASE 1: A three-month-old male toy poodle. The dog is strictly a house dog and does not run free. In addition to the seizures, it has had intermittent diarrhea and is quite thin. Differential diagnoses: Developmental disorder—portocaval shunt, brain malformation Hypoglycemia—could be secondary to poor diet, diarrhea, or intestinal parasites Head trauma—not likely with a strictly indoor dog Toxins—potential for ingesting medications or illegal drugs in the house, chocolate Infectious causes of encephalitis—e.g., distemper Idiopathic epilepsy—very unlikely to begin in a dog this age
CASE 2: A two-and-half-year-old male golden retriever. This dog is in excellent physical condition and has been eating well. This dog is free to roam the neighborhood and recently had one episode of vomiting and one episode where it was limping and stiff. Idiopathic epilepsy—this is high on the list because of the age and breed of the dog at the onset of seizures Head trauma—the recent limping and stiffness raises this possibility Toxins—the list is long but possibilities include lead, insecticides, chocolate Liver disease—definitely needs to be ruled out but the dog has been doing well otherwise Infectious encephalitis
CASE 3: A 14-year-old male Schnauzer. This dog had its first seizure and since that time has not been acting normal. There has been some weight loss and a poor appetite, and the owners feel that the dog can no longer see. The dog is strictly an inside dog with no history of trauma. Metabolic disease—liver disease, hypoglycemia (insulinoma in the pancreas), hypocalcemia all are possibilities because of the advanced age of the animal at the onset of seizures Neoplasia—the age of the dog, the blindness, and the lack of normalcy after the seizure make this a high likelihood Circulatory problem—more likely with the age of the animal Idiopathic epilepsy—very unlikely with the age of the animal

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SUMMARY

Classifying diseases into such categories as parasitic, infectious, metabolic, and toxic helps practitioners, owners, and students make sense of a vast field of study. Even so, some diseases may be classified in multiple categories or cause conditions that could be classified in other categories, therefore causing confusion. Nevertheless, a disease classification system gives veterinarians a tool in the study of their discipline.

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REVIEW QUESTIONS

1. Define the following terms:

   schistosomus reflexus
   congenital
   hemophilia
   arthritis
   pneumothorax
   peritonitis
   idiopathic
   neoplasm
   metastasis
2. True or False: By law, veterinarians can give medical advice to humans because humans are animals.
3. True or False: Benign tumors can be damaging even though they do not spread to other parts of the body.
4. ________ describes all the processes that occur within an animal.
5. Diabetes can be classified as a ________ disorder.
6. Does the risk of tumors increase or decrease with age?
7. Give one possible antidote to ingestion of a rat or mouse poison that causes bleeding.
8. What disease category does hemophilia belong to?
9. Is antifreeze toxic if ingested by a dog?
10. Should vomiting be induced in all causes of toxin ingestion?
11. What does the suffix -*oma* mean?
12. Describe the technique mentioned in the text for stimulating urination in sheep.
13. Describe the appearance of a calf with schistosomus reflexus.
14. What kind of disease is arthritis?
15. How does oral administration of activated charcoal aid in the removal of toxins?

ACTIVITIES

Material needed to complete activities:

Internet access
telephone book

1. Do an Internet search to find indigenous poisonous plants. Attempt to identify any of these plant specimens in your home or yard. Take precautions to have pets and children avoid the plants.
2. Examine the various commercial products in your house for other potential toxins (for both animals and people). Do the labels of these products give guidance on how exposures should be treated? Do you have a poison control number readily available for emergencies? If not, use local telephone books to find the number. Post the poison control telephone number along with other emergency telephone numbers by your home telephone. Also, write directions to your home from the local emergency service provider and put that also by the telephone. This can be of great assistance to an individual already stressed by an emergency situation.

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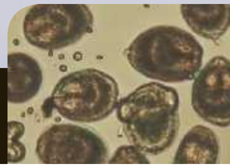
CHAPTER 17



Zoonoses

Objectives

Upon completion of this chapter, you should be able to:

- List and describe several diseases common in domestic animals that are contagious to humans.
- Relate the academic material learned in this chapter to clinical practice.

Key Terms

rabies	cat scratch fever	pasteurization	brucellosis
visceral larva migrans	ringworm	mad cow disease	tuberculosis
cutaneous larva migrans	RNA viruses	scrapie	
toxoplasmosis	Q fever	West Nile fever	

Introduction

All veterinarians have their own reasons for entering the profession. Many veterinarians enjoy science and medicine, working with animals, and the technical challenges of the profession. Once in the profession, veterinarians also undertake responsibilities to people around animals. Many diseases in animals are transferable to humans. The veterinarian is responsible for minimizing these diseases and protecting the people exposed to these afflicted animals.

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A Day in the Life
What are Friends for?

Veterinary school was extremely challenging. The amount of material covered was just tremendous. In the final year, students often put in long, hard hours in clinical rotations. During that time, I made some of the most significant friendships of my life. The support of friends was so important during those times when the academic rigor seemed overwhelming. In addition to working hard, we did find time to have fun and enjoy life. We found things to laugh about, even if they were directed at ourselves.

Chapter 15 included basic principles in preventing diseases. In a hospital setting, such as the barns at veterinary school, contagious diseases are of particular concern. *Salmonella*, a bacterium that causes severe diarrhea, is one of these diseases. There were times in school when horses that were presented for other conditions (such as surgery) would develop diarrhea. To diagnose *Salmonella*, feces from the animal were cultured. It generally took several days for the results to be available. If the disease was confirmed, the horse was transferred to the isolation ward.

While waiting for the culture, precautions were taken to minimize the risk of spreading *Salmonella* to other horses in neighboring stalls. An area outside the stall door was marked with tape. Within this area, disposable plastic boots, a protective gown, and gloves were worn. When leaving the area, shoes were sanitized in a disinfectant footbath. As a student, I did not look forward to this type of case because it increased the time commitment in an already busy day. But the situation was quite common, and everyone knew to follow procedure.

Salmonella is also of concern because humans can contract the disease. The clinical signs of human and animal presentation are similar: high fever and diarrhea. Many humans with salmonellosis need to be hospitalized for supportive treatment and, possibly, antibiotics. My senior year, I developed signs consistent with *Salmonella* infection, although it easily could have been the flu. I was taking large animal pathology, a rotation in which autopsies are performed on horses and cows. It was quite possible that during that rotation I could have been exposed to the organism.

When I developed symptoms, I left the postmortem room and returned to my dormitory. I felt miserable, weak, and feverish. I also experienced severe diarrhea. Late that first night of my illness, I once again had to leave my room to go to the bathroom. I felt so weak and had no desire to get out of bed. But even in my state of misery, I did laugh when I opened my door

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FIGURE 17–1 Humans can succumb to many animal diseases. Dr. Lawhead's classmates hoped to prevent the spread of disease in the dormitory.

(Figure 17–1). My supportive friends had taped off my room, complete with disposable boots and a protective gown! I had become the biohazard of the dormitory. As good luck had it, I made a quick recovery, with no additional evidence of *Salmonella*.

I was quite fortunate in that case, but diseases that affect humans can be devastating. Previously, I was presented with a young kitten that had become ataxic. The kitten was taking high steps with its hind legs and was having trouble staying upright. The kitten was not vicious but was highly anxious and agitated.

This kitten had been found as a stray almost two months earlier. At that point, the kitten did have a couple of small wounds on its hind legs. The owner also mentioned to me that the kitten had bitten her earlier that day when she was trying to pick it up. The history made me nervous. The case was classic for **rabies**, which is of particular concern because it can cause a fatal infection in humans. The kitten continued to worsen and was euthanized. The animal was submitted for testing and did show positive for rabies. The owner rightfully worried that a rabid animal had bitten her.

Further, I visited a farm to examine a cow that was unable to rise. The cow had calved three months earlier, which made milk fever an unlikely cause. When I examined the cow, she had a drooped ear and her eye on the same side seemed sunken in the socket. I noticed that she was unable to blink with that eye. The farmer mentioned that she was holding her head to the side the previous day, but he had not become concerned. This cow likely had a brain infection called

continues

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A Day in the Life continued

listeriosis. The outlook for this cow was not good, but I had more important topics to discuss. I needed to talk about the risk to the farm family.

Recently the national news has focused on the disease caused by the Ebola virus. Although the disease was first discovered in 1976, this is the first time an outbreak has involved treatment of multiple cases in the United States. The disease is spread by contact with bodily fluids from infected people. The mortality rate is quite high and the fact that Ebola is extremely contagious has raised the fear level dramatically.

Ebola initially seemed quite distant from my profession, with the major outbreak occurring in West Africa and only a few cases in the United States. It has been known that other primates can be a source of infection in humans. With cases now in the United States, fear developed over the potential of dogs and cats to be a source of infection. At this time, the knowledge of the disease in pets is actually quite limited. The Centers for Disease Control and Prevention, which is the primary source for information on this type of situation, reports no incidence of Ebola virus in cats or dogs. Although there has been some evidence that dogs have mounted an immune response to the virus, to date neither clinical disease nor transmission to humans has been detected. As with so many diseases, proper sanitation to prevent animals from coming in contact with fluids from infected people minimizes any risk. This disease will be closely watched and studied. Doctors, veterinarians, and pet owners will learn more with time.

ZOONOTIC DISEASES

Objective

- List and Describe Several Diseases Common in Domestic Animals That Are Contagious to Humans

Zoonotic diseases can be transmitted from animals to humans. The transmission may occur through direct contact with the animal, through a vector (such as fleas or ticks), or through food contamination. The type and frequency of zoonotic diseases vary tremendously between geographic areas. In industrialized countries the number of people with direct contact to food animals is very low. For example, less than 2% of the population in the United States works directly with farm animals. The number of households with pets has increased dramatically over the last century. This has increased the significance of pets as a source of human diseases.

As with any infectious disease, the higher the number of infected animals, the higher will be the risk of spread. In addition, the behavior of the owners and the type of interaction with the animals directly influences the risks. Proper sanitation and hygiene can greatly reduce the risk of many zoonotic diseases. Children are at higher risk for many zoonoses. Children are more likely to have close physical contact with their pets and often have worse hygiene than adults. Young children are also more likely to place contaminated items in their mouths and are less likely to wash hands frequently.

Visceral larva migrans (VLM) is one such disease in which children are at a higher risk when they place things in their mouths. (*Viscera* is a term used to describe the internal organs.) The larvae of the roundworms found in dogs and cats cause VLM. *Toxocara canis* is the most common cause of this condition. A roundworm that infects raccoons is also responsible for VLM in humans.

Infected dogs pass eggs in the feces (Figure 17–2). Depending on the amount of moisture and the outside temperature, the eggs develop larvae in approximately two weeks. At this point, the eggs become potentially infective to other animals. Ingesting these eggs or larvae can infect other dogs. The larvae then migrate through the liver and lungs of the dog. Eventually, they are swallowed, and adults develop in the intestines. Puppies can also be infected before birth as the larvae migrate through the mother's body, cross the placenta, and enter the pup. Larvae can enter the pup through the mother's milk as the third means by which new infections can occur.

The adult roundworms are capable of passing large quantities of eggs in the feces of the dog. Over time the feces disappear with exposure to sun and rain. The eggs remain in the ground and develop into an infectious stage. It is this contamination of the ground that puts children at risk. If toys are used to play in the dirt and then placed in the child's mouth, the larvae can be ingested.

Once the larvae are ingested, they migrate through the body. Humans are not a true host, and therefore adults do not develop in the body. The larvae can cause damage as they migrate through the liver, lungs, and eyes. The clinical signs often include fever, coughing, wheezing, an enlarged liver, and abdominal pain. The signs are not very specific and can be misdiagnosed. The disease is generally self-limiting (i.e., it resolves without treatment), and children recover with supportive treatment. Deaths have been reported when the larvae damage the heart or central nervous system.

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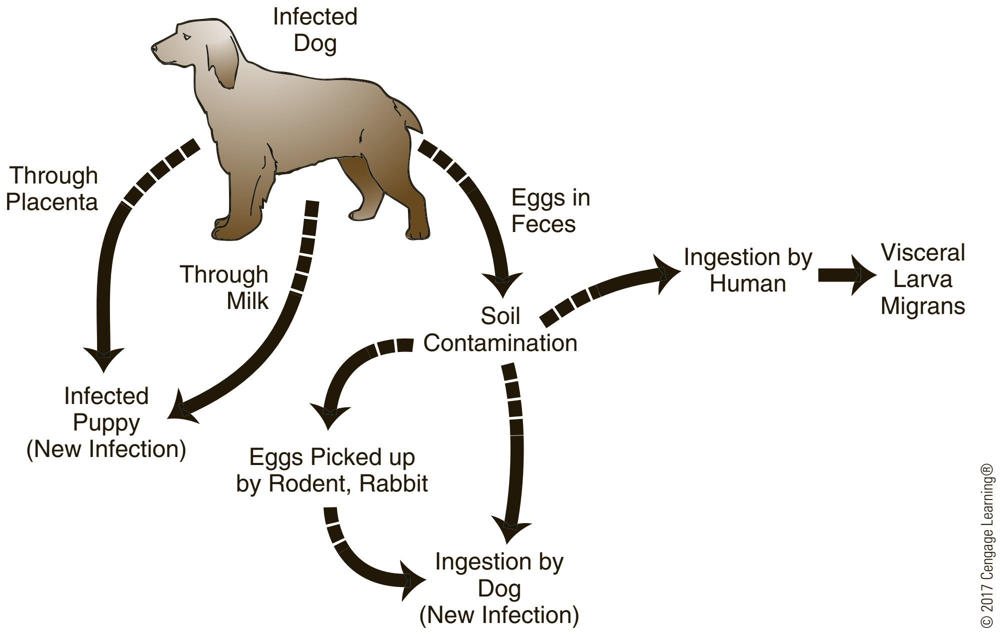

FIGURE 17–2 Roundworm life cycle.

Cutaneous larva migrans (CLM) is caused by hookworms (especially *Ancylostoma braziliense*) in dogs, which have a life cycle similar to that of roundworms. Hookworm larvae that develop from eggs are also capable of infecting other dogs by penetrating the skin. The larvae then migrate through the body and eventually develop into adults within the intestinal tract.

When these infective larvae penetrate the skin of humans, they migrate within the layers of the skin. This usually causes a raised red and itchy path within the skin. The disease in humans has also been called creeping eruption. Fortunately, this disease is generally mild and self-limiting.

Maintaining good sanitation with household pets can prevent VLM and CLM. Immediately removing feces from the environment eliminates the eggs before they become infective. This is very practical for owners and their own pets that are confined to a yard. Problems arise in public areas, such as parks, where multiple dogs are free to roam and contaminate the environment. Parents should be aware of this potential risk. Control must also include training children to keep nonfood items out of their mouths and to wash their hands frequently. Veterinarians also play a significant role by routinely examining dogs for parasites and administering proper medication to eliminate infections.

Another parasitic disease in animals that is of concern to humans is **toxoplasmosis**. *Toxoplasma gondii* is a protozoal parasite that infects cats. Cats are the definitive host, meaning that they are necessary to complete the life cycle. Infected cats pass oocysts (a type of egg) in the feces, which are then capable of infecting others (Figure 17–3). If other animals, such as cattle, pigs, and sheep, ingest the oocysts, the protozoa form cysts in the muscle tissue. These hosts generally do not become sick from the infection and do not pass oocysts in the feces. However, the muscle tissue of these animals is a possible source of infection if consumed by other carnivores.

Healthy humans who happen to consume *Toxoplasma* cysts often do not show any signs or experience only vague, flulike symptoms (fever, chills, muscle aches). This disease is of much greater concern in pregnant women and immunocompromised individuals, such as those infected with human immunodeficiency virus (HIV), those being treated for cancer, or those who have undergone organ transplantations and may not have a normal immune system. In these people, a life-threatening infection can occur. *Toxoplasma* organisms can invade the brain or lungs in these individuals, causing severe damage.

If women have their first exposure to the organism during pregnancy, the fetus may also become infected. This is a risk primarily in women who have had no prior exposure to *Toxoplasma*. When a pregnant woman develops toxoplasmosis, miscarriage, stillbirth, or birth defects may result. The birth defects generally involve the brain and eyes. The result may range from minor visual defects to blindness and severe mental retardation.

Cats are important in the spread of the disease because they are the definitive host, responsible for maintaining the life cycle. Direct contact with cats is a very unusual means of spreading the disease. Cats in general shed the eggs only periodically, and the eggs

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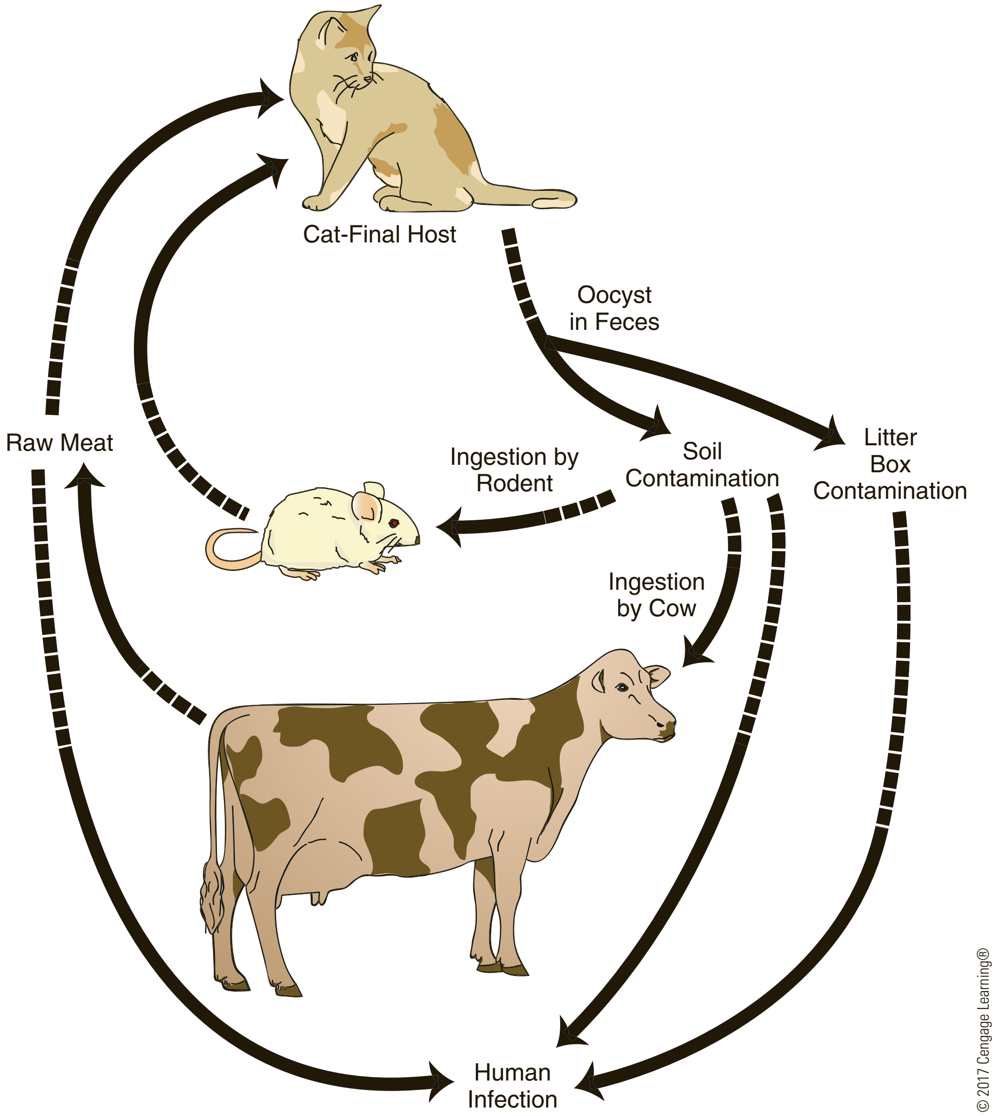

FIGURE 17–3 *Toxoplasma* life cycle.

are not infectious when they first leave the cat. The real risks are from fecal contamination that has been present for several days and from consuming improperly prepared meat from an infected animal.

The emphasis on control revolves around immunosuppressed individuals and women who may become pregnant. Several critical control factors should be followed by at-risk individuals, including the following:

- Litter boxes should be cleaned daily. Feces are thereby removed before any *Toxoplasma* eggs become infective. It is generally recommended that pregnant women have someone else clean the litter box in these situations. (This recommendation is greatly appreciated by women.)
- Cats should be discouraged from being hunters. Even rodents can be infected with *Toxoplasma* organisms and can spread it to cats.
- Sandboxes should be kept covered when not in use. Cats find the loose sand appealing as a litter box.
- When gardening or working in soil, gloves should be worn.
- Meats should be adequately cooked before consumption. Internal temperatures of meat should reach at least 66°C (150°F).
- Hands should be washed thoroughly after handling raw meats and after contamination with soil.

Bite wounds from pets are a common occurrence. This is not exactly a disease transferred from the pet, but it is a condition in humans that results from direct contact with them. Many bite wounds are minor, but some can be so serious that they require suturing,

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antibiotics, and even hospitalization. Alarming cases have been reported in which a dog or pack of dogs has even killed humans.

Many groups are at a higher risk for animal bites. Obviously, veterinarians and animal control officers are placed in situations that increase the risk. Professionals such as letter carriers, meter readers, house cleaners, social workers, and others who must enter other peoples' homes are at higher risk as well. Many dogs feel threatened and become very defensive when strangers enter their properties.

Children may be at highest risk. Often children do not understand proper animal handling, and they lack fear of pets. Young children may handle pets roughly, and in response to pain the animals bite. Children are much more likely to be bitten in the face. Their smaller size and their approaches toward the head of animals increase the risks. Head bites can be quite hazardous and often produce long-lasting scars.

Not every bite wound can be prevented. However, some basic principles can help to limit incidences. Young children should have contact with pets only when supervised. Children should be taught at a young age how to properly interact with pets. When entering a house with a barking dog, the owner should be present to keep the animal under control. Never try to strike at a dog in an attempt to scare it; this often increases the likelihood that the animal will try to bite.

Bite wounds are particularly worrisome when the animal doing the biting escapes. Bite wounds spread rabies, a disease that can infect all mammals. It may also be possible to spread the disease with contamination of deep scratches and mucous membranes from saliva or cerebrospinal fluid.

Rabies is caused by a virus that infects the central nervous system. Wildlife has the highest incidence of rabies. Interaction with wildlife occasionally brings the disease to our domestic animals. In my home region (central Pennsylvania), skunks, raccoons, and foxes have all been detected with rabies. In my career, I have seen rabies affect cats, horses, and cows, all resulting in potential human exposure.

When a rabid animal bites another animal, the rabies virus is introduced into the body. The virus enters nerve fibers and migrates toward the central nervous system. Eventually, the virus reaches the brain, where it establishes infection. The incubation period for rabies is extremely variable. Because the virus must migrate through the nerves, a bite around the head results in clinical disease much more quickly than a bite on the hind foot. The incubation period can range from a couple of weeks to many months.

The virus then moves down the nerve fibers to the salivary glands, where the virus can be shed in the saliva. The virus can be present in the saliva for days before the animal shows clinical signs. Therefore, the clinical appearance of the animal doing the biting cannot be a reliable assurance that it is not rabid.

The clinical signs of rabies can be extremely variable, but all involve the central nervous system. Initially the animal may become restless and have a change in behavior. The animal may then become quite agitated and aggressive, snapping and biting at inanimate objects. Other animals may show signs of being in a stupor, almost nonresponsive. Many neurologic signs, such as ataxia, paralysis, and seizures, commonly occur with rabies. The paralysis may involve the muscles that control swallowing. The common description of a rabid animal frothing at the mouth is due to the inability to swallow. Rabies has also been called hydrophobia (fear of water). The animal is not truly afraid of the water but is unable to drink properly. Eventually, rabies is fatal.

Rabies cannot be diagnosed in a living animal. The brain must be tested to confirm the diagnosis. Tests are available to detect the rabies virus within the brain tissue. When a human or pet is bitten by a suspicious animal, the animal must be available to test. The diagnosis cannot be made based only on the clinical signs. No treatment is available for an animal or human with the clinical disease.

Prevention is essential in the control of rabies. Many vaccines are available to help prevent rabies. In animals, the vaccine must be given before the animal is exposed. Many states and localities have laws mandating the vaccination of pets. These laws have been developed to protect the humans in the communities. In Pennsylvania, dogs and cats must be 12 weeks old for their first rabies vaccination. A booster is required in year one. Many vaccines are currently approved for a booster every three years thereafter.

Dogs are commonly vaccinated for a disease called leptospirosis. The causative agent, *Leptospira*, is a spirochete that has many subtypes. The symptoms in dogs can be nonspecific and include fever, lethargy, vomiting, lack of appetite, and dehydration. The severity can range from sudden death to a long-term mild infection. Leptospirosis needs to be included on the list of differential diagnoses in dogs developing acute kidney failure. It is especially a consideration in cases with sudden onset of kidney and liver disease.

The organism can be shed in urine, which makes good hygiene practices very important. Hospitalized cases are a potential threat to veterinarians and employees at the hospital. Humans also develop a fever when infected and can show evidence of kidney or liver disease. Proper vaccination is used to prevent disease occurrence in dogs. Once a dog is infected, proper hygiene during cage cleaning and handling is essential in preventing infection in people.

Exposure to cats also puts humans at risk for **cat scratch fever** or cat scratch disease. Classically, the

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disease develops after a bite or scratch from a cat. Any contact with a cat increases the potential for developing this disease. Often the disease begins with a sore developing at the site of the scratch. Fever and an enlargement of the lymph nodes, typically the ones responsible for draining that region, follow this. Usually, patients feel tired and weak in response to the disease. Other signs include headache, weight loss, swollen conjunctiva (surrounding the eye), sore throat, and enlarged spleen.

Cat scratch fever is generally self-limiting, and patients recover within two to four months. In some patients the signs can last much longer. The disease is believed to be caused by a Gram-negative bacillus (*Bartonella henselae*). Antibiotic therapy has not been shown to speed the recovery of infected individuals. This organism generally does not cause clinical disease in the cat that carries it. Kittens are much more likely to carry the disease.

Ringworm is a fungal infection in the skin of animals. The disease can infect any domestic species, and all may be a potential source of infections for humans. In animals, ringworm causes hair loss and scaling (Figure 17–4). Often the regions of hair loss are circular, but they can be of any shape. The regions start small and spread outward. In humans, ringworm also causes hair loss on the scalp. On regions of the skin without hair, the first sign is often a raised red lump. The redness then spreads outward and the center heals. This spreading reddened ring provided the name *ringworm*, even though no worm is involved.

The disease is not highly contagious, but close contact with infected animals increases the risk. Prepubescent children have a higher risk of developing clinical signs. Avoiding contact with infected animals and thorough washing of contact areas are important control measures in preventing the disease in humans. When clinical signs are visible in an animal, avoiding contact is straightforward. Cats quite often are carriers of the ringworm spores without clinical signs. In households in which humans develop ringworm infections, the pets need to be evaluated even if clinical signs are not evident.

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FIGURE 17–4 Gray, crusty patches of hair loss are classic signs of ringworm.

Horses are susceptible to a group of **RNA viruses** that cause inflammation of the brain. These diseases are Eastern, Western, and Venezuelan equine encephalomyelitis. In horses, these diseases often begin with high fevers, stiffness, anorexia, and colic. As the disease progresses, the horses begin to show neurologic signs. These may include severe depression, ataxia, sleepiness, head pressing, circling, and constant walking. Some horses may become very agitated and even aggressive (making rabies an important differential diagnosis). These viruses are often carried in birds and are transmitted among animals by a mosquito.

In humans, the signs may be quite similar. Fever, headache, confusion, coma, seizures, and death are all possible. Humans develop the disease from mosquitoes as well and are not a threat to other humans. Currently, there is no specific cure, and treatment is supportive for an infected individual.

Vaccines are available to prevent the disease in horses. For human protection, control revolves around the mosquito. Eliminating potential breeding areas (stagnant wet areas) and insecticide treatment help to lower the incidence of mosquito vectors. Large wet areas such as marshes and ponds can be a breeding ground for mosquitoes. But mosquitoes can also use smaller collections of water, such as birdbaths and used tires. Monitoring the disease in animals can be useful in alerting humans in that region to watch for potential signs.

Food animals represent a potential source of infectious diseases to humans through dairy and meat products. Listeriosis, or circling disease, in cattle, sheep, and goats is a potential threat to humans. The Gram-positive bacteria (*Listeria monocytogenes*) may be found in harvested feed.

The organism penetrates the roof of the mouth, entering the nerve fibers. The bacteria migrate to the brain, where they cause nerve damage. Many animals show signs of paralysis on one side of the face. This may cause a drooping ear and eyelid and a loss of the ability to blink. Often these animals hold their heads to one side and when walking always turn in one direction (hence the term *circling disease*). When this occurs, it is nearly impossible to force the animal to turn the opposite direction. Some animals continually walk, whereas others may enter a corner and press forward against a gate or wall. The organism may also cause abortions in cattle.

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Infected animals may shed the organism in their milk. Humans consuming unpasteurized dairy products, including certain soft cheeses, may potentially become infected. In humans, the organism also infects the brain. Headaches, fever, nausea, vomiting, coma, and death are all possible. Consuming only pasteurized dairy products is essential in preventing the disease in humans. Proper sanitation when handling animals and aborted fetuses is also essential.

Q fever, caused by *Coxiella burnetii*, results in abortions in sheep and goats. Many infected animals do not show clinical signs. The disease is of much more importance because of the potential threat to humans. In humans, Q fever has a sudden onset of flulike symptoms. Humans may show fevers, headaches, chills, and weakness. Some humans develop chronic signs due to damage to the heart. Only a very small percentage of cases result in death. The infectious agent can be inhaled, which makes workers in slaughter facilities at a high risk. Raw milk is also a source of infection. **Pasteurization** is effective in destroying the organism.

Food-borne pathogens are a major concern in food animal medicine. A number of bacteria that are normal intestinal inhabitants and many pathogens of animals can cause serious illness in humans. The goal of animal producers, veterinarians, meat processors, and the human medical profession is, ideally, to eliminate or, more realistically, minimize, the number of cases of food-borne illness.

The major human pathogens include the bacteria *Salmonella*, *Escherichia coli* (*E. coli* O157:H7 is the strain most commonly seen currently), and *Campylobacter*, and the protozoan *Cryptosporidia*. The bacteria may cause clinical diseases in farm animals, and some, such as *E. coli*, may be part of the normal flora. Primarily, these organisms cause intestinal signs, such as diarrhea and anorexia, in the infected animals. *Cryptosporidia* is a protozoan found in food animals that causes severe chronic diarrhea. Contamination by this organism is a potential threat to water supplies. Large numbers of all these organisms may be passed in the feces. It is important to recognize that humans are a potential reservoir of these organisms as well.

In recent years, many cases of food poisoning (often *E. coli* O157:H7) have resulted from improperly cooked food. Several of these cases have occurred at fast-food restaurants, resulting in large numbers of people being exposed and becoming ill. In humans, vomiting, diarrhea, and fever are often the primary signs. Children, the elderly, and immunosuppressed patients face the highest risk. The disease often becomes so severe that kidney failure results. Many deaths have been reported.

Several food sources may become contaminated with pathogenic bacteria. These organisms can survive on the food source outside the animal. The list of potential contaminated foods is actually quite long and includes beef, pork, dairy products, lamb, poultry, eggs, raw vegetables, apple cider, fish, shellfish, mushrooms, and water. In this chapter, the discussion emphasizes the risks associated with meat and dairy products. Many of these principles apply to these other foods as well.

As food is delivered from the farm to the dinner table, there are many potential sources of contamination. The food supply process begins with the producer on the farm and continues to the slaughterhouse or processing plant. From this point, the food is shipped to a retailer, purchased by the consumer, stored, and eventually prepared and served. The FDA Food Safety and Modernization Act was signed into law in 2011. This act brought sweeping changes to food handling.

Due to the large number of organisms that may be shed in the feces, the farm does represent a major potential source of contamination of the product. Animals shipped to slaughter typically have some degree of fecal contamination on their hides and hair coats. Producers strive to maintain a healthy herd, which maximizes their productivity. However, not all diseases can be prevented, and many healthy animals may be shedding pathogens. Maintaining good sanitation and minimizing stress of the shipped animals help to keep contamination to a minimum.

At the slaughter facility, the animals must be skinned and the meat processed. Contamination on the hide can potentially spread to the carcass. Removing the abdominal and thoracic organs also provides a potential source of contamination. Every step, including grinding and cutting, provides an opportunity for the meat to be handled and potentially contaminated. Strict guidelines are in place that emphasize the importance of cleanliness of facilities, the equipment, and personnel. Inspectors are present to ensure that proper procedures are followed and that animals being slaughtered are not showing evidence of disease.

Meat and dairy products are then shipped to retailers, where proper storage is essential. Care during all the steps involved is essential to minimize the number of bacteria on the food. It is not realistic to think that all bacteria have been eliminated. Maintaining the food at proper refrigerated temperatures keeps the organisms from dividing.

Likewise, once purchased by the consumer, proper storage is important. Meats should be thawed in the refrigerator to keep the bacteria from rapidly dividing. An alternative is to rapidly thaw the meat using a microwave. The surface of meats thawed at room temperature can allow bacteria to flourish before the center of the meat is thawed. Meat can become contaminated in the household as well. Proper sanitation in the home is the key to maintaining a healthy product.

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The ultimate responsibility for food safety lies at the home. The final step is proper food preparation. Meats must be cooked to adequate temperatures to ensure that any existing bacteria have been killed. Red meats need to be cooked to an internal temperature of at least 160°F (poultry should be heated to 180°F). A meat thermometer is useful to confirm the internal temperatures.

Television news and articles in the popular press can heighten the awareness of certain diseases. Articles are common on anthrax, **mad cow disease**, **scrapie**, and **West Nile fever**. These diseases' effects on human health make the public both very aware and concerned.

Bacillus anthracis is a spore-forming bacteria that causes anthrax, which can infect humans as well as animals. Anthrax may be seen in cows, sheep, goats, and horses. The most consistent sign of anthrax in animals is sudden death. Animals may show fever, anorexia, and bloody urine or diarrhea. Just as in humans, the spores can be introduced into an animal by ingestion, by inhalation, or through a wound in the skin. The organism exists throughout the world. Within the United States, South Dakota, Arkansas, Louisiana, California, and Missouri have higher incidences.

Often outbreaks occur during the warm months and may follow heavy rainfall. Heavy downpours may bring anthrax spores to the surface. The most common form in animals is the intestinal form, which presents after contaminated grasses are ingested. The bacteria can then penetrate the lining of the intestinal tract and begin to replicate.

The organism does not survive for long periods within dead animals. However, these animals often have a bloody discharge (urine, feces, or saliva) that contaminates the environment. It is the contamination of the external environment and the hair coat of the animal that provides the highest risk for humans. Individuals in professions handling animals or animal products are at the highest risk for developing the disease. These occupations include veterinarians and any worker that processes hide, hair, or wool.

In humans, the cutaneous (affecting the skin) form of the disease causes a severe sore that becomes very swollen. The inhalation form of the disease causes a severe pneumonia that may be fatal. The intestinal form is the least common and causes fevers, cramping, and diarrhea. The intestinal form may also be fatal. The disease can be treated successfully with antibiotics if detected early. The difficulty is that the disease progresses rapidly and treatment must begin early.

West Nile fever was first detected in 1999 in the United States. This disease had been commonly found in the Middle East, Africa, and parts of Europe and may infect many animals, including humans, horses, dogs, cats, and several species of birds. In many animals the disease is mild and goes undetected. In a small percentage of cases, more serious illness may result. The West Nile virus can cause inflammation within the central nervous system and may be fatal. The signs may be quite variable but often include ataxia, paralysis, and weakness. The disease is often fatal in birds. Dying birds may provide a clue that the disease is present in an area. Public health officials often monitor the death of birds to detect the presence of the virus. In this manner animals are used as sentinels for diseases that may infect humans. Monitoring other susceptible species allows officials to assess the relative risk for humans. Likewise the number of human cases is reported to alert health care workers to an endemic area. For example, in the first 10 months of 2014 the states of North and South Dakota, Nebraska, and Louisiana all reported more than 1 case of West Nile Virus per 100,000 population, whereas Maine, Vermont, and New Hampshire had none.

The virus is spread among animals by mosquitoes. A mosquito that bites an infected animal can then transfer the virus to humans. In humans, the disease typically produces flulike symptoms, such as fever, muscle aches, headaches, and vomiting. The disease is fatal in many cases. Mosquito control is a very important part of managing the spread of West Nile fever. Insecticide spraying and minimizing breeding grounds are essential.

Mad cow disease and scrapie have become household names. These two diseases and the human disease Creutzfeldt-Jakob disease (CJD) are classified as transmissible spongiform encephalopathies (TSEs). TSE is descriptive of the damage caused to brain tissue. Encephalopathy is a disease of the brain. *Spongiform* describes the holes that form in the brain tissue, making it appear spongelike. These diseases are transmissible; that is, they can spread from one infected animal to another.

The prion, a poorly understood infectious agent, causes this group of diseases. As described in Chapter 14, all other infectious organisms contain protein and nucleic acid. The prion is an abnormally shaped protein molecule. No nucleic acid has been identified within a prion. Prions have an extremely long incubation period, typically measured in years, whereas most bacteria and viruses have an incubation period in the range of days to weeks.

These diseases typically produce a gradual onset of neurologic signs. Mad cow disease, or bovine spongiform encephalopathy (BSE), often begins with a change in the animal's behavior. Infected cattle become very agitated and aggressive. Small noises or sensations often stimulate a violent reaction from the cow. The disease is eventually fatal.

Scrapie is a similar disease found in sheep and goats. The clinical signs are quite like BSE. The disease often begins with behavioral changes and weight loss.

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The animal becomes restless and nervous. Some animals develop an incessant itching, causing a sore area on the body. As the disease progresses, the animal worsens, with seizures or severe weight loss and anorexia. There is no cure for scrapie.

CJD has been known in humans for many years. In recent years a relationship has been found between mad cow disease and a new variant Creutzfeldt-Jakob disease (nvCJD). It is believed that the prion responsible for mad cow disease is also the causative agent of nvCJD. It is suspected that ingesting beef products from infected animals is the source of this infection in humans.

Mad cow disease has primarily been a problem in the United Kingdom. The United States has maintained an aggressive surveillance program since 1990. To this point only a few cases of BSE have been identified in the United States. Control measures have been implemented in an attempt to prevent future cases from becoming established. There is currently a ban against any import of ruminants from countries at high risk for BSE. Mad cow disease may be transmitted through feeding of meat and bone meal from other ruminants. As a result, this practice has also been banned. The U.S. Department of Agriculture (USDA) and the Food and Drug Administration are taking a very active role in trying to limit the occurrence of BSE in the United States.

While the emphasis of this text is on the seven domestic mammalian species, avian influenza has recently been making the news. Specifically, a highly pathogenic strain of avian influenza (H5N1) that infects poultry has been transmitted to humans. In poultry, the virus can cause illness, depressed production, or death in the birds. Worldwide over 200 cases in humans have been diagnosed in the past few years. In humans, the signs are typical flu symptoms and can be so severe as to cause death. In general, most of those affected have had significant direct contact with infected poultry. Fortunately, no sustained transmission has occurred between humans. However, there is concern that the virus could mutate into a form that could result in a flu epidemic in people. The USDA establishes guidelines for monitoring imported poultry and testing within the United States.

CLINICAL PRACTICE

Objective

- Relate the Academic Material Learned in This Chapter to Clinical Practice

This chapter covers a variety of pathogens that may be shared between humans and animals. Many more zoonoses exist. This discussion helps to illustrate the veterinarian's role in protecting the health of humans. The specifics of each disease vary, but the principles tend to be the same.

Veterinarians work with owners and producers in an attempt to keep all animals healthy. Many of the principles discussed throughout this text are once again used. Proper nutrition, minimizing stress, and vaccinating for important diseases help to protect the health of the animals. When all this fails and animals do become sick, veterinarians also work to keep the health of the humans protected. Educating clients is an important step in this process.

The cow infected with listeriosis that was discussed at the beginning of this chapter offers an excellent example of the need for client education (Figure 17–5). This particular farm family consumed raw milk from their own cows. They had done it for many years and had never suffered an illness. This cow or another in the herd may have been shedding *Listeria* organisms in the milk, which could pose a health threat by infecting a member of the family. I emphasized this risk to them and mentioned that many other organisms, such as *Salmonella*, might also be present in the milk. I had to make a strong recommendation that only pasteurized milk be consumed.

Many people have consumed raw milk for years without any problems. It is easy to develop the mindset that "since I've never gotten sick there must not be a problem." Additionally, recent movements have advocated for the health and economic benefits of consuming raw milk products. However, two men who live nearby to the text's authors developed life-threatening illnesses due to the consumption of raw milk. One developed *Salmonella* and the other Q fever. Both had been drinking raw milk for decades before the onset of these illnesses. They were the ones who developed the diseases even though others were also consuming the same raw milk.

Pasteurization was developed to minimize the risk of pathogens in dairy products. In pasteurization milk is heated to 62°C (143°F) for 30 minutes and then rapidly cooled. Flash pasteurization is a process in which milk is quickly heated to 72°C (162°F) and maintained at that temperature for 15 seconds. The milk is then

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FIGURE 17–5 A cow infected with listeriosis; she was unable to rise.

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quickly cooled. This process was initially used to kill common pathogens, such as *Brucella* and *Mycobacterium tuberculosis*.

Brucellosis is a reproductive disease that causes abortions in cattle. Humans can develop the disease through contact with infected fetuses or by ingestion of raw milk. In humans, brucellosis is also called undulant fever or Bang's disease. In humans the signs are much like a severe flu, with intermittent and irregular fevers (i.e., the fevers undulate up and down).

Tuberculosis is a disease that typically causes a debilitating respiratory infection in humans. Humans often have fever, weight loss, coughing, and chest pain when suffering from tuberculosis. The disease is very difficult to treat, often requiring long-term antibiotic therapy. The disease is still quite common in many parts of the world, although the incidence is low within the United States. The causative organism of tuberculosis, *M. tuberculosis*, can be shed in the milk of infected cows. Farmers may also develop the disease through aerosol transmission from the cow. Pasteurization of milk and frequent testing of cattle have helped to decrease the incidence within the United States.

Currently, brucellosis and tuberculosis occur infrequently, thanks to stringent testing and control measures. The pasteurization process is still effective on the large numbers of pathogens that still exist (e.g., *Salmonella, Listeria, Coxiella,* and *E. coli*). Pasteurization is not a complete sterilization of milk. Some heat-resistant organisms can still survive, which is the reason that milk has a limited shelf life even when stored in refrigeration. Pasteurization is used because it has little effect on the taste of the product.

Rabies is not treatable once clinical signs have begun. When a rabid animal bites a person, the disease is still preventable. The first step is an injection of antibodies at the site of the wound. The goal is that any virus present will be bound with the specific rabies antibodies. The person then undergoes a series of five vaccinations to raise the level of active immunity. The vaccines are extremely effective as long as exposure is known.

People in certain professions, such as veterinarians, wildlife officers, and animal control officers, are at a higher risk than the general population for becoming exposed to a rabid animal. Because of this risk, many elect to undergo rabies vaccination before any exposure. Just as in animals, the rabies vaccine requires a series of vaccinations and then periodic boosters. If a rabid animal bites a vaccinated individual, the person is immediately given boosters but no injection of antibodies. A vaccinated individual will quickly raise his or her own level of immunity with the booster shot.

Lyme disease is often discussed as a zoonosis. The concern is not direct transmission from the pet to the human but rather through a shared vector. It is not uncommon for a tick to detach from feeding on a dog and reattach on a human. When walking in wooded areas, both owners and their dogs are at risk of having contact with ticks. With Lyme disease, dogs can be used as sentinels to evaluate the relative risk in a given area. While testing a dog for Lyme disease, I have had many clients tell me that someone in their family was also being treated for the same problem.

As a profession, veterinarians strive to maintain a healthy animal population. In addition, educating the public on proper safety and health concerns helps to maintain the health of the humans involved with the animals. Monitoring the health of animals, conducting routine vaccination programs, controlling parasites, and engaging in sound sanitation practices all help to protect the general public.

SUMMARY

Outbreaks of zoonotic diseases cause international concern. Veterinarians and physicians alike are trained to identify more commonly occurring zoonotic diseases. Students of veterinary science should familiarize themselves with the causes, symptoms, treatments, and prevention of such disease conditions.

REVIEW QUESTIONS

1. Define the following terms:

   rabies
   visceral larva migrans
   cutaneous larva migrans
   toxoplasmosis
   cat scratch fever
   ringworm
   RNA viruses
   Q fever
   pasteurization
   mad cow disease
   scrapie
   West Nile fever
   brucellosis
   tuberculosis

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2. In order to prevent food poisoning, red meat should be cooked to an internal temperature of ________.
3. What causes salmonellosis?
4. Name the disease associated with roundworm larvae invasion.
5. What is another name for creeping eruption?
6. What animal serves as the definitive host of *Toxoplasma gondii*?
7. Is rabies a viral or bacterial disease?
8. What is another name for rabies?
9. What disease is caused by the Gram-negative *Bartonella henselae*?
10. What shape does a ringworm infection take?
11. What is another name for listeriosis?
12. What problems can arise for pregnant women who contract toxoplasmosis?
13. What treatments are available for a person who has presented with clinical signs of rabies?
14. What group of viruses, mentioned in the text, cause brain inflammation?
15. What is the best defense for prevention of *E. coli* infection?

ACTIVITIES

Materials needed:

Internet access

1. Research the Food Safety Modernization Act. Fact sheets can be located at the U.S. Department of Agriculture's website. Report the significant changes to the class.
2. Consider becoming a ServSafe certified food handler. Visit the ServSafe.com site to find study materials and details on testing option.
3. Learn how to prepare and handle foods safely at your local Cooperative Extension office. Ask for help with food handling, storage, and preparation.
4. Investigate the status of zoonotic diseases by searching the USDA site on the Internet.

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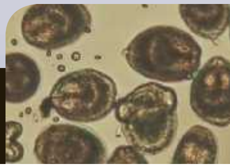
CHAPTER 18



Diagnosis of Disease

Objectives

Upon completion of this chapter, you should be able to:

- List the major methods used to diagnose disease and cite examples of disease diagnosis with each testing method.
- Discuss the clinical significance of disease diagnosis.

Key Terms

signalment
borborygmi
ophthalmoscope
packed cell volume
chemistry panel
complete blood cell count (CBC)
serology

Introduction

Throughout this text, you have been introduced to a variety of diagnostic tests. In general these tests have been discussed in reference to a specific disease or type of disease. The challenge arises when a case first presents. Every clinician must develop a systematic approach to reaching a diagnosis. There is no perfect system, but common principles do exist.

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A Day in the Life
A Road I Traveled . . .

Graduating veterinarians have a variety of choices when deciding how to direct their careers. Opportunities exist with pharmaceutical companies, research, consulting, teaching, and advanced training through internships and residencies. Most veterinarians enter private practice. They take on a role very similar to the family physician in human medicine. This is the road I chose to travel.

The transition from veterinary school to private practice can be quite challenging. I joined a practice that had two other veterinarians. I entered practice with a vast amount of knowledge but lacked experience. Fortunately, my employers were extremely helpful and guided me as I began my career. New graduates bring the latest information and techniques to their new jobs. Their employers possess essential experiences that play a critical role in the profession.

I was out of school less than a year when I visited a farm to see a cow that had trapped a foot beneath a metal plate. The cow was no longer trapped when I arrived. The injury was severe, though; she had nearly amputated one claw of her front foot. It was obvious that the damage was too severe to save this toe. I thoroughly cleaned the area and proceeded to finish the amputation. I controlled the bleeding and bandaged the foot.

As I sanitized my equipment, I explained the necessary bandage care. I also warned the producer that the cow's life span was likely to be limited. The stress of bearing weight on only one toe would eventually take its toll. Most cows in this condition last only one lactation.

We continued to visit, and the farmer began asking about veterinary school. He inquired, "How do they get all of these different cases, so that you can learn how to do these different things?" He was pleased that the new vet could handle such an unusual situation. I told him that my only experience came from a book! I had never witnessed an amputation of a claw but had been taught about the procedure. Veterinary school had provided me with all the necessary knowledge to handle this situation. My practice experience was improving with time.

One reward of the profession comes from systematically working a case, making a diagnosis, and successfully treating the condition. This process can be quite challenging, but in the end it is also quite rewarding. The entire process has many facets. It takes communication with the owner, examination of the animal, and a combination of knowledge and experience to be successful.

A major difference existed between my veterinary school experience and that of private practice. In veterinary school, multiple veterinarians were often working on each case, and the results of testing were often available within hours. For certain tests, such as radiographs, the results were available quickly and, in addition, had been interpreted by a specialist.

In private practice, I do not have the luxury of waiting on immediate results before deciding on a treatment. When I visit a farm and examine a sick cow, I would love to know what her blood calcium level is. Unfortunately, I do not have an on-the-farm test available, so I must rely on my clinical findings. I must decide if the treatment is warranted and then proceed. Often, administering the calcium proves the diagnosis. After receiving calcium, the afflicted animal often responds quickly, thus showing that the calcium was actually needed.

Over the years, I have seen many examples of the same cases, and to this day I continue to see new variations of the same diseases. My education is continuing, even after two decades of practice. Through differing experiences, I see the variations that can occur with any disease.

This chapter discusses the process followed in making a diagnosis. An almost countless number of diseases exist. Furthermore, many diagnostic tools are available. Not every possibility can be discussed. The goal is to show the organized approach that helps in reaching the diagnosis. While proceeding through this chapter, think about the following case that was seen at our office. Then consider what procedure would help diagnose the disease.

Merzee, a 10-year-old female dachshund, presents to the office for the first time. The owners are concerned because Merzee has been lying around more than normal and is not eating well. The owner thinks that Merzee has been losing weight.

DISEASE DIAGNOSIS

Objective

- List the Major Methods Used to Diagnose Disease and Cite Examples of Disease Diagnosis with Each Testing Method

All cases must begin with a thorough history. The range of questions possible in a good history is extensive. History proves extremely valuable because of the information that it provides. It is also important to recognize that the history does not increase the cost, is not invasive, and has no risk associated with it. It is obvious that in veterinary medicine the owner's perception is crucial to guiding the process of making a diagnosis. A thorough knowledge of veterinary medicine helps to plan for the questions asked in the history.

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Certain clues that present with answers to one query may lead to further questions.

Veterinarians must also adapt their questioning based on the species of animal. For example, asking what type of work a horse is doing (e.g., pleasure, racing, or jumping) helps determine a diagnosis in a case of lameness. On the other hand, that question has no relevance in a case of a vomiting cat. In this situation, inquiring whether the cat has access to the outdoors is more important. Cats free to roam have a higher likelihood of ingesting a toxin than a closely observed, strictly indoor cat.

There are basic principles that every history follows. **Signalment** is the basic description of the animal. The signalment includes the name or number of the animal, age, breed, sex (including spay/neuter status), reproductive status (e.g., whether the animal could be pregnant, time since last delivery), and use or activity (such as indoor/outdoor cats and dogs, training status of a horse). Asking these simple questions is the first step in developing the decision-making process. The obvious differences in male and female anatomy lead to other important considerations. Further, certain breeds stand at much higher risks for certain diseases.

The next step is to discuss the chief complaint, the reason that the animal is being presented for examination. Once this point is established, the questions can provide further details on the history of the problems. Common questions include the length of the problem, the course of the disease (such as sudden or gradual onset), and how the disease has progressed. Many times one sign develops early and then progresses into further problems.

It is always important to inquire about home remedies. At times, these remedies may be masking subtle signs. For example, an animal being treated with aspirin may not experience the degree of pain felt earlier. The question is also important because the treatment may not be benefiting the animal and may even be worsening the signs. Aspirin again offers an example—using it to treat a painful condition may result in a dog beginning to vomit.

It is important for the veterinarian to control the flow of the history. Owners have their own perceptions of what is important and may not recognize other valuable points of information. For example, a case in which a dog is eating aggressively but losing weight requires questions about diarrhea and water consumption. A dog with chronic parasitism may lose weight even though it is eating well. The history of diarrhea may help point to that diagnosis. A diabetic dog often shows the same signs but has an excessive thirst.

It is important to ask very specific questions as well. In one familiar case, the veterinarian merely asked if the owners had ever seen diarrhea from their cat. They replied that they had not. Later the veterinarian came to find that the cat never used the litter box in the house and they had never seen a bowel movement. The practitioner assumed that the cat did not have diarrhea. Had the veterinarian asked the owners to describe the cat's bowel movements, they would likely have replied that they could not. The veterinarian discovered the cat had diarrhea after it was hospitalized. Although the veterinarian assumed that the diarrhea began in the hospital, the cat's entire history became clearer with further discussion and the possibility of previous diarrhea was noted.

History taking can be challenging. It is not unusual for a husband and wife, or parent and child, to have different perceptions about the history. In addition, there are times when the owner is wrong. One example comes to mind. An older female dog presented for lethargy and poor appetite. The dog was feverish, had an elevated white blood cell (WBC) count, and an abdominal radiograph showed evidence of a fluid-filled structure in the lower abdomen. All of the evidence pointed toward an infected uterus, but the owners had reported that the dog had been spayed. Further questioning revealed that the owners had adopted the dog as an adult, had been told it was spayed, and had never seen it in heat. The diagnosis was confirmed that it was a uterine infection. The owners had been misinformed when they adopted the dog and never had reason to doubt that information. The outcome was positive in this situation, but the history made the diagnosis much more difficult.

The next step in diagnosis is the physical examination. During the physical examination (also called the physical or the exam), all the organ systems need to be evaluated (Table 18–1). In many diseases, more than one system may be affected. Detecting the problems in all systems is important in determining the underlying cause. Not every possible point is evaluated on every physical examination. For example, a complete neurologic examination requires testing of all the cranial nerves and the peripheral reflexes. This is not necessary in the kitten that presents for sneezing, sore eyes, and a fever. Emphasis is placed on the major problem during the examination.

Veterinarians develop a system to perform an organized physical examination. By systematically and repeatedly performing each step in the physical exam, important systems are not missed. Most veterinarians perform the steps of physical exams in a very specific order. Often during this time, the clients are discussing problems and asking questions. By maintaining a routine, veterinarians are sure to perform all steps involved in the physical.

The first step in the physical exam is a general observation of the animal. Many questions can be answered during the first contact with the animal. Is there any lameness or weakness? Are the eyes sunken, as if dehydrated? Is the breathing normal? Does the animal have a typical awareness of the environment? Is there

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Table 18–1 The Physical Examination

General appearance	Awareness/attitude Body condition Movement: lameness, ataxia
Vital signs	Temperature Pulse Respiratory rate Capillary refill time, color of mucous membranes Evaluation of hydration status
Cardiovascular system	Heart: sounds, rhythm Pulses: strength, regularity Distension of blood vessels (e.g., jugular veins) Swellings of extremities or dependent areas (e.g., under the jaw, lowest part of chest)
Respiratory system	Respiratory sounds: evaluated over lungs, trachea, and upper airways Nasal discharge Evaluation of respiratory difficulty: open mouth breathing, laboring Does difficulty occur on inhalation, exhalation, or both? Can a cough be caused by squeezing on the trachea?
Digestive system	Manure: amount, color, odor, consistency Abdominal palpation: abnormal masses, pain, splinting of the abdomen Rectal examination Mouth examination: normal teeth, foreign bodies
Musculoskeletal system	Normal movement of head, neck, and legs Evidence of swelling Symmetry between legs
Nervous system	Awareness Coordination Eyes: structure, reflexes Cranial nerves and reflexes Peripheral nerves and reflexes
Skin and hair coat	General appearance Hair loss Sores, rashes
Mammary system	Swellings Milk characteristics
Lymphatic system	Lymph nodes: shape, size, pain, symmetry
Urinary system	Abdominal palpation External structures
Reproductive system	External genitalia Rectal examination (horses, cattle)

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any distension of the abdomen? Is there fecal contamination on the hair coat that may indicate diarrhea? Does the hair coat appear healthy?

Following the physical examination, most veterinarians take the animal's vital signs. This includes the temperature, pulse, and respiratory rate. The pulse is evaluated not only for beats per minute but also for strength and rhythm. In cattle, the rate of rumen contractions is also considered a vital sign. This is a very important indicator of the cow's health.

A normal animal's gums or mucous membranes should be pink. An anemic animal has much paler

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Photo courtesy of Patricia Curley.

FIGURE 18–1 The dog's mucous membranes are checked for color and capillary refill time.

membranes. When pressed by a finger, the gums become much whiter. When the finger is released, the gum should quickly return to its pink color. The elapsed time is called capillary refill time (CRT) (Figure 18–1). In a healthy animal, the CRT is less than one or two seconds. In an animal whose blood is not being distributed effectively through the capillaries (such as occurs with animals in shock), the CRT can be much slower.

The stethoscope proves a valuable tool in the physical examination. The heart sounds are evaluated to determine if the beat is regular and if any murmurs are present (Figure 18–2). Review Chapter 4 for an understanding of the normal heart sounds and murmurs. A pulse point may be palpated at the same time the heart is evaluated. It is important to confirm that a pulse is created with each heart contraction. The respiratory system is also evaluated with the stethoscope.

Photo courtesy of Patricia Curley.

FIGURE 18–2 A stethoscope is used to listen to heart and lung sounds.

Listening to the chest evaluates the lungs for any evidence of disease. Review Chapter 5 for an understanding of lung sounds.

The stethoscope can also be used to listen to the normal sounds of the gastrointestinal tract. In ruminants, the activity of the rumen allows for an important evaluation of the health of the animal. A displaced abomasum, a disease discussed earlier in the text, fills with gas and moves upward, out of normal position. To diagnose this, the stethoscope is placed over the side of the cow, toward the end of the rib cage. While listening, the body wall is struck rapidly with a finger. Because the stomach is distended with gas and also contains fluid, the procedure creates a pinging noise (the ping has been described as sounding like a coin dropped in a well). The presence of a ping is diagnostic of gas distending an organ that also contains liquid. The size and location of the ping helps to distinguish what structure is distended.

In horses, it is also essential to evaluate the normal sounds of the intestinal tract. **Borborygmi** (singular is borborygmus) describes the normal noise made within the intestinal tract as gas and fluid move through the tract. (This is the noise in humans that is commonly described as stomach growling.) This type of noise should be audible in all regions of the horse's abdomen. A lack of noise could represent a problem that has limited the activity of the intestines in that region. Examples include an impaction of feces or a twisted loop of intestine.

In small animals, palpating the abdomen is extremely important. In large animals, only the outer edges of the abdomen can be felt. In small animals, several organs can be identified if the animal is relaxed. In many dogs and cats, the kidneys, urinary bladder, spleen, and caudal edge of the liver may be felt. These can be evaluated for normal size, shape, and sensitivity. The palpation of the abdomen is the most important aspect in evaluating the urinary system in small animals. Other organs may become palpable if there is an abnormality. Normally, the intestines cannot be identified. The same structure with a large foreign body or intussusception may be felt.

A rectal examination evaluates the size and shape of the prostate gland in male dogs. In addition, the internal bony structure of the pelvis may be felt. The character of the feces in the colon is also detected during this procedure. A rectal exam can be a very important diagnostic tool in evaluating a dog straining to defecate. An older male dog that has been having difficulty defecating could have constipation with dry, hard stool or a prostate gland that has enlarged to the extent that the feces has difficulty moving through the narrow opening that remains.

In horses and cattle, the rectal examination may provide even more information. In these animals,

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the veterinarian may insert an entire arm and palpate many structures in the caudal regions of the abdomen. This is most routinely done to evaluate the reproductive tract. In addition, regions of the intestinal tract, rumen, pelvis, kidney, and lymph nodes may be felt. Just as in small animal medicine, much can be learned about the fecal characteristics during this procedure.

Evaluation of the nervous and musculoskeletal systems begins with observation of the animal. The gait or movement of the animal can easily show lameness, weakness, or neurologic problems affecting the motor nerves. The interaction of the animal with its surroundings can also provide clues as to whether the animal can hear and see.

A complete neurologic examination evaluates all the cranial nerves and reflexes of the body. More often, enough tests are performed to localize a problem. For example, a dog with hind limb paralysis due to intervertebral disk disease would undergo extensive examination of the peripheral reflexes. The animal would be evaluated for awareness and to interpret the prominent cranial nerve functions (e.g., whether the animal can see). The neurologic examination may then be able to localize the problem to the spinal cord and rule out problems in the brain.

Examination of the eye may be considered in the neurologic examination. The reflexes of the pupils and the ability to see are an essential part of the exam. In addition, the optic nerve is the only portion of the nervous system that is actually visible. An **ophthalmoscope** is the instrument used to observe the structures in the interior of the eye, such as the optic nerve, retina, and retinal blood vessels (Figure 18–3).

Photo courtesy of Patricia Curley.

FIGURE 18–3 An ophthalmoscope is used to examine the structures of the eye.

The veterinarian must rely on visual observation and palpation of the musculoskeletal system. Musculoskeletal problems may be seen and felt as a swelling. Often lameness may direct attention to a particular limb. During the exam, joints are bent and manipulated to detect any limitations or unusual movements. At times the movement may create an unusual noise or feel. A damaged joint may develop a clicking or popping feel as the joint is bent. The animal also gives feedback if the procedure is painful. With pain, the animal may attempt to bite or kick the veterinarian. Even well-mannered animals often develop tense muscles in the region when a procedure causes pain. Tight flexion or full extension of a joint may worsen the lameness and therefore help to localize the source of pain.

Lameness is a significant problem in performance horses. Even a subtle lameness can hinder the horse's time in an event. It can be challenging to determine which leg is affected. The horse needs to be observed not only standing but also walking and trotting. The horse is typically watched walking away and coming toward the veterinarian. Watching the animal turn can also help to determine which leg is sore. Subtle changes in the manner in which the horse moves one leg (such as dragging a toe or a shorter step) can provide evidence of the problem. Once the affected leg is identified, it is palpated and moved in attempt to localize the specific site of the problem. Often the region is narrowed but the specific site remains unidentified. Nerve blocks may be used to specifically localize the source of pain. A local anesthetic such as lidocaine is injected into a specific location to block the sensation carried by a nerve. If this results in an improvement of the lameness the site has been identified. A sound knowledge of the anatomy of the horse leg is essential to properly utilize nerve blocks. Further diagnosis of the condition may then require radiographs.

The lymphatic system can be examined by palpating lymph nodes that are located under the skin. These structures can be felt in many animals even when they are normal. The lymph nodes are evaluated for enlargement or pain. An enlargement may give evidence of infection in that region or could possibly be an indication of cancer.

When examining lactating animals, the mammary system is checked. The mammary glands can be palpated to evaluate for any swelling or heat. The milk is also examined for any signs of abnormal secretion. Mastitis typically causes flakes or clots and often makes the milk discolored. These clots are formed by large numbers of WBCs that enter the mammary gland due to inflammation.

The case is evaluated following the history and physical examination. The specific approach taken by each veterinarian varies. One method is called the problem-oriented approach. In this method, the

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problems are listed. Next, a list of differential diagnoses is developed. Ideally, all the problems should be covered by one disease. Unfortunately, this is not always possible. There are times when an animal has two diseases occurring simultaneously.

The diagnoses are ranked with the most likely causes first. A diagnostic plan is then developed to confirm or rule out the diseases. Diagnostic tests include blood work, urinalysis, radiology, biopsy, and pathology. These tests have been discussed in the context of individual diseases throughout this text.

A wide range of blood tests are available. **Packed cell volume**, complete blood cell count, and **chemistry panel** are among the most commonly used blood tests (Figure 18–4). The packed cell volume is a rapid test that provides the percentage of the blood composed of red blood cells (RBCs). In this test, blood is placed in a small capillary tube and spun in a centrifuge. The RBCs settle to the bottom of the tube and plasma rises to the top. A simple measurement then allows the packed cell volume to be established. The plasma from the tube can be placed on a refractometer to measure the protein. This test helps in monitoring patients for changes. The test requires only a small amount of blood and is completed within a few minutes.

A **complete blood cell count (CBC)** requires a larger volume of blood. This test evaluates the RBC count (often a packed cell volume is a part of this testing). In addition, the size of the RBCs and the amount of hemoglobin is measured. This can provide a more complete evaluation of the anemic patient. The number of platelets present is also evaluated.


Photo courtesy of Patricia Curley.

FIGURE 18–4 A vein in the front leg is a common site to obtain a blood sample.

The CBC also measures the total WBC count and provides a breakdown of the types of cells present. This aids in evaluating infectious and inflammatory diseases. The role of the individual WBCs was discussed more completely in Chapters 4 and 11.

A classic example of WBC changes occurs in a bacterial infection. Typically, the total WBC count and primarily neutrophils, increases rapidly. This change occurs rapidly as mature neutrophils are released from the bone marrow. As the infection continues, the bone marrow releases more immature neutrophils (band cells) trying to maximize the infection fighting cells available.

A large number of neutrophils can be lost from the bloodstream during a serious infection. A high band cell count combined with a low mature neutrophil count can indicate that the bone marrow is rapidly releasing immature cells but is unable to keep numbers at adequate levels. This can occur in an animal with a widespread, overwhelming infection. Monitoring the changes that occur in WBC counts over the course of infection can be very informative.

Numerous individual tests can be run on blood. Most laboratories offer a collection of tests measuring components that are often evaluated. The collection of tests often has a specific name, such as a chemistry profile or screen. The efficiency of routinely performing the same group of tests allows this profile to be offered at a lower price than if all the tests were run individually. The specific tests included vary among laboratories.

The chemistry profile often evaluates blood sugar, electrolytes, protein, liver and pancreatic enzymes, bilirubin, and nitrogen-containing wastes. Blood sugar obviously evaluates the endocrine function of the pancreas but also can be altered with diet and stress. Cats are especially prone to having an elevated blood sugar due only to the stress of being at the veterinarian's office. The electrolytes are essential to evaluate the hydration status of the animal and also evaluate the hormones that regulate these levels. For example, a diagnosis of hypoadrenocorticism might be suspected from the results of a chemistry profile showing elevated potassium and low sodium levels.

The protein level in the blood may be elevated when an animal is dehydrated. Other factors also influence the total protein in the blood. Protein has two components: albumin, which is produced in the liver, and globulin, the protein of antibodies. Albumin levels can be decreased due to low production in an animal with a diseased liver. In addition, excessive loss from parasites or a disease of the kidney or intestines may also result in low levels. When albumin levels are too low, the osmotic pressure of the blood may become so low that fluid leaks from the blood vessels and into the surrounding tissues. If the globulin fraction of the

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protein is elevated, it may be a result of a chronic infection. In response to the long term infection, the body has had the opportunity to produce a large amount of antibody.

The liver is a metabolically active organ. It plays a number of roles and is able to perform these functions due to the variety of enzymes contained in cells. A small amount of these enzymes leaks into the bloodstream on a regular basis. Two examples of liver enzymes are alanine aminotransferase (ALT) and alkaline phosphatase (Alk Phos). ALT is found primarily in the liver cells, and therefore an increase provides direct evidence of damage to liver cells. Inflammation or death of liver cells leads to a dramatic increase in the serum level of ALT. A toxin such as acetaminophen can cause such liver cell damage. The increased levels of ALT are often noticeable within one to two days. If the toxin is removed and the liver is able to heal, the ALT levels will decline over a period of several weeks.

Alkaline phosphatase is found in locations other than the liver (i.e., bone, kidney, intestine, and placenta), so an alteration in this value must be interpreted. Within the liver, alkaline phosphatase is found in the cells of the bile ducts. A large increase in this liver enzyme can represent a blockage or inflammation of the bile ducts. Alkaline phosphatase also increases in response to corticosteroids, so an increase can be found in hyperadrenocorticism.

Bilirubin is also measured in many chemistry profiles. Bilirubin is produced as RBCs are destroyed. The liver is responsible for clearing the blood of this pigment. An elevation in bilirubin can result when the liver is not functioning properly or in cases where RBCs are being destroyed too quickly. Combining a CBC and the bilirubin measure can help to detect if RBC destruction is occurring (Figure 18–5).

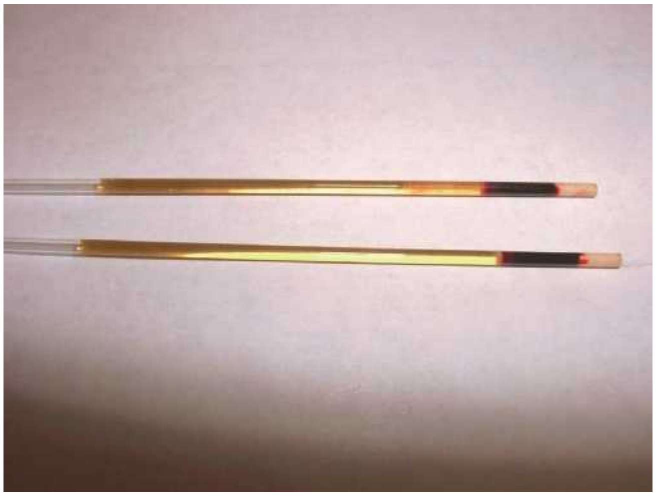

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FIGURE 18–5 A blood sample spun to perform a packed cell volume. Note the yellow color of the serum showing icterus or jaundice.

The exocrine portion of the pancreas produces the enzymes lipase and amylase. In much the same manner as the liver enzymes, any inflammation in the pancreas causes an elevation of these enzymes in the blood. Pancreatitis, an inflammation of the pancreas, is a common cause of vomiting in dogs. This is especially common in overweight dogs that are fed a meal high in fat.

Unfortunately lipase and amylase are not specific to the pancreas and can be released from other tissues as well. To overcome this problem a test has been developed to evaluate the level of lipase that is released from the pancreas. This pancreatic lipase immunoreactivity (PLI) test is species-specific and measures only the lipase released due to inflammation in the pancreas. PLI offers a more accurate means of diagnosing pancreatitis.

Creatinine and urea nitrogen are two measures of nitrogen-containing wastes. These two compounds are cleared from the bloodstream by the kidneys. An elevation can be a result of kidney disease or dehydration. In dehydration, the protein levels are usually increased as well. In diseases such a kidney failure, other features (e.g., elevated phosphorus and anemia) often help to rule out dehydration.

The CBC and chemistry profile provide a tremendous amount of information. This discussion is not designed to explain all the possible changes that occur. The goal is for the student to understand the thought process designed in choosing such tests. These two simple tests provide an evaluation of a wide range of organ systems. Understanding the physiology and function of these systems is essential to interpreting the results. A large portion of this text has emphasized this information in an attempt to provide an understanding of the disease conditions that may result.

A tremendous number of tests may be performed on blood. Hormone levels and the normal feedback control of these hormones can be evaluated. The speed at which blood clots, as well as the individual clotting factors, may also be measured. Toxins can also be detected within the blood, but it generally requires some suspicion of the specific toxin involved. Many of these tests are quite expensive, and most toxins require that a specific test be requested.

In addition to evaluating the function of the kidneys through blood testing, urinalysis may provide information. Chapter 6 has a detailed description of urinalysis. Often urinalysis is used in conjunction with information derived from the chemistry profile. For instance, consider a dog with a chemistry profile showing a moderate elevation in both urea nitrogen and creatinine. To determine if this is a result of dehydration or kidney disease, a urine sample is collected. Typically, if the animal is dehydrated, the specific gravity of the urine should be very high, as the kidneys attempt to conserve the body's water. With kidney disease, it is

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FIGURE 18–6 Wearing protective apron and gloves, a veterinary assistant prepares to radiograph a dog.

much more likely that the specific gravity will be much lower.

Radiographs have been shown throughout this text as a means to look within the body (Figure 18–6). Evaluating bone often provides the clearest examples of how beneficial a radiograph can be. A complete fracture of a bone is an example of a diagnosis that is definitively confirmed with a radiograph. Not all radiographs provide such a concise diagnosis.

Radiographs provide valuable information because the x-rays penetrate tissues of different densities at different levels. The five densities found in animals include air, fat, soft tissues, bone, and mineral (see Chapter 3). On a radiograph these would range from dark to light, respectively. Changes from the normal pattern can be interpreted. It is also important to remember that a radiograph is a two-dimensional image of a three-dimensional object. Typically, at least two views, 90 degrees apart, are necessary to adequately evaluate a patient.

Consider a chest radiograph. The thorax is clearly outlined by the bones of the vertebrae, ribs, and sternum (these appear as light structures on the radiograph). The air-filled lung tissue appears dark. The heart and surrounding vessels appear as a medium density. The lung field should fill the entire chest cavity. If fluid is present in the thorax, the lungs are compressed and the fluid can be seen to outline the lower portion of the lung lobes. The detection of fluid in the thorax may at times be quite obvious. However, the radiograph does not define the type of fluid. The fluid might be blood, pus, or lymph. Although the radiograph detected the problem, further diagnostic tests must be used to finalize the diagnosis.

Knowledge of anatomy proves key in radiology. Not only must the normal positioning of structures be evaluated, but the normal size in relation to other structures must also be interpreted. The chest radiograph again provides an example. The size of the heart on the radiograph can be interpreted in relation to the size of the chest. This can be used to detect an abnormal enlargement of the heart.

In many situations, radiographs show clues that must be combined with the results from other tests. In the discussion of chemistry profiles it was mentioned that amylase is elevated in animals with pancreatitis. Radiographs are often taken in these cases to rule out intestinal foreign bodies and tumors. In pancreatitis, inflammation surrounds the pancreas, which lies behind the stomach and liver. On a radiograph, this appears as a loss of detail. The distinction between adjoining structures becomes less obvious.

The differences in density of normal structures may not be adequate to make the diagnosis. Certain conditions may require the use of a contrast medium to help outline specific structures. Many examples have already been shown. Administering barium orally can help to detect obstructions in the intestinal tract. Dye may be injected into the vertebral canal to confirm a diagnosis of intervertebral disk disease. Certain bladder stones and tumors can be shown more clearly on contrast radiographs. In this situation a gas, a dye, or both can be used to fill the bladder.

Another commonly used technique is submission of tissue samples or biopsy specimens to a laboratory for evaluation. It is common to surgically remove a tumor and submit the entire structure (Figure 18–7). In this excisional biopsy, the goal is to remove the entire tumor. The purpose of the biopsy is to determine the type of tumor and whether normal tissue is present at the margins of the specimen. If tumor cells are present at the margins of the specimen, there is a much greater chance that the cancer will recur.

Determining the type of tumor also provides the information necessary to decide on further treatment. Various tumors behave differently. If the diagnosis is a benign tumor and no tumor cells are present in the surgical margins, no further treatment is usually required. With malignant tumors, the biopsy can provide information on future outlook. Some malignancies invade the local tissues, whereas others are likely to spread to more distant locations. A decision can then be made regarding whether additional treatment may

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FIGURE 18–7 A benign growth on the leg of a dog.

be necessary. Radiation or chemotherapy can be used to kill cancer cells that remain in the body.

Situations occur in which the entire tumor cannot be removed or more information is needed prior to surgery. In such cases a small portion of the tumor may be submitted. This sample may be taken surgically; that is, a region of the tumor is removed. Another technique is to aspirate cells from the region with a needle and syringe. The needle is inserted into the tumor, and suction is applied with the syringe. Cells gathered in the needle can then be forced onto a slide and that sample submitted. This technique is less invasive than surgery but collects a much smaller sample. Sometimes the aspirate does not provide enough diagnostic information. Within a tumor there can be normal cells as well, and by collecting a relatively small sample, the diagnosis may not be possible. In addition, the structure of the tissue is disrupted and the cells are spread over a slide. Other tools are available that allow a small piece of tissue to be collected. The sample is still small but maintains the normal structure of the tissue being sampled.

The same techniques can be used to diagnose any diseased tissues, such as those from animals with autoimmune and infectious diseases. In the section on radiology, disease conditions in which fluid is present in the thorax were discussed. Often a final diagnosis cannot be made from the radiograph. The fluid can be aspirated from the chest cavity and submitted for analysis. The contents of the fluid and an analysis of the cells from within the fluid are often used for the final diagnosis.

With all these processes, the pathologist must have a significant knowledge of cells and tissues. The pathologist must first be able to recognize what normal structures are present and to interpret all the abnormalities. Pathologists also perform necropsies, or postmortems, on animals that have succumbed to a disease. Necropsies play an essential role in herd health. With an individual animal, a necropsy may help to explain the cause of death and help the owner cope with the loss. In herd situations, the necropsy may provide the information necessary to prevent a large outbreak within the group. In such a situation, the death of an animal may provide valuable information that prevents a much larger loss.

The pathologist is aided by a complete history. With this information, the pathologist may direct attention to the most likely affected regions. The pathologist has the option to do biopsies of any tissue. If a specific region is suspected, extra samples may be collected. For example, the brain and spinal cord cover a large area. If a specific disease is suspected based on the clinical signs, additional samples may be harvested from the central nervous system. In addition to sampling the tissues and organs for evaluation, biopsy samples may be taken to isolate infectious organisms or test for toxins.

Bacterial and fungal culturing was discussed in Chapter 14. Fluid from infected regions or swabs of infected tissue may provide samples of the organism that allow for its identification. These samples can be taken from a living animal or during a necropsy. In the living animal, the fluid may be milk, urine, blood, swabs from mucous membranes, or fluids aspirated from diseased regions. Many veterinarians perform bacterial and fungal cultures at their offices. For a more detailed identification or for isolation of viruses, samples are often submitted to a diagnostic laboratory.

In certain cases, it is difficult to isolate an infectious organism. **Serology** measures the presence of antibodies against a specific organism. It is essential to understand the humoral immune response to interpret the results of a serologic test (see Chapter 11). A positive result shows that the animal has been exposed to the organism but does not prove that it was the cause of the disease. A negative result can occur if the test is taken before the animal has the opportunity to increase antibodies to a detectable level.

To confirm a diagnosis with serology, the animal is tested twice, with usually three to four weeks between samples. If the level of antibody or titer changes four times, it is proof that the animal was exposed and responded to the organism. The change can be either an increase or a decrease, depending on the timing of the testing.

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Many students will be familiar with DNA technology discussed in television shows about crime investigation. Similar technology is used in diagnosing infectious disease as well. In a given sample taken from a sick animal, the number of live organisms may be quite small and difficult to culture. Tests are available to utilize polymerize chain reaction (PCR) amplification to detect small amounts of bacterial or viral DNA. In this testing if DNA of the organism exists, the laboratory procedure is able to replicate the DNA to make billions of copies in a matter of hours. This amplification allows the DNA of the specific organism to be identified. PCR testing provides a rapid and extremely sensitive means of detecting the presence of infectious agents.

A tremendous number of tests are available. Typically, one or more tests are run that are most likely to confirm or eliminate the diagnoses on the differential list. When the results are available, the problem list is adjusted to account for any new findings. Combining all the information available from the history, physical examination, and subsequent testing, the differential list is reevaluated.

Several possibilities exist. Ideally, a diagnosis is confirmed with the information and treatment then begins. For example, a 15-year-old cat presents with an increased thirst, increased urination, poor appetite, weight loss, and vomiting. The blood chemistry shows elevated creatinine, urea nitrogen, and phosphorus. In addition, blood sugar and thyroid hormone levels are normal. The CBC shows a normal WBC count but an anemia, or low RBC count. Urinalysis shows extremely diluted urine, even though the animal appears dehydrated. The collection of information confirms the diagnosis of renal failure, and appropriate treatment options may begin.

After the initial testing, one of the diagnoses may become more likely, but further testing is necessary to confirm that fact. Consider a dog that presents for weakness, vomiting, and diarrhea. The dog had seemingly been very normal until the signs began. The list of differential diagnoses for a dog with vomiting and diarrhea is quite long. The chemistry profile shows a mild elevation in urea nitrogen and creatinine, elevated potassium, and low sodium. The result is very suggestive of hypoadrenocorticism but does not completely confirm the diagnosis. With this high level of suspicion, a more specific test may be run to confirm the diagnosis.

Another option that is less favorable occurs when the initial testing offers no clues toward furthering the diagnosis. One solution is to run additional tests. For example, when a chemistry profile and CBC offer no guidance, radiographs may provide more information. At times all the options available to the veterinarian do not provide the answer. These cases may then be referred to a specialist. The specialist has taken advanced training in a particular field (such as surgery, medicine, cancer, or ophthalmology). The advanced training of specialists and the availability of more sophisticated equipment often provide the diagnosis. Many of the advanced technologies that are available in human medicine are also available at some of the university veterinary hospitals and advanced referral centers. Technologies such as computed tomography (CT), magnetic resonance imaging (MRI), ultrasonography, and endoscopy are becoming much more available in veterinary medicine.

Ultrasound technology has become more economical and is available at many specialist and private veterinary practices. Ultrasound imagining or ultrasonography utilizes very-high-frequency sound waves which are transmitted into the body. The reflection of these waves is then evaluated to provide an interpretation of the tissues and structures encountered.

Sound waves are measured on the frequency of oscillations that occur within one second. Normal sound waves heard by humans are typically in the range of 20,000 kilohertz (kHz); 1 kHz is equivalent to 1,000 cycles per second. Ultrasonography uses much higher frequencies, in the range of 2 to 15 megahertz. One megahertz is equivalent to 1,000 kHz or 1,000,000 cycles per second. As a result, ultrasound is not audible to humans. The ultrasound machine has a probe which generates the sound waves. The probe is held in close contact to shaved skin with a gel that easily allows the waves to be transferred into the underlying tissue. The ultrasound waves are generated in a very small percentage of time, while during the remainder of time the waves reflected or echoed from the tissues are evaluated by the probe and the connected computer. The character and speed of the echo waves are converted into an image on the ultrasound machine.

The image created shows varying shades of black, white, and gray (Figure 18–8). A radiograph may show the outline of an organ, providing evidence of its overall size, shape, and location. The ultrasound machine can provide additional details of the internal structure and density of an organ. This can be extremely useful in an organ such as the heart, where the actual function of the contractions can be observed. Ultrasonography can also clearly show the presence of a tumor within the structure of an organ such as the liver or spleen. Ultrasound may also be used to guide the collection of a biopsy with a needle or biopsy tool.

Many examples have been shown of radiographs. The standard technique is to take at least two views at 90 degrees to each other. The clinician then takes the two flat images and interprets the information to evaluate the three-dimensional body. Computed tomography is an imaging technique that takes a series of x-ray images as the machine rotates around the body.

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Photo courtesy of Patricia Curley.

FIGURE 18–8 This ultrasound image was taken during the examination of a cat's abdomen. The black region in the center is the urinary bladder. Fluids such as urine and blood do not reflect the ultrasonic waves, and appear black. At the bottom of the bladder are two urinary calculi. The high mineral content of the stones reflects most of the ultrasonic waves, causing the stones to appear white. The stones actually block so much of the sound waves that an acoustic shadow is created, which appears black below the stones.

The computer then interprets the series of images and creates a three-dimensional image. The image is then presented as a "slice" through the body. Each slice can then be viewed in series, allowing the veterinarian to interpret the structures within the body. This technique provides much more information than a plain radiograph.

Figure 18–9A shows the CT scan of a two-year-old German shorthaired pointer that presented for bleeding from her left nostril. The problem began several months earlier when the dog was hunting in the woods and suddenly screamed in pain. Attempts to look in the nostril did not provide a diagnosis. The CT scan shows a slice through the nasal cavity of this dog. The asymmetry is obvious, with a density visible on the left side of the center line. With the dog anesthetized a rigid endoscope was passed up the nostril to visualize the foreign body. Endoscopic forceps were used to grasp the object and pull it from the nose. Figure 18–9B and C show a stick being pulled from the nostril and the dramatic view of the object that had been lodged in the nose.

An experienced diagnostic approach comes only through years of education and on the job training. Every experience helps to train the veterinarian and show the variations that occur with each disease. In many situations, treatment must be started before all the tests are completed. The veterinarian relies on experience to begin treatment, often directing it at the one or two most likely diseases. An animal responding to a specific treatment can be one more hint confirming a diagnosis.

A

B

C

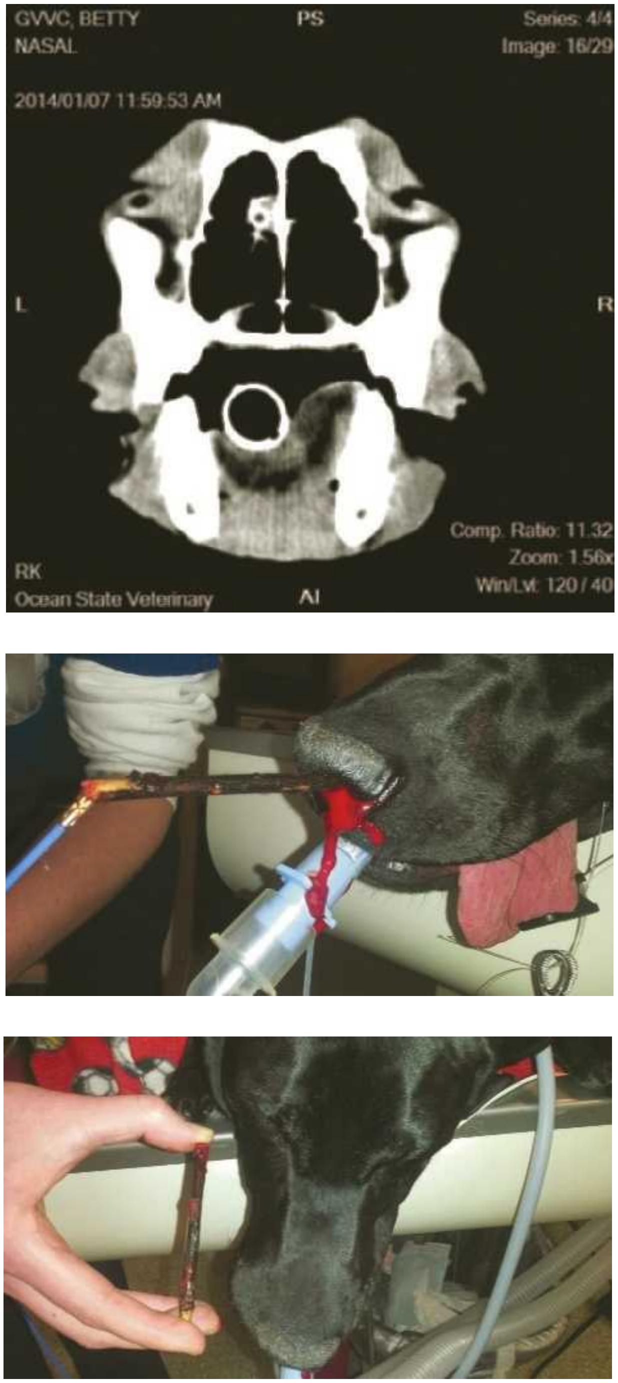

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FIGURE 18–9 A. This CT scan shows obvious asymmetry with a density on the left side of the center line in the nasal cavity of a two-year-old German shorthaired pointer. B. After endoscopic visualization, the foreign body was removed using forceps. C. A dramatic view of the stick that had been lodged in the hunting dog's nose.

Many times the results of a test will come back normal, not supporting the results that are anticipated. It is tempting to report this as not providing any helpful information. Even normal results provide valuable information. Normal values help to eliminate many diseases. It is the total information provided by normal

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and abnormal results of testing that allows the veterinarian to make a final decision.

CLINICAL PRACTICE

Objective

- Discuss the Clinical Significance of Disease Diagnosis

The process of diagnosis may seem very confusing at this point. The huge number of different tests available may seem overwhelming. The goal of this chapter is to show the different types of tests available and how the thought process proceeds. This section uses the sample case from the introduction to summarize the diagnostic procedure.

Case Summary: Merzee, a 10-year-old female dachshund, presents for the first time. The owners are concerned because Merzee has been lying around more than normal and is not eating well. The owner thinks that Merzee has been losing weight.

This is the first visit of this dog to the office, so a complete history is necessary. From the phone call when the appointment was made, it is known that the dog has been lying around more than normal and is not eating well. There is also a concern that Merzee has been losing weight.

History (Owners' responses in italics):

1. How long has she had the problem? *It may have been going on for a couple of weeks but has gotten much worse over the last two days.*
2. Has there been any vomiting or diarrhea? *Not really, although she did vomit once three or four days ago.*
3. Is she up to date on her vaccinations? *Yes.*
4. Has she been spayed? *No.*
5. Has she been in heat recently? *Maybe, but we're not sure. She acted a little funny a few weeks ago.*
6. Has there been any change in her water consumption? *Now that you mention it, she may be drinking more water recently.*
7. Is she eating anything? *She has been eating a little bit but hasn't eaten anything today.*
8. What is her normal diet? *She eats anything we eat.*
9. Does she eat any dog food? *Oh my, no, she doesn't like dog food.*
10. Does Merzee run free at all (evaluates the likelihood that she could have been traumatized or ingested a toxin)? *She never leaves the house unless she is on a leash.*

Physical Examination:

Temperature: 102.8°F (slightly elevated)

Pulse: 150 beats per minute (seems normal for an excited dog)

Respiratory rate: panting (again, very excited)

General appearance: mildly obese, walks well with no limping, very aware of her surroundings

Mucous membranes: good pink color, slightly tacky (mild dehydration?), with capillary refill time less than 1 second

Cardiovascular system: regular heart rate, no murmurs heard, good pulses

Respiratory system: normal lungs sounds, no difficulty breathing

Digestive system: abdomen very tense and somewhat distended, difficult to palpate, normal bowel movement with no parasites found

Urinary system: unable to palpate kidneys or bladder

Neurologic system: no abnormalities found

Musculoskeletal system: no abnormalities found

Skin: no abnormalities found

Mammary system: no abnormalities found

Lymphatic system: no abnormalities found

Problem List:

Anorexia

Weight loss

Increased thirst

Mild fever

Differential Diagnoses:

Infected uterus (consistent with the dog's age, fever, possible history of recent heat; increased thirst, anorexia, and weight loss common)

Kidney failure (increased thirst, anorexia, weight loss, age are consistent; fever not typical, but dog was very excited)

Diabetes mellitus (increased thirst and weight loss are consistent; initially appetite is increased; usually no fever unless there is a secondary infection)

Diagnostic Plan:

Blood chemistry—evaluates kidney function, liver function, electrolytes, and blood sugar

Complete blood cell count—evaluates for infection, along with RBC count

Abdominal radiographs—evaluate for an enlarged uterus (Figure 18–10)

Urinalysis—evaluates for kidney disease

Results: The group of blood tests has helped to illustrate the cause of Merzee's illness. The chemistry profile shows a slight increase in urea nitrogen (Table 18–2). This is consistent with mild dehydration. The CBC shows elevated WBCs, neutrophils, and band cells.

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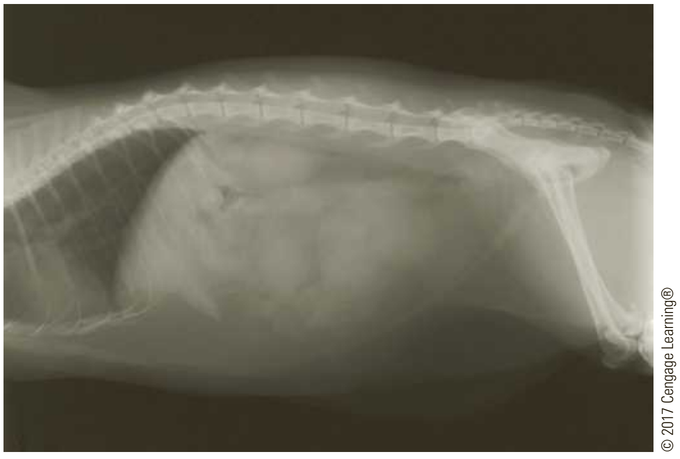

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FIGURE 18–10 A radiograph of a dog with a uterine infection. The uterus is quite large and filled with pus. The intestines are displaced from their normal position.

These changes, along with the fever, are consistent with the body's response to an infection. The abdominal radiographs show a region in the lower portion of the abdomen with a solid density. Intestines are generally present in this location, so there is evidence that some structure is displacing them.

It is not unusual to proceed with treatment without a guarantee of the diagnosis. Merzee's case offers a perfect example. The history of an older (unspayed) female dog, recently in heat, combined with the blood test results and the radiographs makes the diagnosis of uterine infection extremely likely. Often the radiograph does not definitively prove that it is the uterus that is distended, but the combination of diagnostic clues allows treatment to begin.

Merzee did have an infected uterus, which was removed surgically. Fortunately, she has responded well.

Table 18–2 Merzee's Blood Results

Test	Result	Reference Range	Units
Glucose	84	65–120	mg/dl
Urea nitrogen	8	6–24	mg/dl
Creatinine	1.2	0.4–1.4	mg/dl
Sodium	148	140–151	mEq/L
Potassium	4.6	3.4–5.4	mEq/L
Chloride	110	105–120	mEq/L
Bilirubin	0.1	0.0–0.4	mg/dl
Alkaline phosphatase	119	10–150	units/L
Alanine aminotransferase (ALT)	12	10–70	units/L
Total protein	7	5.2–7.2	g/dl
Albumin	2.6	2.4–4.3	g/dl
Globulin	4.4	0.9–4.0	g/dl
Calcium	10.2	7.9–12.0	mg/dl
Phosphorus	3.7	2.1–6.8	mg/dl
Amylase	702	400–1,400	units/L
White blood cell count	86,800	6,000–17,000	cells/μl
Red blood cell count ($\times$ 1,000,000)	5.52	5.5–9.0	cells/μl
Packed cell volume	37.5	37.0–54.0	%
Mature neutrophils	55,600	3,000–11,800	cells/μl
Bands (immature neutrophils)	20,800	0–300	cells/μl

continues

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Table 18–2 *continued*

Test	Result	Reference Range	Units
Lymphocytes	5,200	1,500–5,000	cells/μl
Monocytes	2,600	0–800	cells/μl
Eosinophils	0	0–800	cells/μl
Basophils	0	0–100	cells/μl

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Numbers highlighted in red are above the normal reference range.

An infected uterus can be a life-threatening condition. The infection can become overwhelming, even entering the bloodstream. The kidneys can also be damaged in this condition, leading to kidney failure. This condition is one reason that routine spaying of young healthy dogs is highly recommended.

Two recent cases presented to the author's veterinary clinic help to illustrate how each case must be handled individually. Both cases were large, middle-aged mixed-breed dogs that had been vomiting for several days. The first dog happened to be quite aggressive, which made handling quite difficult. Blood work and plain radiographs did not clearly define the underlying cause of the vomiting. The dog seemingly responded to medical treatment and began to eat without vomiting while at the hospital. The dog went home, however, and became much worse. One option would be to do a barium series in an attempt to detect an obstruction. Unfortunately, there was no way to get the dog to swallow the barium, so the dog was referred for an ultrasound examination. The specialist could not positively detect the cause but was highly suspicious of an intestinal foreign body. Surgical exploration was performed and a rubber piece of a toy was discovered within the jejunum.

The second case presented with almost identical signs. The dog was not responding to medical treatment and survey radiographs did not provide answers. While waiting on the results of blood tests, a barium series was performed. The barium series showed that the area of the pylorus and duodenum was not filling well. However, the barium did continue through the intestinal tract. The blood tests showed a dramatic elevation in amylase and lipase consistent with a diagnosis of pancreatitis. Fortunately this dog did improve with medical treatment and avoided surgery. While these two cases presented with almost identical histories and signs, each case was handled differently.

Figure 18–11A shows a CT scan through the thorax of a dog. This dog presented with lameness of the left foreleg and a swelling over the scapula. The

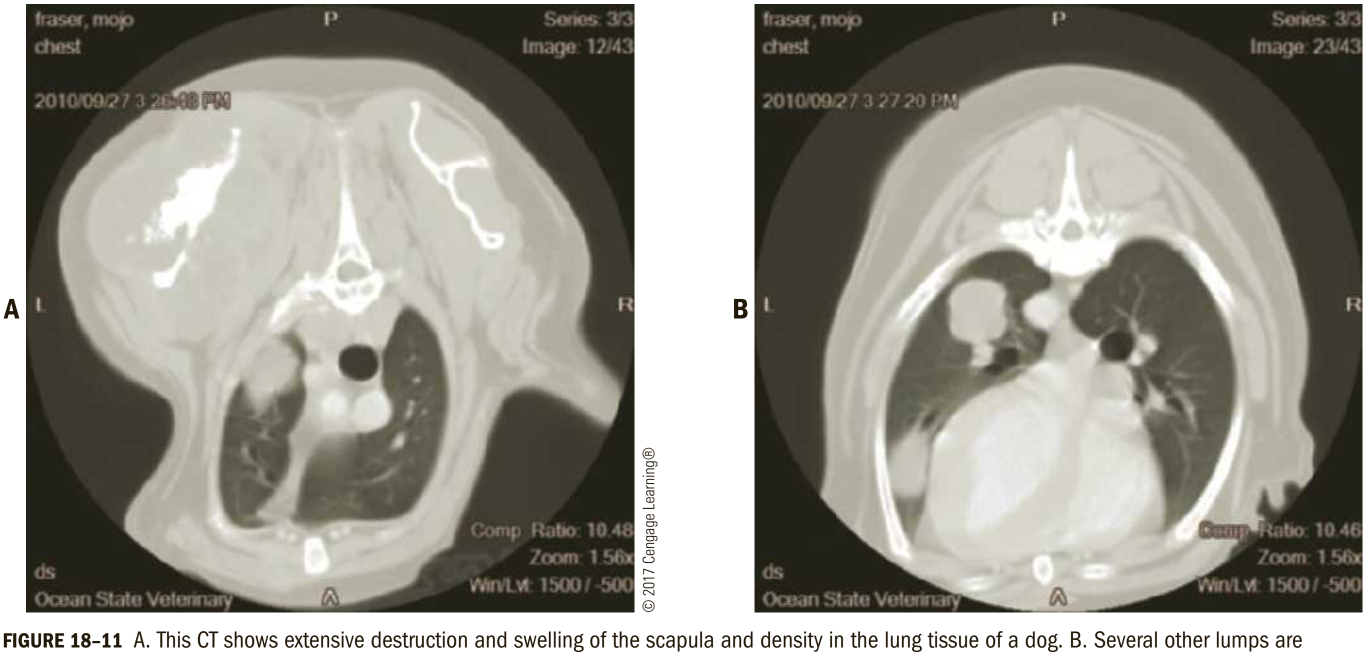

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FIGURE 18–11 A. This CT shows extensive destruction and swelling of the scapula and density in the lung tissue of a dog. B. Several other lumps are visible in the second slice shown. This dog was diagnosed with a chondrosarcoma in the scapula and metastasis to the lungs.

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CT shows extensive destruction and swelling of the scapula. In addition there is a density in the lung tissue along with several other lumps in the second slice shown (Figure 18–11B). This dog was diagnosed with a chondrosarcoma in the scapula and metastasis to the lungs. The CT scan provided clear imaging establishing the severity and extent of the disease.

SUMMARY

Diagnosing diseases in animals requires a systematic approach. Information can be acquired in each step from the history, physical examination, and subsequent diagnostic tests. Combining all of the information, the veterinarian works toward developing an accurate diagnosis and creating a successful treatment plan.

REVIEW QUESTIONS

1. Define the following terms:

   signalment
   borborygmi
   ophthalmoscope
   packed cell volume
   chemistry panel
   complete blood cell count (CBC)
   serology
2. True or False: Establishment of home remedies previously given is irrelevant when diagnosing a disease condition.
3. True or False: The problem-oriented approach is one means that veterinarians use to arrive at a diagnosis.
4. The third step in diagnosing a disease is performing a ________.
5. ________ is produced as red blood cells are destroyed.
6. To confirm a diagnosis with serology, the animal in question is usually tested ________ with several weeks between samples.
7. If an animal is dehydrated, will the specific gravity of urine be high or low?
8. Can stress interfere with blood test results in cats?
9. Can a stethoscope be used to evaluate intestinal sounds?
10. What is the first step a veterinarian must take in diagnosing a disease?
11. After establishing a history, what is the second step in diagnosing a disease?
12. Describe the mucous membrane of an anemic animal.
13. How can an enlarged prostate be determined in a dog?
14. List two problems that a lack of noise in the intestinal tract could represent.
15. List specific information found in the signalment.
16. List and describe three common laboratory tests.

ACTIVITIES

1. Students can evaluate their own CRT in the fingernail bed. The tissue under the fingernails should be pink. When the nail is pressed, the blood is forced out of this tissue, creating a white appearance. When the nail is released, the blood should quickly return to the nail.
2. In this case the instructor will serve as the moderator to provide information about the animal. The pertinent history has been provided. You may ask additional history questions. The instructor may answer with relevant information or may say, "I don't know." Unfortunately, in the real world the person bringing the animal to the veterinarian does not always know the answers.

   Step 1: The initial history and signalment.

   It is 12:30 A.M. on December 27 and the phone rings. When you answer, a very upset man is

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telling you that Buffy the cocker spaniel has been vomiting for the last five hours. He is very concerned that she has made a mess all over the floor, and by the way, she seems to be getting weak. He wants to bring her in immediately. As you crawl out of bed, you tell him that you will meet him at the office in 15 minutes.

A young man and woman bring Buffy into the office. Buffy is a 60-pound spayed female cocker spaniel. She is six years old. As you look over the records, you see that she has been well vaccinated and is up to date. The couple tells you that they are dog-sitting Buffy for the actual owners.

Step 2: Develop a history from the sample questions provided. Your questions may not be identical to those of other students. Your questions about topics not covered can be answered with "I don't know" because it is not this couple's dog.

Step 3: Ask about specific findings that concerned you on physical examination. Office examination is $28.00.

The initial impression of the dog as it enters the room: Dog walks without lameness, is aware of surroundings, has a slight arch to its back as if having abdominal or back pain. The dog is obese.

Temperature: 102.6°F

Pulse: 185, strong and regular

Respiratory rate: panting (very anxious)

Mucous membranes: pink, slightly tacky or dry

Capillary refill time: less than 1 second

Cardiovascular system: regular heart rate, no murmurs heard, good pulses

Respiratory system: normal lungs sounds, no difficulty breathing

Digestive system: abdomen very tense; Buffy acts like she's in a lot of pain when front portion of the abdomen is being palpated; normal bowel movement, no parasites found

Urinary system: kidneys feel normal in size and shape; bladder small, no stones palpable

Neurologic system: no abnormalities found

Musculoskeletal system: no abnormalities found

Skin: oily but appears healthy; skin turgor slightly decreased

Mammary system: no abnormalities found

Lymphatic system: no abnormalities found

Step 4: Establish a problem list.

Step 5: Prepare a list of differential diagnoses. You may not have a specific name for the disease, but you should suggest likely causes. Use the MAD TIN mnemonic to aid in the process.

Step 6: Choose from the list of diagnostic tests that follow. Remember, economics are very important. Run only tests that are necessary. The owners will be very upset if they find that unnecessary tests have been run. Choose a test or group of tests that need to be run immediately. Once the results are available, further testing may be selected. After selection of tests, contact your instructor for results.

Packed cell volume and total protein	$8.00
Complete blood cell count	$34.00
Platelet count	$21.00
Chemistry profile	$69.00
Urinalysis	$17.00
Chest radiographs	$56.00
Abdominal radiographs	$56.00
Myelogram	$350.00
Barium series	$250.00
Adrenocorticotropic hormone (ACTH) stimulation test	$70.00
Dexamethasone suppression test	$60.00
Exploratory surgery and biopsy of stomach and intestines	$600.00

Step 7: Based on the results of the testing, physical exam, and history, choose a course of action from the following. The instructor will share the correct course of action.

Buffy likely has an intestinal foreign body and requires immediate surgery.

Buffy is in the final stages of kidney failure and immediate intravenous fluid therapy is necessary.

Buffy likely has a stomach tumor and should be treated with chemotherapy.

Buffy likely has pancreatitis and should be treated medically to control the vomiting and correct the dehydration.

Buffy should be referred to the university hospital for a more thorough evaluation.

3. Research the effects of age, stress, and environmental factors on the vital signs of an animal.

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Create a visual aid (table, graph, chart) showing your results.

4. Take the temperature, pulse, and respiratory rate for a variety of animals. Chart your results.
5. Using Table 18–1, research normal findings for all of the sections of the physical examination for a healthy two-year-old Labrador retriever. Chart those findings. Using the same table, chart possible abnormalities that would indicate the animal was diabetic.

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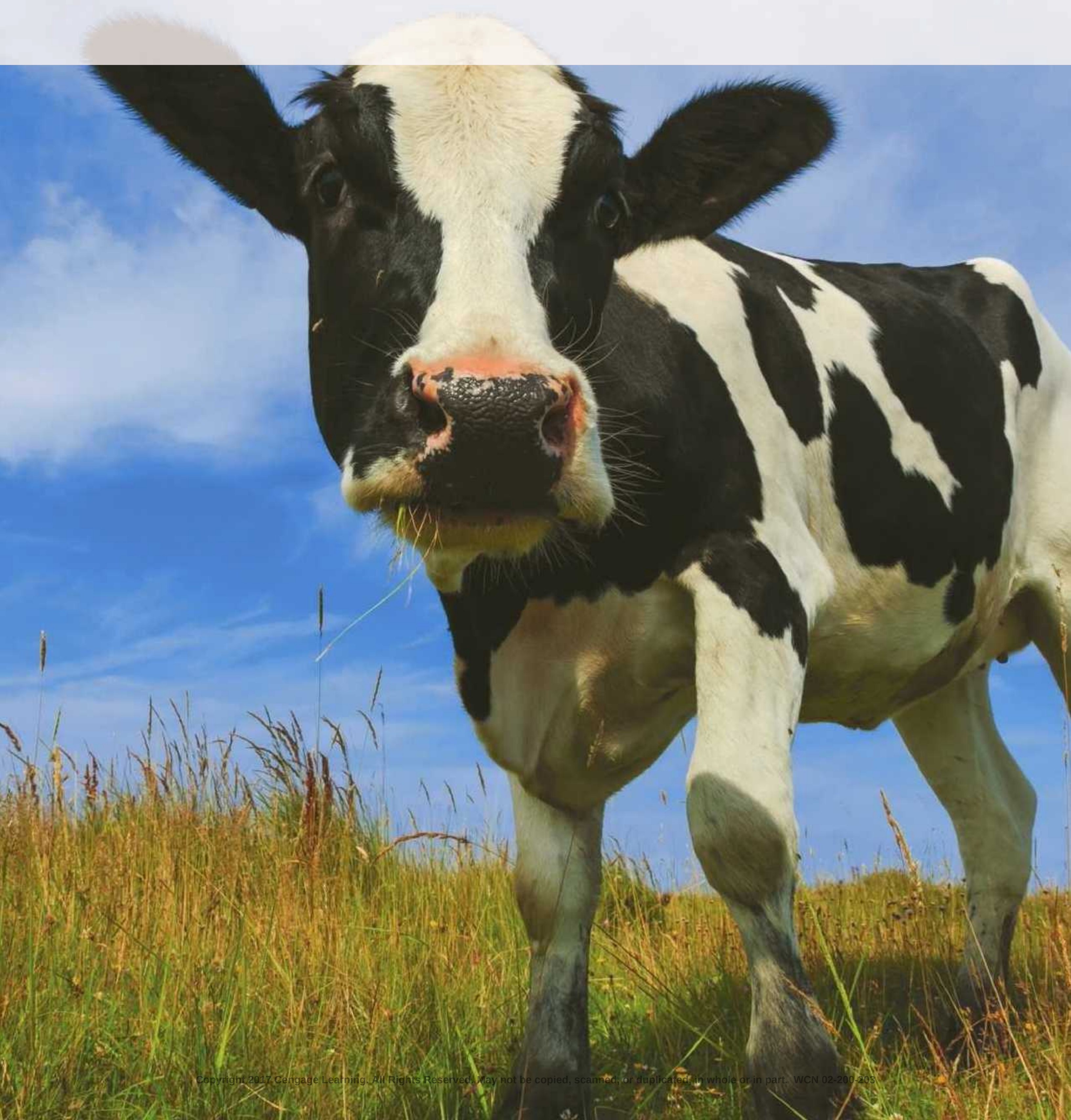
Unit IV
Surgery



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CHAPTER 19

Principles of Surgery

Objectives

Upon completion of this chapter, you should be able to:

- Explain the clinical significance of the basic principles of successful surgery.
- Explain the clinical significance of healing of lacerations by first and second intention.
- Explain the clinical significance of common considerations in veterinary surgeries.

Key Terms

aseptic technique
sterilization
autoclave
granulation tissue
first intention healing
golden period
second intention healing
proud flesh
débridement
hematoma
seroma
dehiscence
intestinal anastomosis
gastric dilatation–volvulus syndrome
necrotic

Introduction

Surgery remains a challenging field in veterinary medicine. In addition to requiring knowledge of anatomy, physiology, and disease conditions, surgery requires delicate manual skills. Much can be taught in a classroom setting about the techniques and principles of surgery. Eventually, the final learning process must come with experience.

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A Day in the Life
A Chance to Cut Is a Chance to Cure . . .

This adage is supposed to represent the mindset of a true surgeon, someone who is anxious to operate on any animal in an attempt to save its life. Realistically, surgeons evaluate each case individually and decide if surgery is the best option. Surgery is one of the most visible skills that a veterinarian possesses.

When I attended veterinary school, the first two years provided little exposure to live animals. There were a few exercises on topics such as physical examination, restraint, and foot trimming, but there was very little responsibility for the animal's well-being by the veterinary student.

During third year we finally had the opportunity to have responsibility for the livelihood of a living animal. Our class was divided into groups of three. Each group had a dog to care for by performing physical examinations to ensure that the animal was healthy for anesthesia and surgery. Finally, the big day arrived—our first experience at performing surgery. Within the group, one student performed the anesthesia, one acted as the primary surgeon, and the third stood as assistant surgeon.

This was truly an exciting time. With anesthesia, the animal is sedated to a point that it does not outwardly respond to pain and is immobile. The concern in the back of everyone's mind was the realization that administering too much anesthetic would cause the dog to die. The surgeons had their own responsibilities. For the first time, we were going to cut into a living animal and repair a wound. After all the long hours of bookwork, we had finally reached the real world! We were sure nervous!

As students, we had a tremendous amount to learn. Our movements were inefficient; we were slow and ever so cautious. As in any surgery, there was bleeding. It was quite scary the first time the student surgeon cut through an artery and we all saw blood pulsing across the table. To control the bleeding, we had to hold pressure on the bleeding vessel with a gauze sponge, clamp it with an instrument, and then tie it off with suture. It seemed so simple in theory, until the first time that blood was spraying us.

The same process that was so scary then is one that I have now done thousands of times. I am much more comfortable as a surgeon after many years of experience. But even with extensive practice, there are times when surgery can make my heart race. Surgery has provided me with some of the highest and lowest points of my career.

As a new veterinarian, my confidence was tested at times. To this day, there are still cases that do not work out the way I plan. As a recent graduate, though, the failures made me question my own skills.

Surgery to correct a displaced abomasum was discussed in Chapter 2. I became very comfortable performing this surgery during my first year as a practicing veterinarian. The abomasum can become displaced either on the left or the right. In a left displacement, the stomach is out of its normal position and needs to be moved to the anatomically correct position. When the abomasum displaces to the right, the stomach can actually twist on itself (often referred to as torsion). This is a much more serious condition and becomes life threatening if not treated quickly. In torsion the contents cannot escape, and the blood supply to the stomach can be compromised.

It was a hot August afternoon when I pulled into the farm lane. The owner was not there that day, but the hired man showed me which cow was sick. I detected a right-sided abomasal torsion on a very sick cow. The cow was dehydrated, with a very rapid heart rate and weak pulses. I told the hired man that the outlook was not good. We had the option of trying surgery or selling her as a cull cow.

The hired man called the owner of the farm and I then explained the same options to him. The owner elected to try surgery; the cow was a valuable animal if she survived and was worth very little in her present condition. With the hired man's assistance, I moved the cow into position to perform surgery. Everything was going well until I maneuvered into the abdomen and attempted to correct the position of the stomach.

The torsion of the stomach was severe. The stomach was extremely distended and had become discolored from the poor circulation. These stomachs not only contain a large amount of trapped gas, but they have a large volume of liquid as well. I knew exactly what to do; I just did not know if I could accomplish the task. I reached into the abdominal incision as deep as I could go and placed the flat of my hand and arm against the stomach. I lifted and pushed as hard as I could, but the stomach would not come back into position.

Between the heat of the day and my nerves, the sweat was rolling down my face. Things were not going well, and I was beginning to doubt myself. I had corrected displaced abomasums before, but none as large

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A Day in the Life continued

as this. Then disaster struck. With the poor circulation, the severe distention, and my pressing as hard as I could, the stomach tore. I now had stomach contents pouring into the abdomen.

I felt horrible as I realized how serious the condition had become. This cow was definitely going to have peritonitis, and I still had not corrected the underlying problem. I discussed the situation with the farmhand and then closed the incision. I had to admit defeat; the cow was going to die. I was crushed, and any confidence I had developed was destroyed. At that moment, surgery was not a fun part of my job.

Looking back on that moment, I realize that there are cows that I will not be able to save. To this day, I still encounter abomasal torsions that are equally bad, and the same problem can occur. Fortunately, I have enough experience that I do not question my skills. I have to help the farmer make an informed decision, and together we realize that the outcome may not be positive. Even still, the discouragement is still very real when an animal dies in surgery. The loss may not shake my confidence, but it is still a blow to my ego that I was unable to save the patient.

Surgery can also provide the experiences that renew my enthusiasm. Toby, a six-year old Doberman pinscher, presented with wounds to his nose and mouth. It was obvious that Toby had been shot with a high-power rifle. The bullet had entered through the top of his nose, penetrated the roof of his mouth, and fractured his mandible, leaving a gaping exit wound under his jaw. The bullet then continued, leaving a laceration on his shoulder.

Toby was an exceptionally nice dog. I discussed the severity of the wounds with the owners. I had to raise the options of referral to a specialist or euthanasia. The owners felt that we had to give Toby a chance, but they did not have money for a specialist. We agreed that I would do the best that I could. I started intravenous fluids and anesthetized him. I then attempted to put the pieces back together. Unfortunately, there were teeth, pieces of bone, and gum missing. I repaired the mandible with a piece of stainless steel wire and sutured the gum together as much as possible.

Between the contamination and the extent of the injuries, my initial repair failed. The mucous membranes did not heal over the bone, and the bone was not healing. I once again offered referral, but the reality was that it was going to be too much money. I told them that I would look into options that I might be able to perform.

I called a friend, Dr. David Sweet, a veterinary surgeon. I explained the situation to him, and we discussed what options I had. Finally, we developed a plan. I called the owners and explained that I was willing to make one last attempt. I emphasized that this was going to be a learning experience for me. I had never attempted anything like this, and there were no guarantees. I made one last offer to refer Toby to a specialist. The owners agreed to allow me to try. I reached an agreement with the owners that I would donate my professional time, but there would still be substantial charges for materials, anesthesia, and antibiotics.

Dr. Sweet and I had broken the repair into three stages. I first stabilized the fractured mandible with a set of stainless steel pins driven into the bone (Figure 19–1). The pins were joined together with another rod on the outside of the jaw. I then collected cancellous bone from the humerus to pack into the defect still present in the mandible. This bone graft was going to provide mineral and bone cells to help heal the defect. The final step was to move a flap of mucosa from the inside of the cheek to cover the exposed bone. The flap remained attached to the cheek, maintaining its blood supply.

I was exhausted after the five hours of surgery. I had been tense the entire time. I read extensively in preparation for the surgery. Dr. Sweet had talked to me many times about the surgery protocol. At the end of surgery, I just was not sure how Toby was going to do. Fortunately, this case turned into a success. The bone healed, and the flap of mucosa remained intact.

I was very pleased with the outcome. The owners were extremely appreciative. This surgery provided me with one of my greatest accomplishments. Although I had not performed any of these procedures before, I was successful. Surgery requires knowledge of anatomy and physiology. The actual procedures require proper care to prevent infection and proper handling of tissues to allow for proper healing.

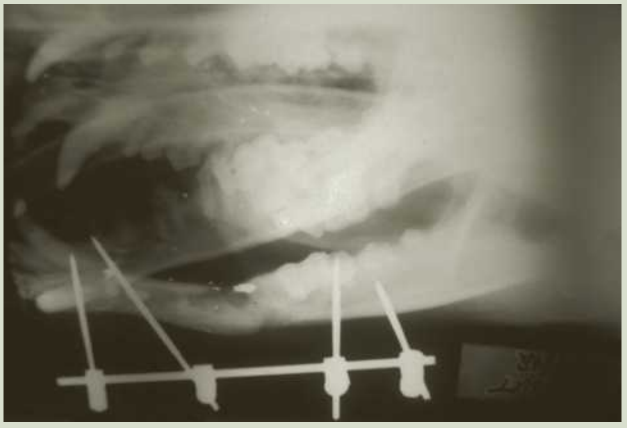

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FIGURE 19–1 Radiograph of Toby's jaw repair.

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PRINCIPLES OF SURGERY

Objective

- Explain the Clinical Significance of the Basic Principles of Successful Surgery

The skin and mucous membranes provide a barrier to invading pathogens. Surgery disrupts this barrier and provides a potential site for bacteria to invade. Animals' normal bacterial flora, surgeons, and the environment all are potential sources of bacteria. Special care must be taken to minimize the exposure of the patient to bacteria. **Aseptic technique** describes the general practices used to minimize the risk of infection that may occur following surgery. Aseptic technique must be comprehensive; any weak link can be a source of infection. Proper aseptic technique must include management of the surgical facility, the patient, the surgical site, the surgeon, and the surgical equipment.

Disinfectants are used to thoroughly clean the facilities within the operating room. They are not used on the patient. Disinfectants are too harsh to be used on skin or mucous membranes but kill a majority of the pathogens present on the equipment. Disinfectants do not eliminate spores. By thoroughly cleaning the operating facility, the exposure of the animal to bacteria is lessened. In addition, it is ideal to minimize the flow of people through the room. This helps to reduce the spread of bacteria through the air.

Every surgical instrument is a potential source of contamination. Initially the instruments are thoroughly cleaned of any debris, such as tissue or blood. The surgical instruments are then sterilized prior to surgery. **Sterilization** is a procedure in which all microorganisms, including spores are destroyed. Pressurized steam and chemicals are two means of sterilization.

An **autoclave** is used to sterilize instruments with pressurized steam (Figure 19–2) Water boils at 212°F. Adding additional heat may make the water boil faster, releasing more steam, but it does not in itself increase the temperature. Water within the autoclave is brought to a boil. The autoclave has a tight seal, which allows pressure to increase. By increasing the pressure within the autoclave, higher temperatures may be reached.

Instruments are generally packaged within a special wrap that allows the steam to penetrate. These surgical packs can then be handled on the outside without contaminating the surgical instruments. These packs are placed in the autoclave and maintained at 250°F to 275°F for 15 to 30 minutes. At these temperatures, all microorganisms, including spores of bacteria or fungi, are destroyed.

Because sterilized equipment does not differ in appearance from unsterilized equipment, special heat-sensitive markers are used to identify equipment that has been sterilized. A common example is a special tape used to close the wraps around the instruments (Figure 19–3). Initially, this tape is light brown with faint lines. Following sterilization, these faint lines become a very dark brown. This identifies the surgical equipment that has been processed through the autoclave. The tape does not guarantee that the instruments within the pack are sterile, but it does ensure that adequate temperatures have been reached on the exterior of the pack.

A collection of surgical instruments necessary for a given procedure is often put together in a pack. Most surgical packs contain a needle holder, forceps, hemostats, and a tissue scissors. In addition, draping material and absorptive gauze sponges are included. This basic collection may be all that is necessary for a procedure such as a displaced abomasum surgery in cattle. For a dog spay, the surgeon may elect to include

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FIGURE 19–2 An autoclave provides high-pressure steam heat to sterilize surgical instruments.

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FIGURE 19–3 A surgery pack—a collection of instruments used for one procedure. A roll of indicator tape is next to the pack. Note that the unused roll has light-colored lines. The surgical pack has been autoclaved, and the indicator lines have turned dark.

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Carmalt forceps for ligating the large vessels of the ovarian pedicle. The size of the instruments can vary significantly based on the delicacy of the surgery. For instance, the instruments used in the abdominal surgery of a horse are going to be more substantial than those used in a delicate ophthalmic surgery. Ultimately, the specific instruments will vary with the preference of the surgeon.

Good quality surgical instruments are made of stainless steel. The stainless steel is produced with a hardness that allows good durability, especially for instruments with a cutting edge. The metal in the instrument is also treated to minimize corrosion. Without this treatment, the steam sterilization of an autoclave could result in severe corrosion.

The complete list of surgical instruments available is extensive. Many instruments have been designed for specific surgeries or procedures. The following list includes many commonly used instruments (Figure 19–4).

1. Scalpel: Most surgeries begin with an incision into the tissues. The scalpel or surgical knife makes that incision. The actual blade is designed for a single use, is disposable, and is attached to a scalpel handle. The handle is the portion that is reused. Different sizes and shapes of scalpel blades are available.
2. Needle holder: This instrument holds the needle used for suturing. Many needle holders have a serrated tungsten carbide insert in the jaws that holds the needles. This material is very hard and lasts a long time. As this insert becomes smooth, it becomes difficult to hold the needle. The insert can be replaced, rather than the entire instrument. Most needle holders have a ratchet lock, so that the needle can be clamped and held without maintaining grip pressure on the tool.
3. Scissors: For surgery, several different styles of scissors are available. Curved scissors are often more maneuverable during the procedure, whereas straight-blade scissors more readily cut through tougher tissues. Surgical packs commonly have Metzenbaum dissecting scissors, used for delicate tissues, and heavier Mayo scissors for tougher tissues.
4. Tissue forceps: Many tissue forceps have the appearance of a pair of tweezers. The tip of tissue forceps varies depending on the usage. The tip may have a serrated end for handling delicate tissues or interlocking teeth for a secure grip. Another type of tissue forceps has a ratchet lock for securely holding tissues. In general the ratchet lock type should not be used on delicate tissues.
5. Hemostatic forceps: These forceps are generally called hemostats. These instruments have a ratchet lock and are used to clamp blood vessels. Once clamped, the vessel can be ligated (or tied off) to prevent bleeding. These come in different sizes depending on the type of procedure being performed.
6. Retractors: These tools are used to hold tissues and expose the surgical area, so that the surgeon has a better view. Retractors can be held by an assistant or they can be self-retaining.
7. Towel forceps or towel clamps: Surgical drapes are used to cover the animal, except for the region of the incision. This prevents contamination of the surgeon and instruments by the surrounding areas on the dog and surgical table. Towel clamps are used to clamp this material to the animal.
8. Spay hook: The spay hook is used to bring the uterus through a relatively small incision.

A

B

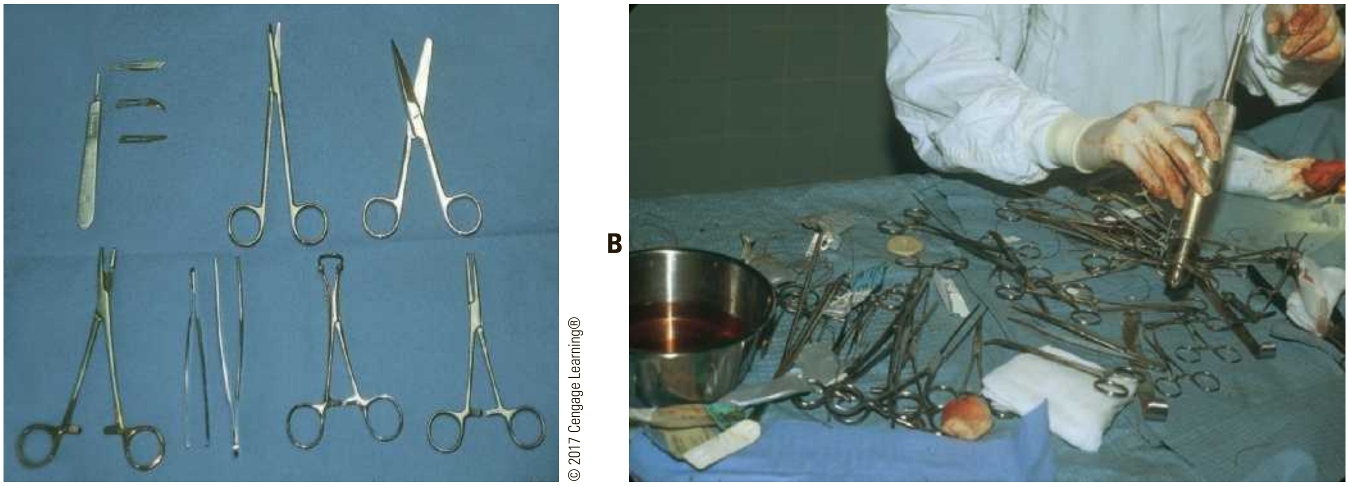

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FIGURE 19–4 A. Surgery instruments. Top, left to right: scalpel handle and blades, Metzenbaum scissors, Mayo scissors. Bottom, left to right: needle holders, thumb forceps, towel clamp, hemostat. B. Orthopedic surgery. A wide selection of instruments is used during surgery.

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As stated, stainless steel surgical instruments can withstand the high temperatures of an autoclave. However, such heat may damage other surgical instruments. These instruments may be sterilized by chemical means. Ethylene oxide is a gas used for chemical sterilization. The gas is quite toxic and requires special chambers that expose the instruments to the gas without contaminating the environment.

The surgeon also represents a source of bacterial contamination. Large numbers of bacteria are present on normal skin. Hair and cells from the outer skin layers are constantly being shed and often carry bacteria. In addition, air exhaled from the surgeon can be contaminated with pathogens. Proper preparation of the surgeon minimizes contamination risk.

The surgeon wears a head cover and surgical mask. The head cover is designed to cover all hair. Surgeons with facial hair wear a head cover that protects these regions as well. The surgical mask covers the mouth and nose of the surgeon. These facemasks are designed to block the spray of saliva that may occur while talking.

Surgeons then wash their hands and forearms with a surgical scrub. An antiseptic soap is used to thoroughly clean the skin. The scrubbing procedure not only removes dirt and oil from the skin, but also greatly decreases the number of bacteria present. The scrubbing procedure needs to be very thorough, covering all areas of the hands. This includes cleaning under the fingernails. Generally, a scrub brush is used along with the antiseptic soap.

Contact time is extremely important with the use of antiseptics. Antiseptics do not immediately kill bacteria and require prolonged contact with the microorganism. Proper technique dictates that the skin be scrubbed all over the hands and forearms down to the elbows. Then an organized scrubbing is performed. This allows the antiseptic to be in contact with all areas while the scrubbing continues. The standard rule is for the surgical scrub to last five minutes. This provides adequate time for the antiseptic to greatly reduce the number of bacteria.

During the scrubbing, the hands are held higher than the elbows. The principle is to hold the cleanest part the highest. In this manner, if the elbows have a higher bacterial count, water does not run from the elbows to contaminate the hands. Using a sterile towel, the hands are then dried, followed by the arms.

The classic method of hand preparation is time consuming and the repeated scrubbing and prolonged exposure to moisture and soap can also be quite irritating to a surgeon's hands. There is also a significant amount of water usage during the conventional hand preparation. For this reason, studies have been done to compare a more efficient hand rubbing technique using alcohol-based hand sanitizers. The studies found comparable reductions in bacterial numbers and the latter technique is currently accepted by the World Health Organization. It is important to recognize that these tests were done with specific hand sanitizers and not every over-the-counter hand sanitizer would meet these standards.

Courtesy Dr. David Sweet and Ann Zackim.

FIGURE 19–5 The sterile surgical environment. Dr. David Sweet is performing a surgery, while Ann Zackim, Certified Veterinary Technician, monitors anesthesia.

The surgeon then puts on a sterile surgical gown with the aid of an assistant. Sterile surgical gloves are placed on the hands, with the cuffs of the gloves sealing over the sleeves of the surgical gown (Figure 19–5). While not actively operating, the hands are held in front of the surgeon (still above the elbows). This prevents any accidental contact of the hands with a non-sterile item, such as the surgical table.

The question may arise as to why such a thorough scrubbing is necessary when gloves are being worn over the hands. The gloves that are used are sterile and are ideal for handling the surgical instruments and tissues. Unfortunately, the gloves are easily damaged with sharp tools or even tissues, such as a tooth or bone fragment. A small puncture in the glove does not result in severe contamination when the hands have been thoroughly scrubbed with an antiseptic soap.

The animal has to be prepared for surgery as well. The hair is clipped from the surgical region. Hair needs to be clipped in a large enough area that the surgical incision can be enlarged if it becomes necessary during the procedure. Loose hair is vacuumed to further prevent contamination during surgery. The skin is then scrubbed with an antiseptic soap. Just as with the surgeon, the scrubbing removes dirt and oils and greatly reduces the bacterial population. Contact time is equally important for the animal preparation

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FIGURE 19–6 A veterinary assistant prepares a dog for surgery.

(Figure 19–6). During scrubbing, the central region over the anticipated incision is scrubbed first, working in larger circles to the outside of the clipped area. This prevents dirt and hair from the peripheral region from contaminating the central region.

Following all the preparation of the surgeon and the animal, the actual surgery may begin. The preparation described previously is for a clean surgery. Examples are a spay or castration, where healthy skin is entered and healthy tissue is being removed. Not all surgeries are this clean. Surgeries involving the mouth, the intestines, and contaminated wounds may have varying degrees of contamination. The risk of infection following a procedure is directly proportional to the degree of contamination.

Conditions surrounding the surgeon also vary dramatically. The entire procedure for animal and surgeon preparation minimizes the risk of infection following the surgery. The photograph of the surgery on a cow does not show all these precautions. Although some veterinary clinics have a large-animal surgery facility, I do my cattle surgeries in the barn. I still do a thorough job of scrubbing the animal and myself but I do not take the precautions of using a cap, mask, and sterile gown. These surgeries are kept as clean as possible, but they do have the increased risk of contamination from the environment. A gust of wind blowing dust or a cat jumping onto the surgical field is possible when operating in barn conditions.

Room Preparation

The emphasis of this text has been on the science of veterinary medicine and the role of the veterinarian. The majority of veterinarians rely on a team to be successful. The staff at a veterinary hospital is responsible for keeping the practice operating and allowing the veterinarian to be efficient. When seeing clients and patients at a veterinary hospital, the veterinarian relies on his or her staff to prepare the rooms. Every hospital will have a different stocking protocol, but consistency is critical. Before appointments begin, the staff will check to make sure that all of the necessary vaccines, medicines, and supplies are readily available. In addition, patient rooms need to be properly cleaned and sanitized. Dogs and cats at a veterinary office are often stressed, and this can result in increased shedding. The presence of hair, along with the possibility of blood, urine, and feces, makes frequent sanitation essential.

The surgical suite requires similar preparation. Cleaning and sanitizing the room is critical to maintaining a safe surgical environment. The room also must be stocked and prepared for the type of surgeries being performed. Surgical packs, suture materials, and surgical gloves need to be ready. In addition, the staff must anticipate the need for special equipment that might be critical for a particular surgery. For example, an orthopedic surgery will require different preparation compared to a routine spay. Staff training and teamwork makes the veterinary practice run smoothly.

LACERATION HEALING

Objective

- Explain the Clinical Significance of Healing of Lacerations by First and Second Intention

Surgery creates a wound. Understanding the healing process is essential for both surgery and traumatic wounds. Skin will be used as an example of how tissues heal. Although the healing is divided into phases, the steps actually overlap in time.

The hemostasis phase begins immediately following the trauma or the incision. Bleeding is actually beneficial in flushing the wound of contamination. Instantly, the blood vessels constrict, slowing the flow of blood. Platelets and coagulation factors are marshalled, and the blood begins to clot, protecting the animal from excessive blood loss. The fibrin clot fills the wound and seals it. As the clot dries, a scab is formed. The scab helps to protect the damaged area and allows for healing to occur beneath it.

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The inflammation phase progresses from the hemostasis phase. The blood vessels eventually dilate in response to the release of factors such as histamine and prostaglandins, bringing more white blood cells to the area. These white blood cells help to destroy damaged tissue and invading bacteria. In the first 48 hours, neutrophils are critical in protecting the wound from invading bacteria and removing tissue debris. Monocytes also migrate into the area. Within a few days the monocytes become macrophages. They continue the process of clearing the wound of cellular debris and bacteria. The increased blood flow to the area forces plasma to leak from the vessels. The dilated vessels increase the heat in the region and produce a reddened appearance. The leaking plasma adds to the swelling, which applies pressure to the nerve ends, resulting in pain. Heat, redness, swelling, and pain are the classic signs of inflammation that defines this stage.

The healing process then enters the repair or proliferation phase. This process has actually begun during the inflammatory phase. In this step, connective tissue cells (fibroblasts) enter the damaged area and begin to form fibrous connective tissue. There is a proliferation of cells along with deposition of fibers and matrix. Typically within four days, capillaries begin to grow into this newly forming connective tissue. These capillaries are essential to provide oxygen and nutrients to the rapidly remodeling tissues. In an open wound, the combination of capillaries, macrophages, fibroblasts, and collagen takes on a fleshy red appearance. This healing tissue is called **granulation tissue**. Granulation tissue derives its name from the granular appearance of its surface.

Granulation tissue has an essential role in allowing the healing process to continue. This tissue obviously fills the gap between the wound edges and sets up a barrier to infection. The rich supply of capillaries delivers white blood cells to the area to engulf any invading bacteria. The granulation tissue provides a surface for the epithelial cells to bridge across the wound.

As the granulation tissue forms, epithelial cells from the wound edges begin to move across the wound. These cells initially form a single layer beneath the scab, until the two edges connect. This thin layer of epithelial cells serves the important function of minimizing fluid loss and forming a protective barrier against invading bacteria. The cells then continue to replicate and the layer thickens. Early removal of the scab can damage the newly forming epithelial layer and slow healing. Therefore, parents everywhere are right to tell children not to pick at scabs!

Once the epithelial cells have covered a wound it will appear completely healed. However, the healing process continues into the final phase of remodeling. This typically begins within several weeks of the initial wound, but can last for years. The fibroblasts in the healing wound continue to deposit more collagen in the connective tissue matrix. The connective tissue within the healing wound actually allows for the wound to decrease in size over time. This wound contraction occurs as the healing tissue becomes more organized and actually shrinks. In a large wound, the contraction helps to bring the skin edges closer together, decreasing the time required for the epithelial cells to reach across the wound. In this situation, the repair phase and remodeling phase are occurring at the same time. In certain situations, the contraction may fail before the wound edges have met. If the tension on the skin edges is too high, or if too much motion exists, the wound may not be able to bridge the gap. It is also possible for contraction to cause restricted motion, especially if the wound is across a joint. A developing scar is not very elastic and may restrict the ability to move.

During the first four to six days, there is not a dramatic increase in the strength of the wound. During this time any further trauma could easily reopen the wound. Over the next one to two weeks, the wound increases in strength rapidly as the connective tissue is formed and becomes better organized. Even following this time, the wound continues to increase in strength, a process that can continue for years.

Whenever possible the wound edges in a surgical incision are brought together with sutures. The skin edges are held close together to minimize the healing process. In a well-closed incision the epithelial cells can cross the defect within one to two days. **First intention healing** describes a wound with the edges closely apposed. The healing process is generally quite rapid and successful.

Following an injury, bacteria begin to multiply within a wound. The damaged tissue, blood, and plasma provide an excellent medium on which the bacteria can grow. The **golden period** describes the first six to eight hours, when bacterial numbers are still at a moderate level, allowing the wound to be closed. During this period the laceration can be closed to allow for first intention healing.

Beyond the golden period (more than six to eight hours after injury), the bacterial contamination may be too high to consider suturing the wound and allowing first intention healing. Grossly contaminated wounds may also be left open to heal. In some situations, large wounds occur where there is too much tension to allow the skin edges to be apposed. **Second intention healing** describes the healing that occurs in wounds where granulation tissue must fill the gap between the skin edges and subsequently allow the epithelial cells to grow. The size of these wounds can vary from a small bite wound to a very large region of skin lost in a burn.

Second intention healing effectively heals large wounds. Horses are prone to a condition called **proud flesh**. Proud flesh appears as an overgrowth of

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granulation tissue that prevents epithelial cells from growing across the wound. This condition most commonly occurs on wounds of the lower legs. In these regions there is little underlying tissue, and the skin has relatively high tension as it heals.

To prevent proud flesh, it is ideal to suture lacerations on horses to allow for first intention healing. Unfortunately, this is not always possible (e.g., when the wound is too large or too contaminated). Limiting the movement of the area is beneficial if second intention healing is necessary. This is generally accomplished by securely bandaging the lower leg.

If proud flesh does occur, it must be removed before the epithelium can grow across the wound. Granulation tissue has little nerve supply, so it can be manually cut back to skin level with little sedation or anesthesia. This process does result in significant bleeding, however, as granulation tissue is rich in blood supply. Bandaging following this procedure is necessary. Topical products are available that may chemically reduce the proud flesh. The decision regarding which method is used depends on the preference of the veterinarian, the size of the wound, and the extent of proud flesh.

Several basic principles are essential to minimizing healing time and ensuring success in a surgical incision. As already emphasized, asepsis is extremely valuable. All the preparation of the patient and surgeon aids in this process. During surgery, gentle handling of the tissues helps to minimize the extent of the inflammation that occurs. Excessive swelling can slow the healing process. When making surgical incisions, surgeons consider the blood supply to the region. Incisions should be made at locations that do not disrupt the blood supply. Damaging the blood supply can greatly slow the healing.

When suturing traumatic wounds, dead tissue and contaminants within the wound or on the skin margins should be removed. **Débridement** describes the process in which the damaged and contaminated tissue is removed. Furthermore, the body's immune system must remove any of this tissue remaining before healing can occur. Within hours of sustaining a wound, the skin edges begin to deteriorate and dry. These edges are trimmed to provide a fresh edge with blood oozing from the capillaries. These edges can then be successfully sutured. Care must be taken to avoid applying excessive tension to the tissue when it is being closed. The tension increases the likelihood that the suture material will cut through the tissues. This can be a problem in larger traumatic wounds or following the removal of a large tumor.

Large open wounds may not always heal by second intention. Infection, movement, and trauma (including a dog or cat licking at the wound) may prevent the complete healing process from occurring. Surgeons can utilize a number of techniques in attempting to repair these open wounds. One technique takes advantage of the elastic nature of skin and underlying tissues. Figure 19–7 shows an open wound on a cat's leg. The wound had been present for months and multiple

A

B

C

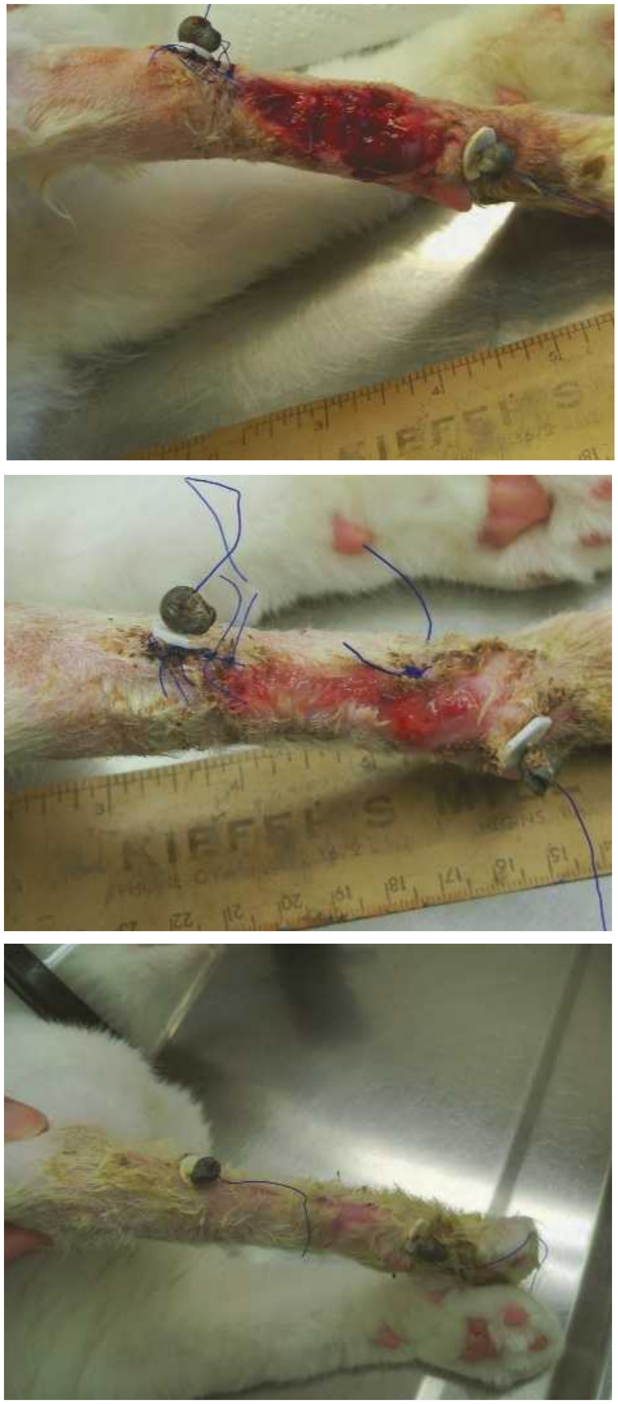

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FIGURE 19–7 A. An open wound on the leg of a cat with a healthy bed of granulation tissue. Tensioning sutures have been applied. B. The same wound one week postoperative. Notice that the size of the granulation bed is much smaller. C. One month postoperative. The tensioning sutures have allowed for almost complete epithelialization. The wound went on to achieve complete healing.

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attempts with antibiotics and bandaging did not allow for healing. A continuous line of suture was run back and forth across this wound. Split shot sinkers at each end of the suture line allowed for daily tensioning, taking up any slack that had been created from the skin stretching. Over the course of several weeks the wound shrank to such a size that epithelialization could occur. With a healthy granulation bed even more advanced techniques such as skin grafting are available to repair large open wounds.

Wounds caused by a high-velocity projectile (such as a bullet from a high-power rifle) present unique difficulties. The bullet not only creates a hole, but the shockwave from the high-velocity impact damages tissue around the defect. It is important to débride the wound aggressively. The bullet also contaminates the wound, dragging dirt and hair into it.

In any wound there can be bleeding from arteries and veins. Before a wound is closed, the bleeding should be well controlled. Oozing of blood from capillary beds may not be a problem, but any significant bleeding may separate tissues and provide bacteria a pocket for growth. Both of these factors slow healing.

Dead space, an important concept to consider in surgery, is actually a potential space that is present because of separation between tissues. Consider a surgery in which a large tumor is removed from the subcutaneous tissue. If the skin is closed over the area where the tumor was present, a large pocket exists. Initially it appears normal, but the skin is not attached to the underlying connective tissue. Fluid accumulates in this space from blood or plasma that leaks from the tissues damaged in the surgery.

Hematoma describes an accumulation of blood in the dead space. A **seroma** has fluid that is similar to serum with only a small number of red blood cells. The fluid in a seroma may be straw colored (basically no red blood cells) or a light red (with a few red blood cells). An abscess is a third fluid accumulation in the dead space. In an abscess the fluid contains bacteria, white blood cells, and dead tissue.

This collection of fluid increases the tension on the skin incision and prevents the skin from adhering to the underlying tissue. The fluid needs to be removed before complete healing can occur. If only small amounts are present, the body will reabsorb the fluid following the inflammation phase. If greater volumes accumulate, the veterinarian may need to remove the fluid through a needle or a small surgical incision. If left untreated, the increasing pressure may cause the wound to break and allow the fluid to leak from the pocket.

Two major methods prevent this type of fluid accumulation. In smaller pockets of dead space, the tissues may be sutured together. For example, the edges of subcutaneous tissue may be sutured. This effectively minimizes the size of the pocket. The second technique places a drain in the region. For example, a piece of soft latex tubing is placed in the dead space and brought out through the skin (Figure 19–8). The tubing maintains an opening in the skin that allows any accumulating fluid to leak from the pocket. The fluid does not drain through the center of the tubing. The purpose of the tubing is to maintain an opening in the skin for fluid to have an escape.

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FIGURE 19–8 A large fluid accumulation in the flank of a dog has been surgically drained. The Penrose drain protruding from the holes maintains an opening to allow any additional fluid to drain to the exterior.

Dehiscence, breaking of wound edges, may occur along the entire length of the suture line or a smaller region. Many factors may contribute to this failure to heal. As already mentioned, having too much tension on the incision may result in the sutures cutting through the tissue edges. Improperly placing the sutures too close to the skin edge or tying them too tightly may also result in the dehiscence. Infection at the incision may also cause it to break open. Finally, animals

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licking or scratching their own wounds may cause enough trauma to produce dehiscence.

The type of suture material used depends on the strength required and the type of tissue being sutured. Suture material is divided into two major classes, absorbable and nonabsorbable. In general (exceptions do exist), absorbable suture material is used within the body. Over time the body destroys the material, and eventually it will be eliminated completely. The goal is for the material to maintain strength long enough for the incision to heal adequately. Surgical gut or catgut is a commonly used absorbable suture material. The material is not made from cats, but from the connective tissue found in sheep or cattle intestines. Catgut is primarily made of collagen. Many other synthetic absorbable materials are available. The various suture materials each have different advantages, such as less tissue reaction, greater knot security, or greater and longer strength. Selection of material varies with the preference of the surgeon and the type of tissue being sutured.

Nonabsorbable suture material is not destroyed by the body and is commonly used to close the skin incision. Because the animal does not destroy these materials, these sutures are later removed. Nylon, polypropylene, silk, and stainless steel are all examples of nonabsorbable suture materials. Although nonabsorbable materials are most commonly used to close the skin, there are times where they are used within the body. In certain instances, the long-lasting strength of the nonabsorbable materials is warranted. The concern in burying such a material within the body would be the potential for the animal to react to the material. If this occurred, a second surgery would be required to remove the sutures.

The needles used with suture material come in a variety of shapes and sizes. The needles may be straight or curved, with the latter often being described in terms of the portion of a circle that they form (such as 3/8 circle). Needles may also be taper point or cutting. In cross section, the taper-point needle would appear as a circle, whereas the cutting needle would appear as a triangle. Taper-point needles are used on delicate tissues that allow easy passage of the needle. Dense tissues, such as the skin, generally require the use of a cutting needle. The edges of the triangle help to cut through the tissue, allowing the needle to pass more readily.

Suture material must also be selected based on the strength required to hold the incision. In addition to selecting the type of material, as discussed previously, suture materials are selected based on diameter (Figure 19–9). A scale has been developed that sizes the suture material from the smallest diameter of 10–0 to the largest diameter of 7. This United States Pharmacopeia (USP) size allows for the surgeon to easily communicate the suture selection. For instance, I often use a 3–0 suture to close the skin of dogs and a 2 or 3 for the skin of cattle. The selection is based on the fact that the tension on the incision line of the cow is much greater than that of a dog. The smallest sizes require the use of magnification to see the actual material. These sutures are obviously used in the finest surgeries.

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FIGURE 19–9 Various suture materials in different sizes and types are available for surgery.

A number of suture patterns can be used to close an incision. A commonly used pattern is called simple interrupted (Figure 19–10). In this pattern the suture passes straight through the two sides of the incision, is tied, and the ends cut. The simple interrupted pattern apposes the edges of the incision neatly together. An entire row of individual sutures is used to close the incision. A simple continuous pattern begins with a similar suture and is tied. With the continuous pattern, the end is not cut. The suture pattern then continues with a number of passes through the tissue until the opposite end is reached. The suture is tied at the opposite end and then cut. This pattern contains one long piece of suture material, with a knot at each end. The simple continuous pattern is much quicker to perform than the simple interrupted pattern. The disadvantage of the simple continuous pattern is that if one knot or strand of suture fails, the entire suture line is no longer secure.

Another commonly used suture pattern is called a mattress suture. A horizontal mattress suture is

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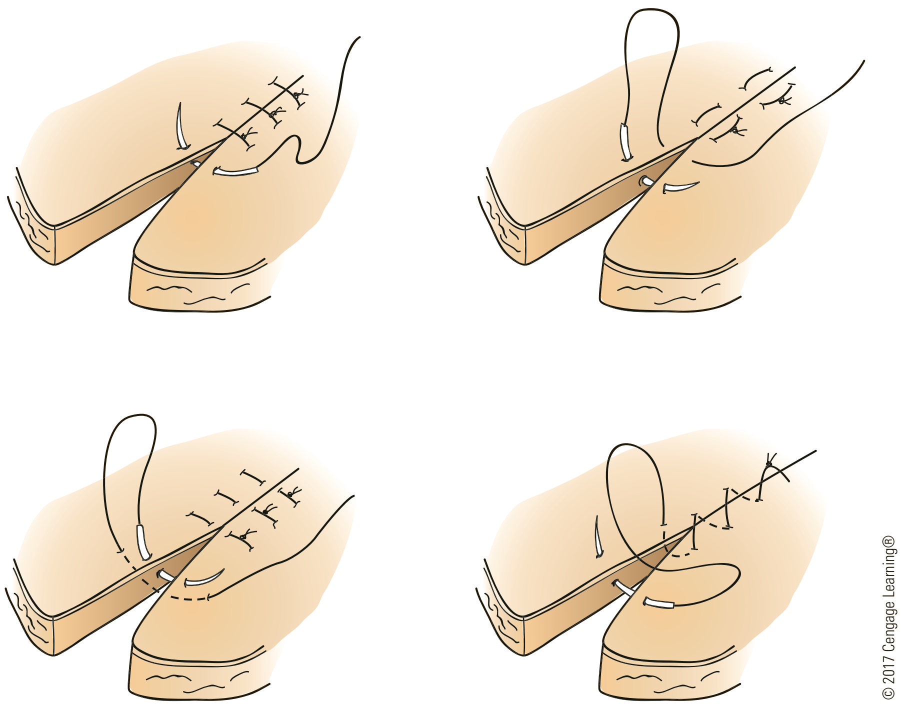

FIGURE 19–10 Suture patterns. A. Simple interrupted. B. Horizontal mattress. C. Vertical mattress. D. Simple continuous.

one example of this pattern. In this suture, the needle passes straight through the two edges of the incision. The needle is then moved farther down the incision and passed back across the edges. The two ends are then tied, which keeps the knot on one side of the incision. The advantage of this pattern is that it increases the area over which the suture applies pressure. A mattress suture is often used in incisions with high tension. This makes it less likely (relative to simple interrupted) to cut through the edges of the incision. Mattress sutures can also be performed in a continuous manner.

Tying knots is an essential skill for surgeons. Multiple square knots are tied to secure the suture. The number of knots placed depends on the type of suture material used. Some suture materials have poor knot security and require a higher number of knots. Granny knots and half hitches are much less secure and are not recommended. It is essential to avoid excessive tightening of the sutures. The suture should be applied to simply appose the edges, not crush the tissue. Overtightening is uncomfortable for the animal and increases the likelihood that the suture will cut through the tissues. This can lead to the animal removing the suture too early or the wound dehiscing.

The stack of square knots used in tying suture materials is actually a series of overhand knots. When the tissues are under tension, a single overhand knot may pull apart before the second knot is applied. To prevent this, a surgeon's throw is used. A surgeon's throw takes a second pass of the suture within the first overhand knot. The remainder of the square knots are then tied as usual.

Along with technological advances in other areas of veterinary medicine, endoscopic surgery has become much more available. An endoscope is an instrument that provides a light source and a means to see inside a body cavity. The image is viewed on a monitor and the instrument is controlled from outside the body. Endoscopy offers the advantage of accessing a region while being less invasive than conventional surgery. Endoscopes can be flexible for tracking through structures such as the intestinal tract or rigid for doing more controlled surgeries. Instruments available for the tip of the endoscope include forceps, needle holders, and scissors. In rigid endoscopy the name of the procedure corresponds to the region where the instrument is being used. Examples include arthroscopy (joint), thoracoscopy (chest cavity), laparoscopy (abdomen), and rhinoscopy (nasal passages).

Consider the radiograph of a dog that ingested a fishhook (Figure 19–11A). Conventional surgery would require an incision into the esophagus or an abdominal incision if the hook passed further down into the stomach. With endoscopy the hook can be visualized within the esophagus and carefully removed using

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A

B

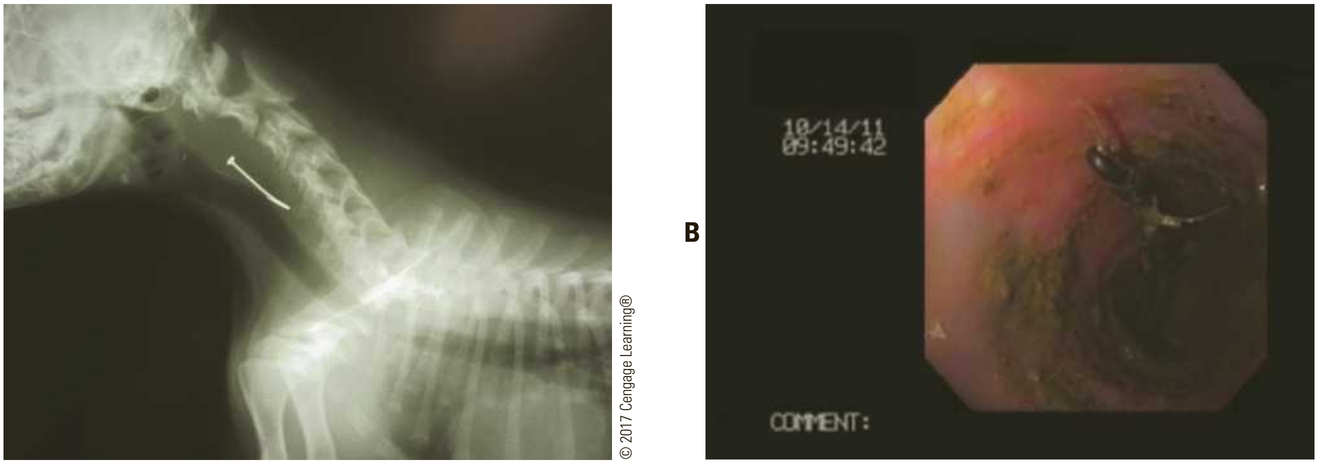

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FIGURE 19–11 A. Radiograph of a dog that had swallowed a fishhook. B. View through an endoscope showing a fishhook in the esophagus of a dog.

forceps (Figure 19–11B). Figure 19–12 shows a pyloric tumor visualized endoscopically. Using this technique a biopsy sample can be collected without the need for major abdominal surgery.

Recumbent Patients

Animals under anesthesia cannot naturally maintain their body temperature so care must be taken to support them. Placing a heavy towel or blanket between the animal and the table or cage floor helps to minimize the transfer of heat. In addition, hot water bottles can provide some supplemental heat. Proper warming pads are extremely beneficial in supplementing heat as well. However, warming pads must be carefully monitored to avoid overheating. Animals have developed severe burns by having constant contact with the hot surface. Being anesthetized prevents the animal from moving away from the heat.

Severely debilitated animals that are recumbent also need similar care. Padding under the animal helps to prevent pressure sores. In addition, rolling the animal from side to side allows for the return of circulation to the tissues. Many of these animals need supplemental warmth as well to support their body temperature.

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FIGURE 19–12 Endoscopic view of a mass in the pylorus of the stomach.

Dehorning

Although polled (without horns) cattle have been introduced through selective breeding, many breeds of cattle develop horns as they age. Horns have the potential to cause injury to other animals and to the people working around cattle. Dehorning is a common procedure that should be done on young calves, ideally before the horn base reaches 1 inch in diameter.

Very young calves (as early as one day of age) can be dehorned with a caustic paste. The hair is clipped over the horn bud and the caustic paste is applied directly to the skin. For the next day the calf needs to be protected from the rain and kept from rubbing its head against other animals. Electric and gas-fueled cautery systems are also available for dehorning. The head of the dehorner is able to cut through the skin around the horn bud, with the heat preventing any bleeding. Other tools are also able to cut through the skin to remove the horn bud, but these require some method of bleeding control.

All methods of dehorning are painful. Local anesthesia, sedation, and pain relief are beneficial to minimize the stress caused in the procedure. In addition, proper restraint is beneficial to make the procedure go smoothly, thus minimizing risk to the animal and the personnel. Cutting large horns should be avoided.

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Tail Docking

Tail docking is commonly performed on pigs and lambs. Docking in swine typically eliminates tail biting, which can result in very serious infections. In sheep, removing the tail can prevent fly strike, which may occur when the wool becomes matted with fecal material. Flies lay eggs in the matted wool and the resulting larvae can invade the skin. In both pigs and lambs a cautery tool can remove the tail, minimizing any risk of bleeding. In addition, elastrator bands can be placed on the tail, cutting off the circulation to the caudal end of the tail. In sheep, the tail is removed at the end of the distal tail folds. In either species removing the tail too close to the body can result in subsequent rectal prolapse and increase the amount of pain involved. Using proper technique and equipment along with appropriate pain relief is critical to minimize the stress on the animal.

SURGICAL CONSIDERATIONS

Objective

- Explain the Clinical Significance of Common Considerations in Veterinary Surgeries

It is useful to realize that there is not just one method of performing a given surgery. Many variations are possible. The differences may involve the approach, the order of the steps performed, or the specifics of the technical methods used. The descriptions that follow provide only one possibility for how the selected procedures may be performed.

One of the most commonly performed abdominal surgeries in pets is the ovariohysterectomy, or spay. In this procedure the animal is anesthetized and secured to the surgery table. The abdomen is clipped and scrubbed in preparation for the surgery. Most commonly spaying is performed through a ventral midline incision. *Ventral* refers to the lowest portion of the abdomen (which becomes the highest point when the animal is on its back). The midline is used because the connective tissue from both sides of the abdominal wall meets at this point, the linea alba (Figure 19–13).

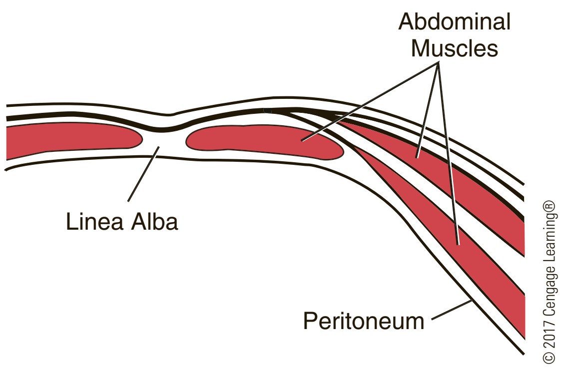

FIGURE 19–13 The structure of the linea alba. During abdominal surgeries this is a common site of incision.

The incision is made through the skin and subcutaneous tissues to expose the linea alba. An incision can be made through the linea alba with very little bleeding. At times the incision may deviate from the exact midline. When this occurs, muscle is incised. The incision can still be easily closed, but it is much more likely that bleeding will occur from the muscle tissue. This bleeding can obscure the view of the surgery field.

Special care must be used when incising the linea alba to prevent lacerating any abdominal organs. Once the linea alba is open, the surgeon has access to the abdomen. The surgeon then uses a finger or spay hook to locate the uterus. With the animal lying on its back, the uterus is generally found close to the spinal column and surrounding muscles. With the ventral midline approach the uterus is found deep within the abdomen. Once located, a horn of the uterus is brought to the surface and the ovary associated with that side is identified.

The ovarian artery supplies blood to the ovary and the cranial portion of the uterus. This artery, branching from the abdominal aorta close to the kidney, needs to be ligated. The closely associated ovarian vein is ligated at the same time. One technique of ligating major vessels is called the three-clamp method. The first clamp (hemostatic forceps) is placed immediately beneath the ovary. Special care is taken to identify the entire ovary and avoid clamping it with the hemostat. If a portion of the ovary is left within the animal, it may still show estrus activity. Two more clamps are placed across this vessel, each slightly farther from the ovary.

A suture is placed around the ovarian vessels at the level of the deepest clamp. As this clamp is taken off the vessels, the suture is tightened into the groove crushed by the clamp. Depending on the size of the vessels, a second ligating suture may be used. The vessels are then cut between the two remaining clamps. The stump of the vessels is carefully released, while the veterinarian observes for any evidence of bleeding.

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If this suture slips off these vessels, life-threatening bleeding may occur. The same procedure is then performed on the opposite ovary.

The broad ligament is a thin sheet of connective tissue that runs the entire length of the uterus, suspending it from the dorsal body wall. This thin sheet is ligated on each side. This frees the uterus, allowing the entire length of the uterine horns and body to be exposed. The cervix can be palpated to identify its location. The uterine body and the uterine vessels running on opposite sides are then ligated. A three-clamp method can be performed for this procedure as well. After the ligation, the uterine body is incised and the uterine stump carefully released. In a spay, the ovaries, uterine horn, and a majority of the uterine body are removed.

Once the entire uterus and ovaries are removed, the abdomen is examined for evidence of bleeding. If there is no bleeding, the abdominal incision can be closed. An absorbable suture on a taper-point needle is used to close the linea alba, generally in a simple interrupted or continuous pattern. The subcutaneous tissue is also sutured with an absorbable suture to minimize dead space. The skin is then closed using a nonabsorbable suture material on a cutting needle.

Spaying becomes a very routine procedure for most veterinarians. The benefits of the procedure have already been discussed in Chapter 8. It is important to recognize that even though it is routine, the procedure is a major abdominal surgery. It requires general anesthesia and ligation and incision of major vessels. Uncontrolled bleeding is a possible consequence. Obese animals make the procedure much more difficult because of the fat deposits in the connective tissue associated with the uterus and ovaries. Large amounts of fat in these tissues make the vessels more difficult to identify and make the tissues more difficult to handle. This is one reason that young, healthy, and active (and therefore lean) animals are ideal surgical candidates. Another potential consequence of the procedure may occur if the ureters become entrapped in one of the ligating sutures. This obstructs the flow of urine from the kidney, which may permanently damage the kidney associated with that ureter.

A ventral midline approach is commonly used to explore the abdomen of a horse as well. Table 7–4 lists a number of causes of colic in horses. Depending on the severity, many of these causes may require surgical correction. In abdominal surgery a horse is anesthetized, placed on its back, and secured. A large incision is made along the linea alba, allowing the surgeon to explore the abdomen. By feel and observation, the entire intestinal tract is examined for obstructions and disease conditions. A thorough knowledge of anatomy is critical to interpret the positioning and location of the structure of the intestinal tract.

One possible finding is a loop of intestine or colon that has twisted upon itself. This intestinal torsion cuts off blood supply to this section of the intestinal tract. The region takes on a dark blue or even black appearance. The loop can be repositioned properly, and if the torsion has been caught early, may improve in coloration. However, if the tissues are being too badly damaged they will not recover following the correction. In these situations, the diseased region must be resected or removed.

When removing a length of intestinal tract, the incisions must be made at a region where the tissue is completely healthy. The blood supply to the damaged region must be ligated to prevent bleeding. The intestines are clamped with special forceps that do not crush the tissue but do prevent spillage of the intestinal contents. The damaged section of the intestines is then removed. The newly created ends must be sutured together to create a tight seal. **Intestinal anastomosis** describes the procedure in which two regions of intestine are joined. This can be done manually or with a special tool that allows the placement of stainless steel staples. The stainless steel does not cause a tissue reaction nor support the growth of bacteria, and stapling can be done quite quickly.

This type of colic is severe, and many complications may result following the surgery. The risk of peritonitis is significant following intestinal anastomosis. If too large a region is affected, the procedure may not be practical. These horses are under tremendous physical stress during such a procedure, and secondary infections such as salmonellosis are quite possible.

A condition called **gastric dilatation–volvulus syndrome** (GDV), or gastric torsion, is a surgical emergency in dogs. Classically, this occurs in large, deep-chested breeds. Often these dogs have consumed a large meal or large volumes of water. Many times these dogs have been physically active following the meal. The combination of all these factors allows for the accumulation of gas and the rotation of the stomach (Figure 19–14).

Dogs with GDV develop signs of abdominal distension and make frequent attempts at vomiting. They are quite uncomfortable, and signs worsen quickly. Just as in the horse with intestinal torsion, GDV can compromise the circulation to the stomach. These dogs often develop signs of shock. Diagnosis is made based on the clinical signs and abdominal radiographs. The abdominal radiographs show a stomach severely distended with gas (Figure 19–15). The volvulus, or twist of the stomach, gives the appearance that the gas is divided into compartments.

Immediate treatment is essential to a successful outcome in these cases. Intravenous fluid therapy is begun to reverse the effects of shock. Occasionally, it is possible to pass a tube down the esophagus to relieve

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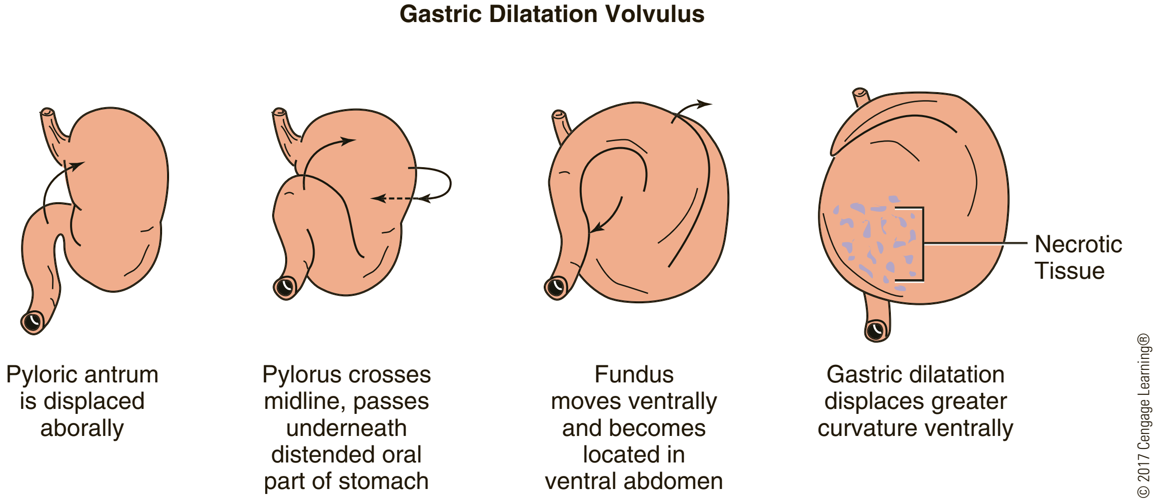

FIGURE 19–14 The formation of gastric torsion.

the pressure from the stomach. More commonly, if the stomach is twisted, the tube is not able to pass into the stomach. Surgery is then required. One approach is to make a ventral midline incision in the cranial region of the abdomen.

The stomach is easily visible and can then be drained to make correction easier. The stomach is then put into its normal position and evaluated. GDV can result in irreversible damage to the stomach and spleen, due to the lack of circulation. **Necrotic** (dead) regions of either organ need to be removed prior to finishing the surgery. This is acceptable as long as limited regions of the stomach are affected. Once the surgeon is comfortable with the appearance of the organs, the stomach is attached to the abdominal wall. This procedure is performed to prevent recurrence. The abdomen is then closed in a similar fashion to the procedure used in the spay.

Following the surgery, complications may still occur. Arrhythmias may occur in the heart rhythm. Shock can persist, and further regions of the stomach may deteriorate. The first few days following the surgery remain critical to the survival of the patient.

Another abdominal surgery performed in companion animals is the removal of bladder stones. The approach is once again a ventral midline incision in the caudal abdomen. This allows for exposure of the urinary bladder. The urinary bladder is brought through the abdominal incision for easy access. Gauze sponges are packed around the bladder to prevent spillage of urine into the abdomen. The bladder is incised in a region away from the ureters. The incision is extended to allow for the urinary stones to be removed (Figure 19–16).

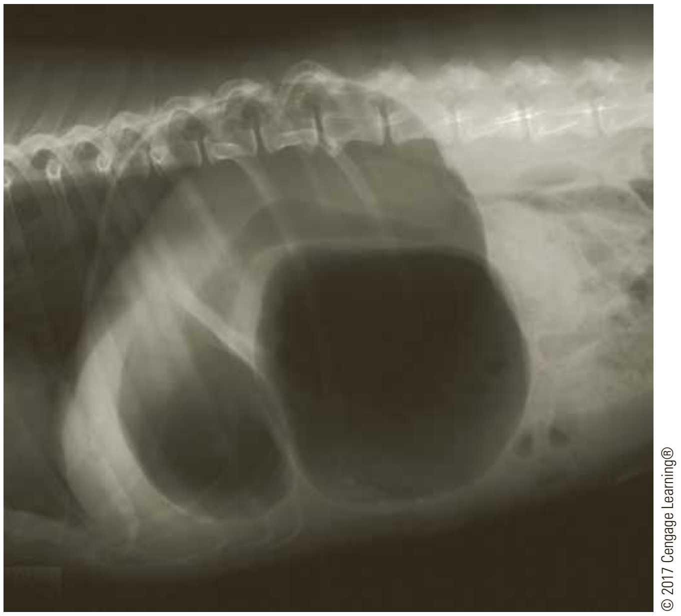

FIGURE 19–15 Radiograph of a dog with gastric torsion. Note the large gas-distended stomach.

FIGURE 19–16 Intraoperative photograph showing an exposed bladder and the urinary calculi that have been removed.

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Once the stones are removed, the bladder incision must be closed. This can be performed with a two-layer closure. It is essential that the suture line be closed securely to prevent the leakage of urine into the abdomen. Continuous mattress sutures are often used. The suture line used will invert the edges of the incision into the bladder itself. A second layer of similar sutures is then added. By inverting the edges, the size of the bladder is made somewhat smaller. The bladder has such an ability to distend that this reduction in size is usually not a significant problem. The midline abdominal incision is closed in the standard fashion.

Tumors within the skin and subcutaneous tissues present a common reason for surgery in small animal practice (Figure 19–17A). Once removed, the specimens are often submitted for biopsy evaluation. The biopsy helps not only to predict the nature of the tumor (benign or malignant) but also to evaluate whether tumor cells are present at the margins of the specimen. The benign tumors are often well encapsulated, and the cells do not extend beyond the visible margin of the tumor. With malignancies, the margins are often not so well defined.

Because the surgeon cannot see the actual boundary of the tumor, a wide margin of apparently healthy tissue is removed in addition to the tumor (Figure 19–17B). This is often quite easy when the tumor is located in the skin in a region where the skin is loosely attached (such as the side of the abdomen or chest) (Figure 19–17C, D). This procedure becomes more difficult when the tumor is located low on a leg. Aggressive removal of tissue in this region may prevent primary closure of the incision. In this situation, the surgical wound may need to heal by second intention.

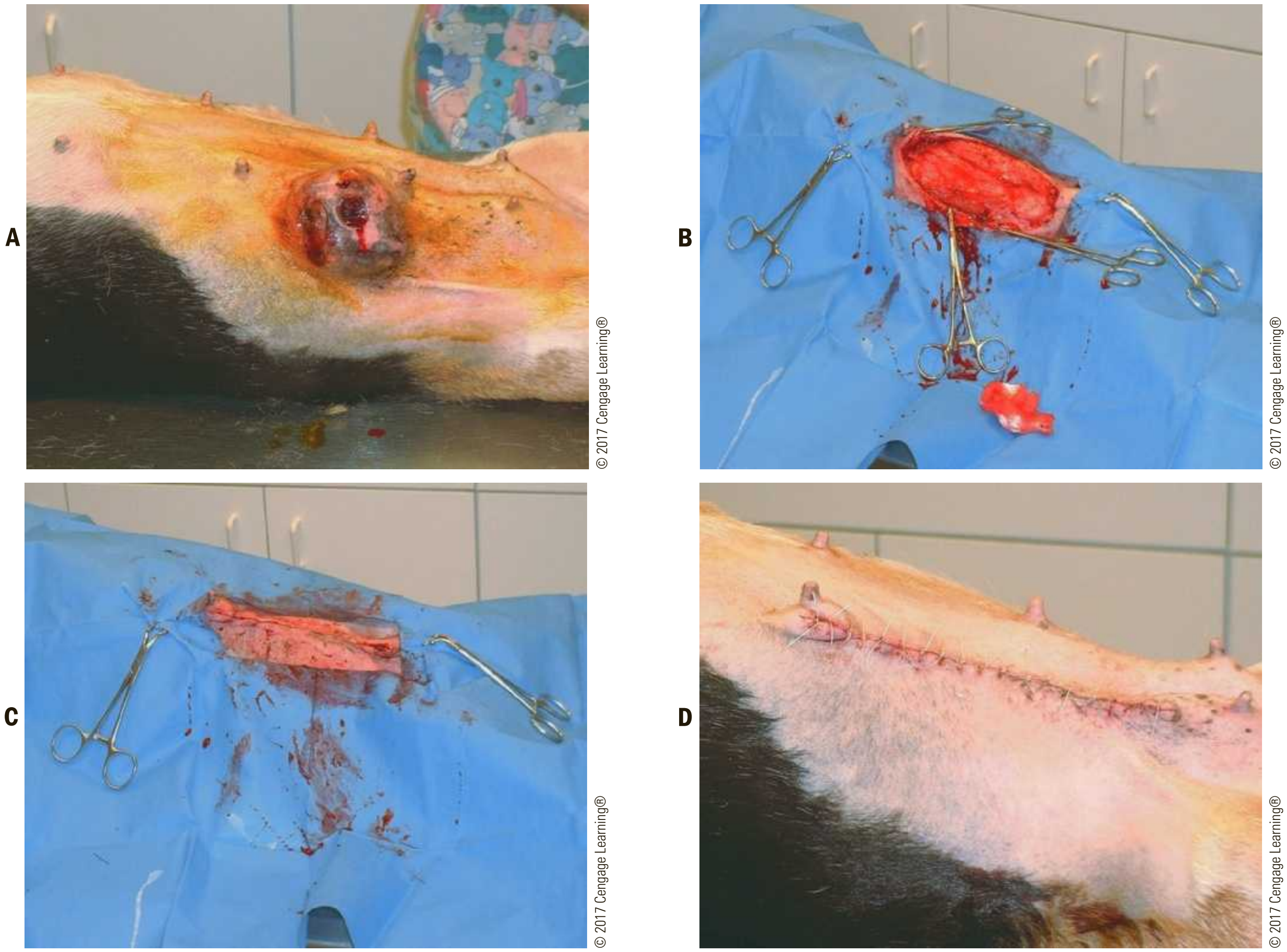

FIGURE 19–17 Surgical process. A. Photograph of a large tumor on the ventral abdomen of a dog. The dog has been prepared for surgery. B. The tumor has been removed with a wide excision. The removal of the tumor has created a very large potential dead space. C. The tissue underlying the skin is closed with an absorbable suture. This process greatly decreases the amount of dead space. D. The skin layer has been closed with a line of single interrupted sutures.

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Another challenge occurs if the tumor invades tissues deeper than the subcutaneous tissues. The surgery may become more difficult to perform if underlying muscles must be removed. In addition, this often creates a larger amount of dead space. I performed a biopsy on a large tumor on the side of a dog. The biopsy showed that the tumor was a malignancy arising from nerve tissue. The tumor was not freely moveable and seemed attached to the underlying muscle tissue. I did not feel comfortable with performing the surgical excision, and I referred the case to a local veterinary surgical specialist. She performed an aggressive surgery, removing a large section of skin, subcutaneous tissue, and muscle tissue from the side of the abdomen and thorax. The biopsy showed no evidence of tumor cells at the margins of the specimen. The incision was well healed at the time of the suture removal.

Surgery in the chest cavity has distinct challenges not present in abdominal surgery. Animals breathe by expanding the chest cavity, which subsequently expands the lungs. The expanding chest cavity lowers the pressure around the lungs, allowing them to expand. Once the chest wall is opened surgically, the animal is no longer able to breathe on its own. Expansion of the chest wall does not change the pressure around the lung tissues because air can enter through the incision. Therefore, the anesthetist must breathe for the animal. An endotracheal tube is inserted into the trachea. This tube has a balloon near the end that inflates, creating a seal within the trachea. Positive pressure can be applied to the oxygen entering the tube, forcing the lungs to expand.

The anesthetist must breathe regularly for the animal but must also coordinate the breaths with the surgeon. The surgeon has the added challenge when operating within the chest cavity of working around the expanding lungs and beating heart. Special care must be taken to avoid perforating the delicate lung tissues with a sharp instrument or needle.

Surgery on lung tissue involves the added challenge of developing an airtight seal on the incision. Although many structures are easily closed to prevent leakage of fluid, leakage of air is a common problem. Even the smallest suture material can create a hole large enough to allow a small amount of air to leak. With time, the body will heal such a small hole in healthy tissue. While the body is healing, a chest tube is used to allow air to be removed from the chest cavity.

The chest tube is placed with an end in the chest cavity, passing out through the chest wall with the other end accessible outside the body. The tube is put in place before the incision is closed. As the surgeon prepares to make the final closure of the incision, the anesthetist expands the lungs fully, forcing as much air as possible out of the thorax. The incision is fully closed. Suction can be applied (continuously or periodically) to the chest tube to draw out any new air accumulating within the thorax. The amount of air removed over time allows the surgeon to evaluate the progress of the patient. When air is no longer accumulating, the chest tube can be removed.

The chest cavity may be entered with an incision between the ribs or by splitting the sternum. Entering the chest between the ribs requires only an incision through the muscle layer between the ribs. The drawback of this procedure is that access is limited within the chest cavity. If the problem is in both the right and left lung fields, the surgeon may not be able to access the diseased tissue. A ventral midline incision provides more complete access to the thorax but requires special tools to split or saw the bones of the sternum.

The chest cavity can also be entered through the diaphragm in an abdominal incision. This becomes necessary with a diaphragmatic hernia. In this condition, a defect in the diaphragm allows abdominal organs to enter the thorax. A diaphragmatic hernia can occur with trauma, or the animal can be born with the condition. When the abdominal wall is opened, the patient is in the same condition as if the thoracic wall had been opened. The animal can no longer breathe for itself.

Once the abdomen is opened, the defect in the diaphragm needs to be identified. The abdominal contents must be carefully removed from the chest cavity. The defect in the diaphragm must then be sutured. It can be quite challenging to properly handle and tie suture material deep within the abdomen. The lungs are fully expanded while the final sutures close the diaphragm. The surgeon must evaluate whether a chest tube is required. The abdomen is then closed in a standard fashion.

All the surgeries mentioned to this point have been soft tissue surgeries. *Orthopedic surgery* describes those surgeries dealing with bones. Orthopedic surgery requires another set of instruments and equipment necessary for repair of bones and related structures (such as joints and intervertebral disks).

Several methods are available for repairing fractures. The specific repair depends on the type and location of the fracture. I handle basic fracture repair with an intramedullary pin. The intramedullary pin provides excellent strength for preventing compression. This type of repair may not prevent rotation of the bone fragments.

The surgery to repair Toby's jaw, which was fractured by the bullet, used an external support. The stainless steel pins were driven through the bone of the jaw and then connected by another stainless steel rod. This type of repair holds the bone in the proper orientation and prevents compression. This repair was very effective because it allowed the bone graft to be placed within the defect.

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FIGURE 19–18 Radiograph of a pelvis repaired with a bone plate and screws.


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FIGURE 19–19 Radiograph showing fracture of the femoral neck.

This repair could also have been performed with a bone plate. In this procedure a stainless steel plate is securely fastened to the bone with screws (Figure 19–18). This too provides a rigid support that prevents rotation and compression. A large inventory of plates and screws must be kept on hand to allow for proper selection for the bone in question. The wide size range of animals that the veterinary surgeon treats makes the size range of bones very large. Consider the difference in size between the bones in a young kitten and those in a mature Newfoundland.

While the ultimate goal is always to completely repair a broken bone, there are times when this is not practical. Severity of injury or financial constraints may not allow a surgical repair. One example is a fracture of the femoral neck (Figure 19–19). Although surgical repair is often possible, the cost can be prohibitive for some owners. Another option is to surgically remove the femoral head and smooth the shaft of the femur. This procedure is much quicker and technically less difficult than a surgical repair and is therefore much less expensive. The animal actually creates a false joint with scar tissue. Instead of the broken ends of the femur rubbing together, the bone end rubs within a relatively smooth scar tissue capsule. This is much less painful for the animal and most return to relatively normal function.

SUMMARY

Successful surgery is a result of both extensive study and practical experience. Surgeons must follow comprehensive aseptic techniques that include management of the surgical facility, the patient, the surgical site, and the equipment. Moreover, they must learn to match the tool to the surgical need. Surgery creates a wound, and postsurgical care may include removing proud flesh, débridement, and draining an abscess. Understanding the process of wound healing by first and second intentions gives surgeons the technical background to appropriately repair wounds.

REVIEW QUESTIONS

1. Define any 10 of the following terms:

   aseptic technique
   sterilization
   autoclave
   granulation tissue
   first intention healing
   golden period

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second intention healing
proud flesh
débridement
hematoma
seroma
dehiscence
intestinal anastomosis
gastric dilation–volvulus syndrome
necrotic

2. True or False: Disinfectants can safely clean surgeons' hands prior to surgery.
3. How high does the temperature rise in an autoclave when instruments are being sterilized?
4. What is a scalpel?
5. Name one toxic gas mentioned in the text that can be used to chemically sterilize surgical instruments.
6. How long does the golden period last?
7. Does gastric torsion occur most typically in larger deep-chested dogs or toy-type canines?
8. What species mentioned in the text are especially prone to proud flesh?
9. Why should surgeons hold their hands higher than their elbows during scrubbing?
10. How can dead space be prevented in surgery?
11. What are hemostatic forceps used for in surgery?
12. What type of approach is used in the removal of bladder stones?
13. What is the primary reason to perform biopsies?
14. List the two main types of suture material.
15. List two means of sterilization.
16. List two types of imaging equipment used during surgical procedures.
17. Explain the use of three of the following surgical instruments:

    scalpel
    needle holder
    scissors
    tissue forceps
    retractors
    towel forceps or towel clamps
    spay hook

18. Provide general guidelines for the care and maintenance of surgical instruments.
19. Explain the purpose and use of an autoclave.
20. Describe methods for preparing and sterilizing small- and large-animal surgery packs.
21. ______________ can be prevented in sheep by tail docking.
22. True or False: Recumbent patients can move if heating pads become too warm.
23. Describe the necessary procedures for preparing a patient room and how they differ from preparing a surgical room.

ACTIVITIES

Materials needed for completion of activities:

hemostatic forceps
two pieces of rubber tubing
a block of wood
thumbtacks
regular thread, yarn, string, or dental floss
needles

1. Do a Web search for "tying sutures." Find a link that illustrates the different methods of tying sutures. The simplest method is an instrument tie. Using hemostatic forceps, practice performing an instrument tie. These instruments are also available at many hardware and craft stores. There is a tremendous variation in quality, but inexpensive hemostats are acceptable for learning the steps of the instrument tie.
    a. A practice board can be made by taking a block of wood and attaching two parallel pieces of rubber tubing with thumbtacks. Regular thread, yarn, string, or dental floss can be used as the suture material. Examine the knots to ensure that each knot is a square knot. To simulate suturing, a needle can be added to the thread and the rubber tubing can be sutured.
    b. Create a simple interrupted pattern by passing the needle through each piece of tubing and then tying the suture with a series of four throws (basically two full square knots). The sutures should be tied only tight enough to appose the two pieces of tubing. Do not crush the tubing. In a real incision doing so could lead to dehiscence. Attempt to space the sutures evenly and close enough together that the tubing does not gap between the sutures.
    c. If you desire a greater challenge, you can attempt to learn the one-hand or two-hand ties. Knots can be tied very quickly with this

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method. These techniques are also a great show of a surgeon's dexterity. The instrument tie is used much more commonly in veterinary medicine. The instrument tie does not require long ends to be cut and wasted. When suturing, the needle holder is in the surgeon's hand and is conveniently used to tie the suture. To do a hand tie, the instrument must be repositioned.

2. Videos of veterinary surgeries can be viewed from a variety of locations on the Web. View the following procedures: castration, dehorning, and docking. Describe the surgical skills used in the videos. Select a specific procedure such as a spay and view several surgeries to compare and contrast surgical techniques. Identify the imaging equipment being used during the procedures. List the monitoring equipment used and the monitoring procedures followed during the surgery.
3. Use the Internet to research the latest advancements in the following types of imaging equipment used for surgical procedures: ultrasonograph, endoscope, electrocardiograph, and radiograph. Compare and contrast the new technology with the older versions, including safety procedures, maintenance, and operation of the equipment.
4. Interview a veterinary technician regarding office protocol for room preparation.
5. Students can research varying dehorning tools via Web search. Differentiate among tools used for varying species.
6. Use the Public Resources page of the American Veterinary Medical Association website to research careers in veterinary science, including career resources, market statistics, and veterinary specialties.

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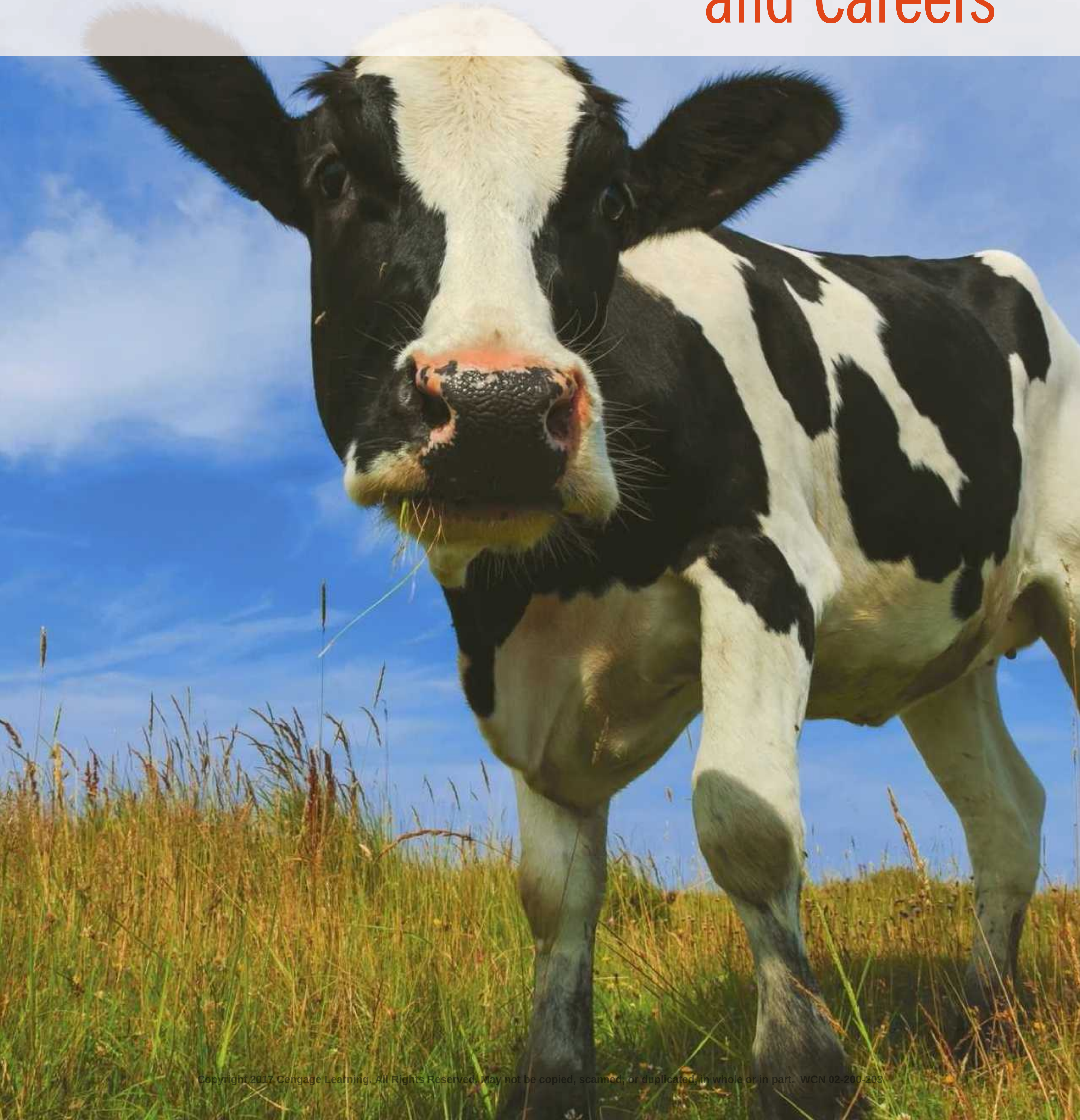
Unit V

Professionalism and Careers



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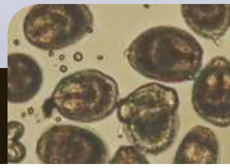
CHAPTER 20



Safety

Objectives

Upon completion of this chapter, you should be able to:

- Identify potential safety hazards encountered in veterinary practice.
- Avoid injury while working in a veterinary practice.
- Maintain a safe work environment in a veterinary practice.

Key Terms

lacerations
Occupational Safety and Health Administration (OSHA)
Material Safety Data Sheets (MSDS)
formalin
collimator
dosimetry

Introduction

Safety must be a priority for all workers in the veterinary profession. Veterinarians and veterinary technicians have to maintain safety for themselves, but they must also protect their coworkers and clients. Veterinary practice presents many of the same risks as other jobs. Slips, falls, and lifting injuries are common risks in many work environments. Accidental injections from needles, **lacerations** (cuts) from scalpel blades, potentially infectious diseases, and exposure to radiation are threats common to both human medical and veterinary practices. Companion animal practice adds the risks of bite and scratch wounds, while working with horses and cattle can result in being kicked, stepped on, and trampled by animals that can easily weigh more than 1,500 lb. In this chapter, we will discuss both official regulations and commonsense rules that veterinarians must know and observe to protect their own safety and that of their peers and patients.

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A Day in the Life
Safety in Numbers

One Monday morning I encountered a displaced abomasum at my second call. As we prepared to roll the cow onto her back, the farmer told me that he was not up to his normal strength. I asked what was wrong. He pulled up his shirt to show me severe bruising over the right side of his rib cage. I am sure I had a look of shock as I asked what happened. He explained that he was moving cattle the previous Saturday and the bull in the pen knocked him down. I was sorry to see the damage but also thankful that he had not been more seriously injured or killed.

I feel very fortunate that in over 28 years of practice the number and severity of injuries at my office have been relatively few. The most common problems are bite and scratch wounds. In the small animal clinic, many of the patients are quite stressed from the trip to the office and fearful of the new surroundings. In addition, the animals may suffer from a painful condition or undergo a painful procedure. These animals may retaliate in attempt to protect themselves. As a result, bite or scratch wounds on the hands and arms are a real risk and unfortunately have happened at our office.

Whether working in the small animal office or on a farm, teamwork plays a key role in ensuring the safety of everyone involved. Good communication between coworkers allows everyone to be aware of what is about to occur. I have tremendous confidence in my staff. They are often at the highest risk because they are often the first to contact the animal. As I work on the animal I rely on my staff to keep the animal properly restrained and controlled. Although the veterinarian has the ultimate responsibility for the patient, a good team leads to success.

SAFETY REGULATIONS AND OSHA

Objective

- Identify Potential Safety Hazards Encountered in Veterinary Practice

Many of the safety precautions veterinarians use in the workplace are based on common sense. It is not uncommon to feel rushed in the routine practice of veterinary medicine, and as a result, one can become careless. It is important for all of the veterinary team members to be aware of safety practices. In 1971, the federal government established the **Occupational Safety and Health Administration (OSHA)** to establish guidelines and training to protect workers. OSHA regulations require employers to provide a safe work environment as well as training and safety equipment for their employees. In addition, OSHA regulations mandate that employees follow safety protocols, use proper equipment, and report dangerous situations.

Employees in veterinary practices are exposed to potentially hazardous chemicals and infectious agents almost daily. Exposure to insecticides, anesthetic gases, drugs, and chemicals becomes so common that the sense of awareness may not be high. OSHA has established the Right-to-Know Standard. Employers are responsible for providing training for employees, having products properly labeled, and providing access to **Material Safety Data Sheets (MSDS)** (Figure 20–1). These sheets

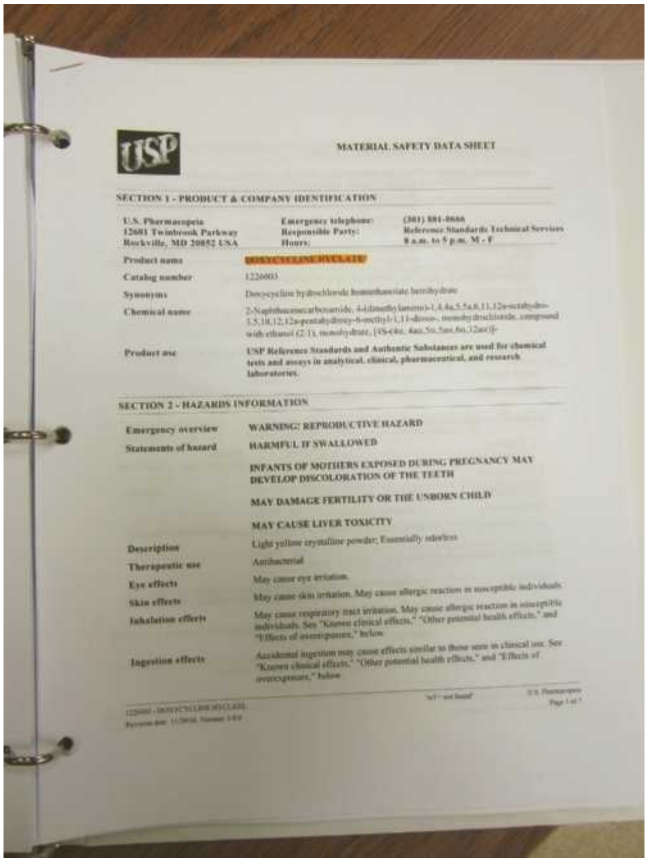

FIGURE 20–1 MSDS files must be kept accessible.

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provide extensive information on hazardous materials and chemical products. The names of the ingredients, manufacturer, contact information, handling instructions, safety precautions, and health risks are all included. Further, these sheets include information on first aid for exposure to the material or chemical based on the route of the exposure (e.g., skin contact, eyes, inhalation, or ingestion).

The MSDS should be organized in a convenient location for ready access in case of an emergency. Being aware of a potential hazard, handling it correctly, and wearing appropriate protective wear will help to eliminate most accidents. Having these sheets readily accessible allows for a quick response if an accident does occur.

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FIGURE 20–2 It is important to warn clients and staff about wet floors.

SAFETY IN VETERINARY PRACTICE

Objectives

- Avoid Injury While Working in a Veterinary Practice
- Maintain a Safe Work Environment in a Veterinary Practice

Slips and falls can occur at any workplace. Conditions at a veterinary office may increase the potential risk. Both pet owners and staff are often walking pets on a leash. Often these pets are distracted by other animals or may just be nervous. At the veterinary office, even some well-trained dogs no longer walk calmly. If the dog pulls or if an extra-long leash becomes wrapped around a person's leg, it can cause the person to fall. In addition, urinary and fecal accidents happen frequently in the waiting room. These accidents create slippery conditions and the frequent mopping to clean the mess adds to the risk. Within the practice, pets are often groomed and this can also result in the floor becoming wet. Bright yellow warning signs are very beneficial in bringing people's attention to the wet floor and potentially slippery conditions (Figure 20–2). Prompt cleanup of accidents or spills is very important to minimize risk.

While we have no control over the footwear choices of our clients, it is important for all members of the staff to wear shoes with soles that provide good traction. Staff members are often responsible for cleaning kennels and runs and this can make the soles of the shoes wet. Smooth-soled shoes can increase the risk of a fall when wet. In addition, the shoes worn by staff should provide protection to the top of the foot. It is possible for hazardous chemicals to be spilled and for sharp objects (such as needles and scalpels) to be dropped on the foot. Open shoes such as sandals are not acceptable for safety. For veterinarians and technicians working with horses and cattle, steel-toed shoes can provide another safety measure. It is quite possible to have a horse step on a person's foot; protective footwear can minimize the resulting pain and prevent a more serious injury such as a fracture.

Driving

Working on horses and other large animals often requires the veterinarian to travel to the farm. While driving is commonplace in most aspects of life, it is also part of the veterinarian's job. The principles of safe driving are the same personally and professionally. Following all traffic laws, including buckling up, is important in protecting everyone's safety. Rushing to get to an emergency or finally finishing a busy day is not an excuse for speeding, tailgating, or aggressive driving. Cell phones have added an additional risk to driving. The pressures of a busy day may raise the temptation to use the cell phone while driving between farms. It is critical that texting should not be done while driving and even talking on the phone should only be done with a hands-free device.

Working Safely in the Farm Environment

The work on farms can be physically demanding, and performing these duties during periods of extreme heat can increase the risk of heat stroke. It is easy to feel pressured to get the job done and not think about the risks. It is critical to maintain adequate hydration, replacing the fluids and electrolytes lost through sweat. When possible, it is beneficial to avoid working in direct sunlight (this can be helpful to the animal as well) and to take breaks when needed.

Working with Large Animals

Working with horses and food animals puts veterinary staff in a dangerous position of interacting with animals that often weigh 10 times more than the individual. Even similar-sized animals, such as a charging ram or buck, can be dangerous for a person. The procedures being performed often make the animal nervous and can induce pain. Proper training is critical to understanding and minimizing the risks involved. Specially designed handling facilities are ideal. Having

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an animal restrained in a properly constructed chute keeps the veterinarian in a safe position and controls the animal. Unfortunately, not all farms have the proper equipment. Sedation is helpful, but even this typically requires some degree of restraint to administer.

Experience, training, practice, and patience are all helpful in learning to interpret an animal's posture and behavior. These skills can be extremely beneficial in predicting how an animal will react. For example, a horse with its ears laid back against its head is giving notice that it is upset and the handler needs to be aware. Even the most experienced technician or veterinarian can be surprised by an animal's reaction. For example, extraneous noise such as a barking dog can cause the animal to react differently than expected.

Regardless of the setting, some key principles hold true. It is critical to make sure the animal is aware of your presence. Approaching cattle or horses from behind is dangerous because their field of vision does not extend behind them. Kicks by horses and cattle are a common source of injury for people working around them. With all animals, using a calm demeanor with slow steady movements is beneficial. Providing contact such as stroking a horse's neck prior to administering an injection can help to calm the animal. Being aware of surroundings is also critical. It is dangerous to be trapped between a horse and a stall wall. If the horse moves quickly it is very possible to be severely crushed. Cattle restrained in a chute can still jump and move. It is essential that handlers and veterinarians not put their arms between the animal and the metal bars. Coworkers need to communicate and be aware of the position of the others. Having the handler and the veterinarian on the same side of the horse allows for an awareness of each other and adds to the overall safety.


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FIGURE 20–3 Bite wounds can be prevented by properly muzzling dogs.

Working with Fractious Animals

Aggressive and scared dogs and cats also present a significant risk to the veterinary staff and owners. It is not unusual for an owner to be scratched trying to get a cat into a carrier at home. Once at the veterinary office, many normally docile pets can become dangerous due to stress and anxiety. Just as with horses and cattle, proper training and experience are extremely important when it comes to handling pets. Extensive information is available to assist in learning proper handling and to interpret posture and behavior of dogs and cats. Bite wounds and scratches are a common injury when dealing with fractious pets.

Aggressive dogs are not only a threat to the staff and owners; they also provide a threat to other animals in the clinic. Owners should bring dogs to the veterinary office on a short leash, allowing them to keep their pets under control and minimize contact with other animals. Muzzles are extremely valuable for preventing bite wounds (Figure 20–3). It is important for clients to recognize that this is a safety measure and is not designed to punish the animal. For many owners who know their pets are aggressive, applying their own muzzles prior to reaching the veterinary office can prevent a struggle. It provides a much safer environment for all involved if the muzzle is applied before a dog becomes agitated.

Fractious cats not only try to bite, but also protect themselves with their claws. Scratch wounds from cats are a common problem. In the veterinary profession, wounds on the hands are common. Whether reaching for a pet or performing a procedure, the hands are often the first site to be bitten or scratched. Heavy leather gloves provide mechanical protection from injury but limit the ability to restrain and perform procedures. Wrapping a cat in a heavy towel or a cat restraint bag can minimize the risk of being scratched.

The owner, the veterinarian, and staff all hate to fight with a fractious pet and make every attempt to keep the animal calm. Just as with horses and cattle, a calm demeanor and a slow approach is beneficial. Studying the signals of animal behavior and posture can benefit the staff, and every experience, good or bad, can be a learning tool. Keep in mind that while there is risk to the people involved, the stress also causes alteration in body temperature, heart and respiratory rates, blood sugar levels, and white blood cell counts in the pet. The stress can make diagnosing health issues more challenging.

Lifting

Lifting large dogs presents an additional safety risk. During procedures it is common to lift dogs, whether it is from a car, floor, or table. In addition, staff members are often called upon to lift heavy objects such as dog food or shipment packages. Heavy lifting often occurs in veterinary practices that specialize in horses and cattle. Just moving a horse or cow that is lying on its side

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to a sternal position can require significant exertion. Proper lifting procedure is extremely important to protect the person's back from injury.

While lifting, it is critical to bend the knees and keep the back straight (Figure 20–4), using the legs to stand. Core muscles of the back and abdomen are utilized while lifting, so maintaining good fitness is helpful in preventing injury. Keeping the object that is being lifted close to the body also minimizes stress on the back. Moving slowly and consistently is important. Most people use proper lifting technique as long as they are conscious of an object's weight, but attention to body mechanics may decline with lighter weights. Even a small bag of pet food can create back difficulties, especially with repeated lifting episodes.

Lift tables are of benefit for large dogs because they allow the dog to step onto the scale and then mechanically raise the dog to a comfortable working height (Figure 20–5). Stretchers are available to allow two people to carry one pet minimizing the stress on

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FIGURE 20–4 A. Proper lifting technique using bent knees and a straight back. B. Improper lifting technique; the assistant is lifting with her back.

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FIGURE 20–5 A mechanical lift table allows large dogs to be raised to a comfortable working height without lifting.

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each person. When lifting with two people, one person should be in charge to communicate when to begin lifting so that there is a coordinated effort.

Using Veterinary Tools Safely

As mentioned earlier, hands are commonly injured with scratch and bite wounds. The hands are also at risk when using tools related to the practice. Scalpel blades and needles are extremely sharp and can easily penetrate or cut skin. Ideally, needles and syringes should be disposed of in an appropriate sharps container without recapping the syringe (Figure 20–6). These containers are brightly colored to warn of the risk of sharp objects and are made of heavy plastic to prevent a needle from puncturing the side. If a needle needs to be recapped it should be done using a one-hand technique (Figure 20–7). In this method the cap would be placed on a flat surface and the needle point reintroduced with only one hand on the syringe. Only after the needle point is safely inside the cap is the second hand used to secure the cap into place.

Scalpels, hoof knives, and other pointed objects such as intramedullary pins also pose a risk to the hands. Care should be taken to always cut or push away from the body and be aware of the other hand's location. When using hoof knives the animal can kick or knives can slip. Awareness of where the knife or scalpel would

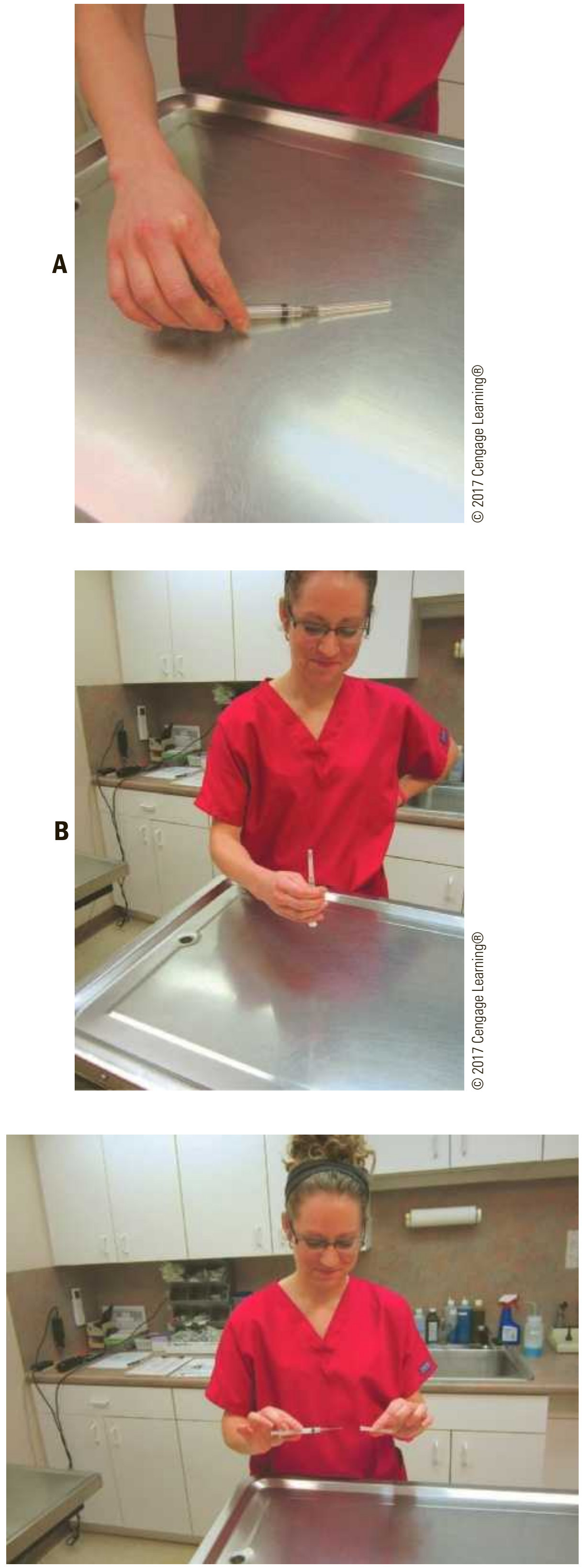

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FIGURE 20–7 Ideally, syringes would not be recapped. When necessary, the procedure should be done with one hand. A. The exposed needle is slid into the syringe cap lying on a flat surface. B. The syringe with a loosely fitted cap is raised and the cap snapped into place. C. This technique of recapping a syringe using two hands is dangerous and increases the risk of accidents.

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FIGURE 20–6 Sharps container.

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go if it slipped is important as it helps ensure that the second hand in a safe location. Accidental injection with tranquilizers or infectious agents, such as a modified live *Brucella* vaccine, pose a significant risk. Animals often jump, kick, or move during an injection so once again ensuring that the second hand is in a safe location is important. Likewise it is important to be aware of the assistant's position and hand location to avoid accidentally hurting that individual.

Cattle and horses are often restrained with some type of rope halter or lasso. Injury from the rope can occur if it is pulled rapidly through the hands or if a hand becomes entrapped between the rope and a post. It is extremely important never to wrap the rope around your hand or any body part. Even a 100-lb sheep can pull very hard and potentially injure a hand or fingers if the rope is wrapped.

Protecting the Eyes

The eyes are particularly vulnerable and need to be protected. Staff at a veterinary clinic are exposed to potentially hazardous chemicals such as **formalin**, insecticides, and radiograph-processing solutions. In addition, dental cleanings have the potential to send small pieces of tissues, plaque, and bacteria airborne. Eye protection is critical to protect the employee's vision and should be worn anytime there is a potential risk. In addition eye wash stations should be made available and employees should be trained on the proper usage (Figure 20–8).

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FIGURE 20–8 Eye wash station.

Radiology

As discussed in Chapter 3, radiology is extremely helpful in diagnosis but represents a health risk to the veterinarian and staff. The occasional radiograph taken of a person for health reasons is of minimal risk with a high return of benefit for diagnosing disease. In the veterinary and medical professions, workers have the potential for higher levels of exposure due to repeated usage on patients. To minimize the risk, only essential personnel should be in the room. If possible sedation or anesthesia can minimize the restraint necessary for the pet.

It is essential for the technician to be wearing a lead apron and gloves (see Figure 18–6). In addition, thyroid collars, worn around the neck, and lead glasses are recommended. The radiograph machine has a **collimator** which restricts the primary beam to the area in question. It should always be smaller than the cassette being used. This technique minimizes the amount of scatter radiation to which workers are exposed. Workers are also required to wear a **dosimetry** device on the outside of the protective lead apron. This individually identified badge tracks the exposure of each worker. OSHA establishes safe ranges for this type of exposure.

Anesthesia

Anesthesia is another potential danger for employees. The waste anesthetic gas has potential risks for the kidneys, liver, and fertility, so attempts are made to minimize the levels in the surgery room. Levels of anesthetic gas below the ability of humans to smell are potentially dangerous. Before starting surgery, the anesthesia machine should be checked for leaks. This is a simple task that should be part of the standard routine. Endotracheal tubes that deliver the anesthetic to the patient should have an inflatable cuff preventing leakage from the animal into the environment. Some type of scavenging system should be in place. This scavenging system can be a specialized charcoal absorbent canister or a fan system that pumps waste gas out of the room. Additionally, using the lowest flow of gas appropriate to the circumstances minimizes the potential exposure. Often compressed oxygen tanks are used; these need to be secured to prevent accidental tipping (Figure 20–9). A fallen tank with a broken valve can become a dangerous projectile.

Safety Concerns during Pregnancy

Anesthetic gases have been linked to health risks in pregnant workers. Many of the other health risks addressed pose an even greater threat to a developing fetus. Physical limitations change over the course of the pregnancy as well. Certain drugs such as prostaglandins and chemotherapy drugs also have increased risks for the fetus. It is important for pregnant workers to communicate their health status with employers and coworkers as

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FIGURE 20–9 Oxygen tanks need to be properly secured.

early as possible to ensure that proper precautions are taken. Zoonotic diseases such as toxoplasmosis from cat feces are also of concern for expectant employees. Standard use of latex gloves and frequent hand washing are essential for maintaining health.

Zoonosis

Chapter 17 offers a thorough discussion of zoonosis and the safety risks for veterinary technicians. Toxoplasmosis is just one of the zoonotic diseases addressed in Chapter 17. Veterinarians, technicians, and the entire staff need to be aware of these potential risks. Having an awareness of the potential threat and following strict protocols can prevent transmission of disease. For many of the infectious diseases, strict attention to sanitation and wearing protective gloves are adequate for prevention. Veterinary personnel are at a higher risk for being exposed to rabies since the infected animals are often brought to a veterinarian for attention. Many veterinary personnel receive preexposure immunization so that they have adequate immunity in the event of exposure. All personnel need to be aware of potential threats especially around food and drink. Proper hand washing is critical prior to handling any items being ingested, and all food and drink should be restricted to a dedicated eating area. It is inappropriate to have food or open drink containers in areas of the veterinary clinic where contamination may occur.

Fire

Whether at home, on the farm, or in the workplace, fire prevention is an important responsibility for all veterinary personnel. Veterinary offices have increased safety concerns as they contain flammable liquids such as alcohol and compressed sources of oxygen. The basic principles of fire prevention hold true for home, farm, and office. Proper storage of oxygen canisters and chemicals minimizes risks. Avoiding overloading of outlets can help to prevent electrical fires. Proper installation and maintenance of smoke and carbon monoxide detectors provides early notification if a fire does begin (Figure 20–10). Having properly inspected and maintained fire extinguishers easily accessible is critical for extinguishing a simple fire. Getting everyone out of the building safely and contacting the fire department is more important than trying to use a fire extinguisher on an out-of-control blaze. Having properly labeled exits is extremely helpful in emergency situations.

A

B

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FIGURE 20–10 Fire extinguishers and smoke alarms are essential for fire safety.

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SUMMARY

Whether performing veterinary procedures or maintaining a safe work environment, working as a team increases the likelihood of success. All members of the staff have a responsibility for keeping the workplace safe and protecting the health of both themselves and their coworkers.

REVIEW QUESTIONS

1. Define the following terms.

   lacerations
   Occupational Safety and Health Administration (OSHA)
   Material Safety Data Sheets (MSDS)
   formalin
   collimator
   dosimetry

2. What year was OSHA established?
3. Which size leash is more appropriate for a visit to the veterinary office, short or long?
4. Should you approach a horse from behind?
5. Should veterinarians and handlers work from the same or opposing sides of a large animal?
6. True or False. Muzzles are a good means of disciplining a dog.
7. Describe one means of restraining a cat in order to prevent bites and scratches?
8. While lifting heavy objects, should the knees be bent or straight?
9. Where should used needles be disposed of?
10. True or False. Veterinarians should cut toward themselves during surgical procedures.
11. True or False. Texting while driving is encouraged to make a veterinary practice more efficient.
12. What piece of safety equipment is essential during dental cleanings?
13. Which entity establishes the safe usage range for radiation?
14. True or False. Some veterinary practices use preexposure vaccines.
15. Should veterinary clinics provide access for employees to examine MSDA sheets.

ACTIVITIES

1. Prepare a report on OSHA requirements for veterinary clinics.
2. Pretend you are beginning employment at a veterinary practice. Explore foot protection options such as steel-toed shoes on the Internet.
3. Look for sharps containers over a week's period of time. List all the places they were seen. Examples can be such places as restrooms and school nurse's offices.
4. Find an MSDS for a product. Note the volume of information available.
5. Research your state's laws concerning cell phone use while driving.

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CHAPTER 21

Careers and Decision Making in Veterinary Science

Objectives

Upon completion of this chapter, you should be able to:

- Identify various career pathways for veterinary professionals in clinical, academic, and public health settings.
- Explain the educational requirements for a variety of veterinary careers.
- Consider necessary factors in making informed decisions in the veterinary care of production animals.
- Contrast the decision-making process in companion animals to that in production animals.

Key Terms

private practitioner	diplomate	break-even point	euthanasia
mixed animal practice	referral practice	decision tree	grief
veterinary specialist	veterinary technician	treatment protocol	
intern	veterinary assistant	management team	

Introduction

Veterinary science careers segment into three areas: veterinary medicine, veterinary technician/assistant, and veterinary specialties. Veterinary medical degrees, referred to as professional degrees (Veterinary Medical Doctor [VMD] and Doctor of Veterinary Medicine [DVM]), prepare individuals for the practice of veterinary medicine. Students selecting a school of veterinary medicine must first successfully complete a bachelor of science degree in a related field, such as animal science, biology, or pre-medicine. Many students also seek advanced degrees prior to admission to a veterinary medicine program. The career outlook for veterinarians remains positive. As discretionary income rises, people are more willing to spend money on veterinary care for companion animals. Further, demand for veterinarians with specialties continues to increase, especially in metropolitan areas. On the other hand, rural practitioners willing to treat both large and small animals are in need, because most veterinarians prefer to work in suburban and urban locales with regularly scheduled work hours.

In this chapter, we will present a series of career profiles to describe the educational experience and daily responsibilities that various veterinary practitioners can expect to encounter in their career pathways. You will see that veterinarians are required to make important decisions every day with their clients. Ultimately, the client makes the final decision. The veterinarian plays a critical role in guiding clients, helping them to make an informed decision. In this chapter, we will also show how that process can vary dramatically for situations dealing with production animals and companion animals.

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A Day in the Life

Some Days You Laugh, Some Days You Cry . . .

As a veterinarian, my personal experiences influence my decision-making process. I base my judgment on the successes and failures of the past. Several years ago, I was presented with a 20-year-old cat that had a large tumor growing on its right shoulder. The tumor had been present for several months but had recently grown rapidly. The skin on the surface of the tumor had deteriorated and was now oozing blood. The margins of the tumor were not well defined, and it invaded the deeper tissues.

I did not have a biopsy evaluation of the tumor, but I presumed that it was malignant. It had many classic characteristics of a malignancy: growing rapidly, not encapsulated, invading the deep tissues, and ulcerated on the surface. I discussed my concerns with the owners. The picture was bleak. The only option that I had for treatment was to amputate the leg. The tumor was too invasive to salvage a functional limb. My concern was that our patient was very old and had a cancer.

I explained that I see very few cats make it to 20 years of age. This was going to be a major surgery and there was always the possibility that other disease conditions could be developing. My fear was that we were going to spend the money on surgery and the result might not be favorable.

I discussed four options with the owners. The first option was not acceptable to any of us. Leaving the tumor untreated was just not practical because of the way the surface was oozing. Secondary infection was likely to occur. A second option was to do a blood chemistry profile to evaluate the cat's overall health. My fear was that at 20 years of age it was quite possible that the cat could have been developing kidney failure, hyperthyroidism, or a long list of age-related diseases. If the tests came back normal, we could proceed with the surgery. A third option was to just take the chance and do the surgery. With this option, we needed to assume the risk that the surgery could make other underlying conditions worse or that, realistically, the cat might fail to survive surgery.

The fourth option is always difficult to discuss. I felt that I had to mention euthanasia as an option. I wanted the clients to understand that I was making no guarantees about the success of any treatment option we chose. They had to realize that they might be spending money on a surgery where the outcome was going to be poor. I did not even know if the cat would be able to walk after the surgery. Young cats do well following amputation, but this cat was already 20 years old.

I am often asked what I would do in the client's position. My answer is always based on the relevant medical facts. I cannot put myself into the position of having 20 years of emotional attachment to the animal. I honestly felt in this case that euthanasia was the option that I would have chosen. I felt that the risks outweighed the benefits.

I had an open and frank discussion with the owners and in the end they elected to have surgery. They wanted to give the cat a chance, no matter what, so they did not have the blood tests performed. I was nervous about the surgery, but excited to give the cat a chance. The surgery went very well, and the cat recovered better than I had expected. Ten days later the cat returned for suture removal and the owners were quite pleased. The cat had adapted to three legs without any trouble and continued to jump onto a window sill, where it could enjoy the view.

I kept in touch with the owners, to see how the cat was doing. It continued to do well for almost two years after the surgery. I made a house call at that point, when the cat's general health had deteriorated severely. It was no longer eating and had lost a significant amount of weight. The time had finally come. The owners tearfully elected to put the cat to sleep. As sad as the moment was, we all rejoiced that the cat had survived two more years of enjoyable life following surgery.

This decision worked well for these owners. The risks of the procedure were high, but the gamble proved successful. However, not everyone would have made this decision. Clients must put an economic value on the emotional attachment to the pet.

In food animal medicine, the decision-making process differs greatly. Every day the client and I make decisions that we hope will reward the client financially. Last week I visited a young Amish farmer who had recently begun to milk cows. He had purchased cattle over the past several months from three different sources. He called because a number of cattle were not eating well.

The diagnosis was quite simple in this case. The sick cattle ran high fevers, breathed heavily, and coughed. When I listened to their lungs, it was obvious that the animals had contracted pneumonia.

His biosecurity had failed. The weather had been variable, with very cold mornings and hot afternoons. The barn was not well ventilated and likely became quite warm and humid during several afternoons. Moreover, the cattle from all three sources commingled within the one barn. The farmer did not investigate animal history

continues

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A Day in the Life continued

before purchasing any of the cattle, but he was told that they were vaccinated. Upon investigation, he discovered that the vaccination history was doubtful and at most the last group had received one shot of a killed vaccine. Those animals never received a booster shot.

The treatment options were simple. First, we began treating the cattle with antibiotics and medications to relieve the fevers. The major decision concerned whether to vaccinate the remaining herd. I had to weigh the considerations. The first choice was to quickly vaccinate the remainder of the herd in the hope that they had been adequately vaccinated and a booster would provide a quick memory response. The second option was to not vaccinate. If the animals were already incubating the disease, vaccination would add to the stress of the animal and might actually make the outbreak worse. If they were never vaccinated, this single shot of killed vaccine would not provide adequate protection anyway.

Potential costs were associated with both options. By vaccinating, the farmer had the cost associated with purchasing the vaccine, the short-term loss of productivity that often occurs immediately following vaccination, and the potential loss associated with making the disease worse. By not vaccinating, the farmer did not have to spend any additional cash. However, if this option failed, a respiratory outbreak throughout the entire herd would cost even more, with medications, loss of productivity in the ill animals, and potentially death of animals.

We discussed the options and elected to vaccinate the remainder of the herd. A week later, our decision seemingly proved correct. No new cases developed in the remainder of the herd. The disease had been restricted to a group of seven animals that were purchased from one location. It would seem that these animals were not properly vaccinated prior to purchase or were exposed to an organism to which they did not have immunity. Veterinarians are responsible for helping farmers to make economic decisions that can affect their financial success. Often veterinarians must rely on their experience to guide the decision-making process.

One of the most difficult decisions in veterinary medicine involves euthanasia. I have talked to many people who had a desire to become a veterinarian but could not come to grips with putting an animal to sleep. Euthanasia is a difficult part of the job, often very sad and never easy. However, it is a crucial part of my work and often relieves an animal of the pain associated with a serious illness.

Over the years, I have put many animals to sleep. To this day, times exist when the task can be a tremendous struggle. Just a few months ago, I had the unpleasant experience of euthanizing one of my partner's dogs. Ali was a sweet 12-year-old golden retriever that had developed a cancer of the bone marrow, called leukemia. I had known Ali since she was a pup, and she often visited the clinic. Every time I saw her, she would roll over slightly, wagging her tail. She had trained me to pet her belly every time we met. After Ali was diagnosed, the veterinarians at our clinic aggressively treated her condition, but we knew that we were losing ground.

One evening I received the call that the time had come. We had all been through the process many times with many people, but this was going to be tough. I was going to euthanize a dog that I loved, for close friends. I felt their pain and knew my own as I scratched Ali's belly before we began. I tried to be strong for the family but could not talk much because there was a huge lump in my throat. I inserted a needle into a vein on her front leg and then steadily injected the medication. The medication sent Ali into a deep state of anesthesia and then reached a point of overdose, causing her heart to stop beating. Thankfully the process went very smoothly. It was a tough evening and a somber next day at work as well. We all felt the loss.

CAREER PROFILES

Objective

- Identify Various Career Pathways for Veterinary Professionals in Clinical, Academic, and Public Health Settings

Private Practitioner

Dr. James Lawhead, a **private practitioner** in Central Pennsylvania, graduated from the University of Pennsylvania School of Veterinary Medicine in 1987. Following graduation, he was employed as an associate veterinarian in a **mixed animal practice**. The practice provides service to 250 dairy farms. The primary emphasis of the practice is dairy cattle, but he also works on beef cattle, sheep, goats, pigs, and horses (Figure 21–1). In addition, Dr. Lawhead spends approximately one third of his time in the small animal clinic seeing primarily dog and cat patients.

When Dr. Lawhead joined the practice, two partners employed him. These two veterinarians were extremely supportive and patient as he gained experience in private practice. They helped to train Dr. Lawhead, who is now a partner as well, and the practice has now grown to employ eight veterinarians.

Dr. Lawhead experiences a wide variety of situations in his career. As a mixed practitioner, he finds value in each aspect of his job. The work with dairy

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FIGURE 21–1 Dr. Lawhead performing a displaced abomasum surgery on a cow.


Courtesy of Dr. Abby Maxson Sage

FIGURE 21–2 Dr. Sage, with the assistance of Dr. Carol Ormund, is performing an ultrasound examination on a horse.

farmers proves very rewarding. While working with the same clients for 20 years, a special relationship between Dr. Lawhead and his clients has developed, because both the veterinarian and farmer strive to maximize productivity and profitability. Dr. Lawhead finds that process challenging and stimulating. Dr. Lawhead has a special interest in nutrition and works closely with many clients on their management practices.

The small animal portion of the profession also offers challenges and rewards. Although similar goals exist for maintaining the health of all animals, the companion animal portion of his job allows him to work on challenging medical and surgical cases. Further, the group practice environment is rewarding and allows for collaboration on cases.

Private practice does have its drawbacks. Dr. Lawhead is often on call, and frequently is called to attend to patients at night. Even so, Dr. Lawhead must be at work the next day. Fortunately, the on-call responsibility is shared equally in his multi-veterinarian practice. The workday varies and is unpredictable. Dr. Lawhead's workday often extends well beyond 12 hours.

Academia

Dr. Abby Maxson Sage is a 1987 graduate of the University of Pennsylvania School of Veterinary Medicine. Following her graduation, Dr. Sage elected to participate in advanced training in an internship and residency, also at the University of Pennsylvania. After the completion of her residency, Dr. Sage accepted teaching and research responsibilities at the University of Pennsylvania. Following extensive training, work, research, and testing, Dr. Sage gained certification as a specialist in the American College of Veterinary Internal Medicine. This honor is given only to the most highly trained **veterinary specialists**. In 1997 Dr. Sage joined the team at the University of Minnesota School of Veterinary Medicine as an assistant clinical specialist.

Dr. Sage carries a variety of responsibilities in her career (Figure 21–2). In addition to admitting animals to the clinic, she uses these cases as teaching tools in training veterinary students. She also lectures to students in the classroom setting. At other times, Dr. Sage performs research on equine-related topics.

Public Health Veterinarian

Dr. Cathy Hanlon is currently a veterinary medical officer in the Rabies Section at the Centers for Disease Control and Prevention (CDC) in Atlanta, Georgia. The CDC is the lead agency for disease outbreak investigations into such concerns as Ebola virus, hantavirus, Lassa fever, foodborne and waterborne outbreaks, suspected bioterrorism attacks, and rabies. Dr. Hanlon received a bachelor's degree in animal science at Rutgers University and a veterinary degree at the University of Pennsylvania in 1987. She subsequently received a doctorate in comparative medicine at the University of Pennsylvania. Her research studied a new type of rabies vaccine used for oral vaccination of raccoons. The vaccine took more than 10 years of work to develop. It is now being widely used to contain the spread of raccoon rabies in the eastern United States.

As a rabies researcher and public health professional, Dr. Hanlon engages in a wide range of activities. Her work includes field investigations involving species such as raccoons, skunks, foxes, dogs, and bats, in the United States as well as other countries (Figure 21–3). Dr. Hanlon also performs laboratory work, including diagnosis and development of new

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Courtesy of Dr. Cathy Hanlon.

FIGURE 21–3 Dr. Hanlon working with a sedated raccoon that had been captured in a live trap.

methods for prevention of rabies, and responds to questions about rabies from other public health professionals and the public.

Veterinary Surgeon

Dr. David Sweet graduated in 1989 from the University of Pennsylvania School of Veterinary Medicine. Following his graduation, Dr. Sweet pursued further training as an **intern** at the University of Pennsylvania and a surgical residency at the North Carolina State University. Following that training, Dr. Sweet accepted an instructorship at Washington State University and returned to the University of Pennsylvania as an assistant professor. During his training, Dr. Sweet met the rigorous qualifications necessary to become a **diplomate** in the American College of Veterinary Surgeons. This honor earned by Dr. Sweet distinguishes him as a surgical specialist.

Dr. Sweet works at a **referral practice**. The center employs veterinary specialists in many fields, including surgery. The veterinary practice provides a service that allows private practitioners to refer difficult cases for more specialized treatment. Dr. Sweet performs both soft tissue and orthopedic surgery (Figure 21–4). He performs many complicated and difficult surgeries. As with all veterinarians, he attends continuing education conferences to learn new procedures and information.

Courtesy of Dr. David Sweet.

FIGURE 21–4 Dr. David Sweet, with assistance of registered veterinary technician Michele Antoch, examines a surgical incision on a dog.

EDUCATIONAL REQUIREMENTS FOR VETERINARY CAREERS

Objective

- Explain the Educational Requirements for a Variety of Veterinary Careers

Veterinary technicians must complete either a two-year associate degree or four-year bachelor of science degree program. Further, they must pass a state licensing exam. The number of institutions offering such coursework has grown significantly over the past several years. **Veterinary assistants** are not required to complete any formal classes. However, increasing numbers of technical schools and community colleges offer veterinary assistant programs.

Both technicians and assistants help the veterinary practice by performing a wide range of tasks (Figure 21–5). These individuals may greet patients, keep records, bill clients, and restrain animals, as well as feed, exercise, and provide basic health care for patients. The responsibilities vary from employer to employer with technicians performing more technical duties. Numbers of available jobs for veterinary assistants and technicians will continue to grow with the demand for veterinarians.

Level of degree separates veterinary assistants from veterinary specialists. Almost 30 programs grant degrees in veterinary specialties. Most of these programs deliver master's and doctorate degrees, although a few award associate and bachelor's degrees. Specialists may provide such supportive services as nutrition counseling, ration balancing, or radiology expertise to veterinary clinics. Conversely, other specialists may be employed in academia, where they perform research or extension duties in veterinary-related

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FIGURE 21–5 A veterinary assistant is shown preparing a dog for surgery.

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FIGURE 21–6 Dr. Lawrence Hutchinson is seen working on his computer as part of his job as an extension veterinarian.

areas (Figure 21–6). Further, specialists may seek employment as pharmacologists for drug companies or experts for agricultural businesses. Career opportunities remain positive for those seeking veterinary specialty degrees.

Students are encouraged to research employment in all veterinary-related fields. Speaking with an agricultural education instructor, visiting the guidance or career placement department, interviewing local professionals employed in veterinary science–related fields, and searching the Internet for information can provide an excellent start. From there, postsecondary school visitations may be in order. Best wishes in exploring the world of veterinary science.

DECISION MAKING IN VETERINARY PRACTICE

Objectives

- Consider Necessary Factors in Making Informed Decisions in the Veterinary Care of Production Animals
- Contrast the Decision-Making Process in Companion Animals to That in Production Animals

Primarily, the decisions made within farm settings revolve around the economic return. Farmers raise animals as a source of income. Their desires are to maximize the health and productivity of these animals. In return, the profitability of the farms is maximized.

Numerous questions arise once an animal becomes ill. Often multiple treatment options exist. The decisions must be based on an evaluation of the cost, the likely success, and the cost of the treatment if there is a failure.

At times the calculations on the cost of treatment can be straightforward. Consider a dairy cow that has developed a severe case of foot rot. In this infectious disease, bacteria invade the skin between the claws of the hoof. If caught early, topical treatment with copper sulfate may relieve the condition. If the entire foot begins to swell, injectable antibiotics are often warranted. The disease can cause a severe lameness, which greatly hinders the productivity of the cow.

Many foot rot treatments are available. For simplicity, this discussion will evaluate two. The options are to use an injectable penicillin (cost of medication per day = $2.64) or ceftiofur (cost of medication per day = $18.20). Assuming that both medications have a similar effectiveness, it would appear initially that penicillin would be the better option. For a standard three-day treatment, the cost for penicillin would be $7.92 and for ceftiofur, $54.60. Further analysis shows that ceftiofur does not penetrate into the milk and does not require the milk from the treated cow to be discarded. Penicillin requires that the milk be discarded for at least two days following the last treatment to prevent antibiotic residue in the milk. Therefore milk will have to be discarded for at least five days (three days of treatment plus an additional two). The value of the milk must then be calculated.

The value of the milk becomes the variable that influences the final decision. If the dairy cow was in her dry period and not producing milk, the decision would be easy—use penicillin. Intuitively, it would seem that a cow producing 100 lb of milk per day would be treated with ceftiofur. The farmer then raises the question; At what level of production does it become economical to use ceftiofur?

Two variables must be considered in this decision: the amount and value of milk being produced.

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In general, farmers are paid for the number of hundredweights (cwt), or number of 100-lb units, of milk they produce. At the time this text was written, milk prices had dropped to almost $22.00 per hundredweight. Compare the two treatment options as follows:

Total cost of ceftiofur: $54.60

Total cost of penicillin: $7.92

Difference: $46.68

Ceftiofur becomes the treatment of choice whenever the value of the milk produced in the five-day period is greater than $46.68.

$46.68 ÷ $22.00/cwt = 2.12 cwt or 212 lb

212 lb in 5 days = 42.4 lb/day

These calculations show that 42.4 lb of milk per day is the financial **break-even point**. At that milk weight, the cost of each treatment is identical. When milk drops below that level, penicillin becomes more economical. At any higher level of production, ceftiofur becomes the better option.

These calculations are very straightforward for a given course of treatment and a given milk price. Variations arise and there can be differences in the length of treatment, level of production, and the value of milk. Neither the farmer nor the veterinarian is anxious to perform such calculations with each change. Spreadsheet programs on computers provide an excellent means of accounting for these variations. Once the program is established, any of the variables can be changed easily. The computer then quickly performs the calculations.

This demonstration assumed an equal success with each treatment. Often success is one of the major variables that make the decision-making process difficult. Situations arise in which one treatment has a higher success rate than another. If the more successful treatment happens to be the cheaper option, the decision is easy. Generally, the more successful treatment also has a higher associated cost.

One method of calculation used to aid in such processes is called **decision tree** analysis. This method uses the percentage of success and the cost of the two treatments to analyze which procedure will provide the most benefit overall. The decision tree analysis does not attempt to predict the outcome of an individual case. With this analysis method, the more cases that are treated, the more likely the results will follow the prediction.

This method uses probabilities to make the prediction. A probability is the chance or likelihood that an event will occur. For example, when flipping a coin, there is a 50% chance that it will show heads. In a small series of flips, the coin may consistently show tails. The results do not make the probability incorrect. The more coin tosses that are performed, the more likely it will be that the number of heads and tails will be similar. During the series of coin tosses, there will be streaks of multiple head tosses, as well as tails.

When making decisions about treatment, probabilities are helpful. However, when dealing with an individual, these probabilities can become meaningless. For example, the author's practice uses approximately 6,000 doses of bovine respiratory vaccine every fall. Typically, one or two cows will develop an anaphylactic reaction as a result of the vaccination. This makes the probability of a reaction approximately 1 in 3,000. When a large herd uses the vaccine, the risk is very manageable. Even with 300 cows, the chance is not great of having a cow react. If a client has only one cow and it happens to be the one that reacts, the overall risk was no higher. Unfortunately, the client will have the impression that the vaccine is extremely risky. The client's perception may be that the risk is 100%.

Decision tree analysis uses this concept of probabilities to predict which treatment method is going to be most economically beneficial when used in large numbers of cases. Decision trees can become very complicated as the options and branches increase. A simple example is provided to illustrate the concept.

The veterinarian is called to a farm that is having a herd mastitis problem. The veterinarian cultures a number of cows and determines that the problem is consistently an infection with *Staphylococcus aureus*. The veterinarian detects this organism in 20 cows that are averaging 60 lb of milk. The farmer must get the mastitis problem under control or risk losing the current market to sell milk. This organism is very difficult to treat and is contagious among cows.

The veterinarian offers two different treatment protocols to the farmer. Option one involves a standard treatment with antibiotics for three days and has an average success rate of 30%. The second treatment protocol uses a series of three treatments with a new, more expensive antibiotic. This raises the success to almost 50%. The farmer asks the veterinarian which option he or she should choose.

The veterinarian calculates the cost of the two treatments. Treatment one with medication and discarded milk costs $79.75. Treatment two costs a total of $157.70. Due to the severity of the problem, the cows will be cured and saved in the herd, or culled if the treatment fails. The value of the milking cow is placed at $2,400. The value of a cull cow is averaging $1,500.

These numbers are inserted into a simple decision tree. The tree has two initial branches for the two different treatment protocols. Each branch then has another two branches: a successful treatment and a treatment failure. The probability of success is placed on each branch, along with the value of the outcome.

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The value of each branch is then calculated, with the cost of treatment being subtracted from the value of the animal. This number is then multiplied by the success of the treatment. The values for the success and failure of each treatment are added together to calculate the final value for each treatment protocol. The numbers for each treatment protocol can then be compared to evaluate which has the best outlook for financial success for the farmer.

Referring to Figure 21–7, the calculations for the two treatments are:

(Value of successful treatment – Cost of treatment) × Percentage of success + (Value of treatment failure – Cost of treatment) × Percentage of failure

Treatment One (2,400 – 79.75) × 30% + (1,500 – 79.75) × 70%

2,320.25 × 30% + 1,420.25 × 70%

696.08 + 994.18

$1,690.26 = Outcome of Treatment One

Treatment Two (2,400 – 157.70) × 50% + (1,500 – 157.70) × 50%

2,242.30 × 50% + 1,342.30 × 50%

1,121.15 + 671.15

$1,792.30 = Outcome of Treatment Two

Comparing the two values, treatment two provides a small economic benefit. The decision tree takes into account not only the cost of the treatment but also the differences in success.

In this example, clinical studies have been performed that provide the expected success rate of each treatment. The success rate on the given farm may not be identical to that of the controlled studies. In addition, changes may occur in the value of cattle and the cost of medications. Decision trees can be calculated on a spreadsheet computer program. Once programmed, variables can be changed to determine if the same outcome is correct. For example, the success rate of treatment two can be lowered to determine at what level it is still the more economical decision. Decision trees can be made much more complex than this example. Computers make the complicated decision trees practical to design and evaluate.

Decision trees provide an excellent scientific method for evaluating different **treatment protocols**. On the farm the veterinarian often lacks the detailed numbers to make the predictions of success and failure. Each farm situation must be evaluated to determine if a change of treatment is warranted. The results of controlled studies provide the foundation for the decision, but this information must be judged in a given setting.

For example, increasing the milking frequency of dairy cattle from twice to three times daily generally increases the milk output. This is often in the range of 6 to 8 lb of milk per cow per day. The change does not require a large investment, except for the cost of labor and running the milking equipment. In general the milk response is quite predictable, and straightforward calculations can be performed to determine if it is of economic value.

Once this change is implemented on a dairy farm, the success needs to be monitored. The author had the experience on one farm where the transition to three-times-a-day milking did not provide the expected results of an increased milk yield of 15%. Further evaluation of the individual farm determined that the milking parlor was very inefficient. By adding the extra milking, the cattle were forced to stand waiting for milking for long periods during the day. This kept them from resting, kept them from their ration, and

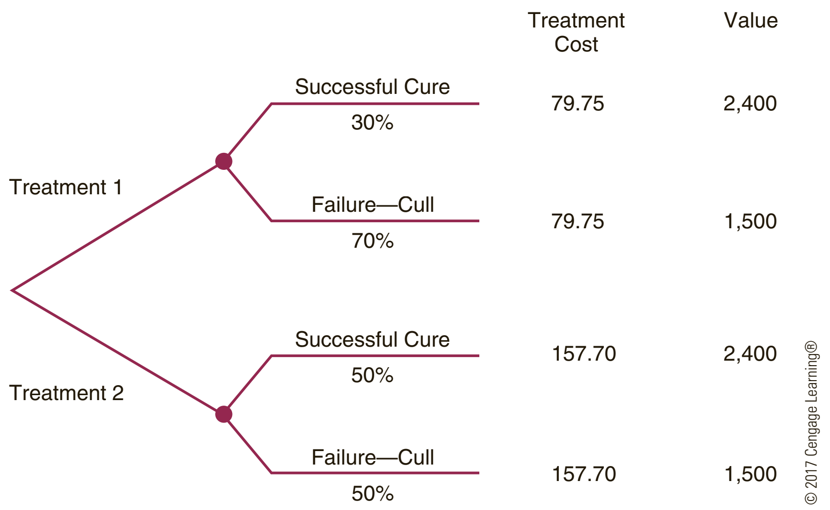

FIGURE 21–7 A decision tree.

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increased lameness problems. While the vast majority of farms benefit from such a change, this farm did not. The underlying causes were determined and were not easily corrected. This farm returned to twice-a-day milking.

Decision making on farms can be very complicated and has led to the development of **management teams**. Consider that a dairy farmer is looking to expand from 300 to 800 cows. This is not a simple decision. The farmer's goal is to increase profitability but a tremendous number of variables occur in this expansion. Rather than making an individual decision, the farmer enlists the help of others that could have input into this decision. For example, the management team might include the following members:

- Banker: Usually expansions require borrowing a significant amount of money and the banker can help determine if the expansion will be profitable.
- Nutritionist: To maintain profitability proper nutrition will be crucial, and the farmer must be prepared to handle the increased number of cows.
- Crops consultant: The crops consultant will work with the farmer to ensure that the soil is highly fertile, and help to plan cropping and weed control strategies.
- Veterinarian: The veterinarian will be involved in the health and nutritional concerns of the expansion. Biosecurity and cow comfort are two areas of high concern.
- Extension agent: Extension agents often have a wide knowledge base that helps to coordinate the entire team setting. They also offer contacts with other specialists from universities.
- Other specialists such as agricultural engineers and economic specialists: These specialists can offer tremendous input into barn and ventilation design and further insights into evaluating the economic concerns.

Although not every team member may attend every meeting, the benefit of this approach is to have the team all gathered to discuss management changes. In this way, multiple viewpoints are able to be presented and discussed. Each member's experiences are helpful in guiding the decision-making process. Ultimately, the farmer has the final say. The farmer must evaluate the input from all the members and finalize any decisions.

The management team tries to establish a plan, and then must monitor the farm to evaluate the outcome. Typically, the plan must include a goal and a deadline. Consider the example of a farm having a high mortality in young calves. On average the farmer is losing about 15% of heifers to diarrhea problems in the first month of life. The management team determines three major problems:

1. Calves are housed in a group pen.
2. No specific dry cow ration is in place.
3. Calves are not always fed colostrum within a reasonable period of time.

It would be easy to come up with a general plan, in which the farmer would keep the group pen cleaner, feed the dry cows better, and improve the colostrum feeding. Unfortunately, all of these goals are open ended and not easily evaluated.

The management team comes up with a very specific plan in response to each of the defined problems.

1. Rather than housing calves in a group pen, the farmer will switch to the use of individual calf hutches. The goal is that within the next two weeks, a pad of stone for proper drainage will be established and calf hutches will be purchased.
2. The nutritionist will calculate a dry cow ration based on forage analyses and the farmer will begin feeding that diet. Again the group decides on a two-week deadline.
3. To correct the third problem, the team establishes a standard operating procedure (SOP) in writing so that all the workers on the farm can easily follow the directions. The protocol establishes that all calves will be fed 4 quarts of colostrum within four hours of birth. In addition each calf will be given a vaccine to improve passive immunity. Each calf will also have its navel dipped with iodine and will be moved to a clean calf hutch. A monitoring system is established so that all of this information will be recorded for each calf as it is born. A goal is established that 90% of calves will be successfully treated in this manner. The team then sets a goal of having less than 5% death loss in calves younger than one month of age.

When the management team meets one month later, the records are analyzed to determine the success of the plan. It is easy for the team to determine if the hutches have been put into use and if the ration changes have been implemented. The team must also review the records to see if the SOP is being followed and if the initial death loss problem has been improved. If the goals and protocol have been met, the team may decide to monitor the situation or actually establish a more stringent goal (e.g., less than 2% death loss). If everything has been followed and the death loss has not been improved, the team must establish a plan to further improve the situation. This might include diagnostic tests on the calves, or improving the calving facility.

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Production animals such as cattle, sheep, goats, and pigs have an inherent value based on the product they are producing. This value may be in the offspring, milk, or meat they can produce. This allows for specific numbers to be used in the calculations determining the economic return. Decision making in horses can also be based on economic return. The value of the horse is evaluated based on the specific use of each animal. The expected success of a racehorse can greatly influence the decision-making process in treating a significant illness or lameness. Likewise, the value of a foal can greatly influence decisions on treating a brood mare or breeding stallion.

Many horses are used solely for pleasure purposes. The decision-making process in these animals is very similar to that in companion animals. Decisions in companion animals, such as dogs and cats, often are based much less on economics and much more on emotional attachment. This is not to say that economics does not play a role in the decision. Owners must place a value on the emotional attachment to their pets. Treatment may be too costly for an owner to afford. Health insurance for pets has yet to gain widespread acceptance, so owners are usually responsible for paying for any treatment.

Just as in the care of production animals, several treatment options may exist for a given condition. For example, a severe fracture may best be treated with a bone plate and screws. This method provides the most secure repair and has the highest likelihood of success. Unfortunately, this option is also quite costly; thus the owners may elect to try a splint or cast, instead. Although the likelihood of success is not as great, the owners are making an effort to give the animal a chance using a less expensive approach. In most situations, pets are strictly companions, and the only return on the owners' investment is more quality time together with their pets.

The veterinary profession uses euthanasia (i.e., "putting an animal to sleep") as a tool in providing relief to hopelessly injured, ill, or dying animals. **Euthanasia** (from the Greek for "easy death") is performed with an intravenous injection of an anesthetic. The medication is given in such high levels that it is fatal. The animal will feel the initial needle insertion into the vein, but the remainder of the procedure proves painless.

The decision to use euthanasia is always a difficult one. Strong emotional attachment to pets exists in our society. Often owners refer to their pets as family. Whether the decision becomes necessary for an elderly pet with organ failure or a young animal with severe trauma, the natural reaction is to want more time with a loved one.

The decision often comes down to economics and the cost of treatment. The likelihood that the animal can recover and the discomfort that the animal faces also play a large role in the decision to use euthanasia. A term that is used to guide owners in this decision is *quality of life*. The owners are asked to evaluate the pet at home and judge whether the quality of life is up to their standard. This is not a clearly defined term. Owners must decide what it means to them and their pets.

Consider an elderly dog with such severe arthritis, secondary to hip dysplasia, that it can no longer rise on its own. The animal is developing sores from lying too long and is soiling its skin and coat with urine and feces. The animal appears bright otherwise and is still eating. Whether euthanasia is essential in this case is not clear-cut. This animal's quality of life has definitely declined. Some owners will feel that the chronic pain and the dog's inability to rise warrant euthanasia. Other owners would see the dog's outward appearances, see it wag its tail, and decide that the dog should not be put to sleep.

The veterinarian's role in the process is to educate the owners on their pets' conditions. Many aspects of a given disease can influence the final decision. These factors include the cost of treatments, the chances of success, the commitment required by the owners, and the discomfort that the pets may feel. The veterinarian can provide medical answers about an animal's condition, but ultimately the owner must make the final decision. The decision to euthanize is often the most difficult decision that pet owners will make.

This process is unique for every individual. At times, owners lack the support of other family members and friends who may not understand the strong emotional attachment that builds between a pet and its owner. The individual facing the loss must understand that grief is a natural occurrence.

Emotionally, almost all owners feel sadness or sorrow over the loss of their pet. In addition, the owners may experience several other emotions. Some people feel an entire range of emotions. Denial may be the first response when a life-threatening illness is diagnosed. The owners may not want to accept the fact that their pet is dying. Denial can progress into guilt. When the owners face the fact that their pet has died, they may begin to question whether they had done something wrong. The feeling of guilt may lead the owners to place the blame for their pet's problems on themselves. When owners experience denial and guilt, it is important for veterinarians to offer support and attempt to explain the medical facts surrounding the case.

Some owners externalize the blame and become angry. This anger can easily be directed at the veterinarian, who failed to save the pet. In the heat of the moment, the owners may make comments that they later understand are not realistic. The extreme pain

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associated with losing a pet can amplify feelings, making such a response possible.

The pain associated with this process can also lead to depression. This, in turn, can lead to a feeling of despair, preventing the owners from handling normal events in their lives. Individuals can experience any or all of these emotions, to any degree of severity. It is important to understand that **grief** is a normal process that varies with every individual. Each person handles the crisis in different ways.

It is very helpful to owners to find friends and family members who are supportive and willing to listen. It can also be quite helpful to talk about the feelings experienced. At some point the owners must recognize that grief is natural and that eventually the feelings will improve.

A major step in the process occurs when the individual obtains a new pet. It is important to recognize that a new pet is not designed to replace the previous one. The new pet will never be identical and has different personality traits. The new pet does not replace a beloved pet; it becomes a new addition to the family. A strong, loving relationship can develop with the new pet without losing the memories of the recently deceased pet.

The amount of time that elapses before an individual begins to desire a new pet varies. Some people feel the need almost immediately; they desire to have a new loved one to fill the loss in their lives. Others may require a much longer time or may never feel the need to have more pets. Each individual needs to pass through the grieving process at his or her own rate and decide when the time is right. It is improper to purchase a pet for others while they are grieving. People often do this in an attempt to help their friends or family members move on from the grief felt for their previous pets. Unfortunately, this can add to the guilt an owner feels for moving on without properly grieving. This decision is best left to each individual.

SUMMARY

Veterinary science careers segment into three areas: veterinary medicine, veterinary technician/assistant, and veterinary specialties. The veterinarian in private practice may work very long days, serve a mix of farm and companion animals, and play a critical role in guiding clients to informed decisions regarding their animals' health. Veterinarians working in academia may work with animals in a clinic, lecture in a classroom setting, and performs specialized research. Veterinarians in the public health arena may perform field research directed by government agencies to assess disease risks and outbreaks. Referral practices employ veterinary specialists in many fields and allow private practitioners to refer difficult cases for more specialized treatment, including surgery.

Veterinary technicians must complete either a two-year associate degree or four-year bachelor of science degree program, and pass a state licensing exam. Veterinary assistants are not required to complete any formal classes. Both technicians and assistants may perform a wide range of tasks, including greeting patients, keeping records, billing clients, restraining animals, and providing basic care for patients.

Veterinary specialists may graduate from an associate, bachelor's, master's, or doctoral degree program, and may provide such supportive services as nutrition counseling, ration balancing, or radiology expertise to veterinary clinics. They may also perform academic research, or work as pharmacologists or agricultural experts.

Veterinary decisions made in farm settings primarily revolve around the economic return. Some of the decision-making calculations are straightforward, such as finding a break-even point. More complex decisions might require a more complex analysis tool, such as a decision tree. When decision making on a farm becomes highly complicated and strategic, a management team can bring a variety of technical and financial expertise to the analysis.

The veterinary profession uses euthanasia to provide relief to dying animals. It is important for all veterinary professionals to understand that the loss of a pet, whether through euthanasia or natural death, is a loss of a loved one, and will initiate a grieving process for the client.

REVIEW QUESTIONS

1. Define the following terms:

   private practitioner
   mixed animal practice
   veterinary specialist
   intern
   diplomate
   referral practice
   veterinary technician
   veterinary assistant
   break-even point

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decision tree
treatment protocol
management team
euthanasia
grief

2. Name the two doctors of veterinary medicine degrees?
3. T or F Cats typically live to 20 years of age?
4. What is the drawback of private practice mentioned in the chapter?
5. Who may be art of a dairy management team?
6. ________ may be the first response when a life-threatening illness is diagnosed.
7. Public health veterinarians typically work for the ________.
8. Veterinary decisions on farms are primarily ________ decisions.
9. How long is the training for a veterinary technician?
10. T or F Grief is a natural process that occurs after euthanizing a dying animal.

ACTIVITIES

1. Research career opportunities in the veterinary medicine field available around your home location.
2. Interview varying professionals currently working in the veterinary field as to their responsibilities and prepare an oral report to share with classmates.
3. Investigate the costs of tuition at several schools of veterinary medicine.
4. Search for potential scholarships to support schooling in the veterinary professions.
5 Write a short essay about which field of veterinary medicine most interests you.

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GLOSSARY

A

abscess accumulation of fluid (pus) in a dead space between tissues containing bacteria, white blood cells, and dead tissue

active immunity disease resistance resulting from exposure of an animal to a pathogen through either disease contraction or vaccination

active transport process that allows the pumping of a substance into an area of higher concentration

acute sudden onset

Addison's disease condition characterized by low levels of cortisol along with lethargy, weakness, weight loss, poor appetite, vomiting, and diarrhea (also known as hypoadrenocorticism)

adipose tissue fat

alopecia baldness

anabolism cellular reactions that combine smaller molecules into larger ones

anaphylaxis generalized life-threatening allergic reaction

anemia low in red blood cells

anesthetize to sedate animals so they lack sensitivity or awareness

anestrus period when an animal is not cycling through estrus

anthrax bacterial infection with skin, intestinal, and respiratory forms

antibiotics drugs that fight bacterial infections

antibodies infection-fighting proteins

antigen any foreign material that is capable of stimulating an immune response

antimicrobial agent that hinders the growth of or kills microorganisms

antioxidant oxidation-inhibiting substance

antiseptics germicides that can be used on the skin of animals

appendicular skeleton skeletal portion consisting of limb bones

arrhythmia any change in rate, rhythm, or conduction within the heart

arteries vessels that transport blood away from the heart

arthritis disease condition in which the smooth lining of cartilage becomes rough and irregular

aseptic technique general practices used to minimize the risk of infection that may occur following surgery

ataxia uncoordinated muscle movement

atopy sensitization to foreign antigens

atrophy shrink

autoclave piece of equipment used to sterilize instruments with pressurized steam

autoimmune disease condition in which the body's immune systems destroys its own cells

autonomic system involuntary portion of the peripheral nervous system

axial skeleton skeletal portion consisting of skull, vertebrae, ribs, and sternum

azotemia elevation of both urea nitrogen and creatinine in the blood

B

bacteriostatic agent that slows the rate of growth of bacteria

band means of nonsurgical castration in which a band is placed above the testicles, thus cutting off the blood supply, causing atrophy

basement membrane collection of fibers that ties the epithelial layer to the underlying connective tissue

benign description of a tumor that is localized and will not spread to other areas of the body

biocontainment practices used to minimize the spread of disease if it is introduced onto the farm

biosecurity practices that protect herd health by preventing the introduction and spread of pathogens

bloat accumulation of gas in the rumen

bolt quick consumption of feed

borborygmi normal noise made within the intestinal tract as gas and fluid move through the tract (this is the noise that in humans is commonly described as stomach growling; singular is borborygmus)

botulism food poisoning resulting from a toxin-producing bacteria

break-even point point at which producer will not lose money considering the cost of procedure and value of animal

bronchodilators medications that open the airways

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brucellosis bacterial disease that causes abortions in cattle and flulike symptoms in humans (human presentation is called undulant fever)
buck male goat

C

calorie unit of measure that defines the energy contained within a food
cancer uncontrolled cell division
cardiac cycle one complete contraction and relaxation of the heart
cardiopulmonary resuscitation (CPR) procedure used to stimulate the heart to deliver oxygen to the lungs
carnivore animal that requires a meat-based diet
castration removal of testes
cat scratch fever bacterial disease resulting from a cat scratch, which causes soreness at the inflicted site, fever, and enlarged lymph nodes
catabolism cellular reactions that break larger molecules into smaller ones
caudal refers to the tail
central nervous system brain and spinal cord
centrifuge machine that spins substances such as blood to separate differing densities within the spun matter
cervical disk disease painful disease resulting from pressure of a cervical disk on the spinal cord
cesarean section surgical removal of a newborn
chemistry panel test that often evaluates blood sugar, electrolytes, protein, liver and pancreatic enzymes, bilirubin, and nitrogen-containing wastes
chronic long term
colic general term used to describe abdominal pain in horses
coliform related group of disease-causing bacteria commonly found in feces
collimator mechanism on a radiograph machine that aligns the rays or beams in a specific direction
colostrum antibody-rich milk that is first produced by the mother and secreted initially after parturition
coma prolonged state of unconsciousness
comminuted fracture bone break in which bone shatters in fragments
complete blood cell count (CBC) test that evaluates red blood cell (RBC) count (often a packed cell volume is a part of this testing), size of RBCs, amount of hemoglobin, number of platelets, total white blood cell (WBC) count, and a breakdown of the types of cells present
compound (open) fracture bone break in which the bone punctures the skin
concentrates nonforage component of a diet consisting of grains, protein sources, vitamins, and minerals
congenital present at birth
constipation condition that occurs when the feces is too dry and moves too slowly
constrict close
contagious disease condition that can be passed among affected animals
cranial refers to the head
cranial drawer sign diagnostic test for a torn cruciate ligament
cribbing wood chewing
cryptorchidism condition that occurs when one or both testes fail to enter the scrotum
Cushing's disease elevated blood levels of cortisol with presentation of clinical signs such as excessive thirst, urination, and appetite, thin skin and hair coat, panting, enlarged abdomen, weakness, and lethargy (hyperadrenocorticism)
cutaneous larva migrans disease condition resulting from the infestation of hookworm larvae into the body (also called creeping eruption)
cyanosis blue color associated with low oxygen levels in the blood

D

débridement process in which damaged and contaminated tissue is removed from a wound prior to the suturing process
deciduous teeth initial set of teeth, often referred to as the baby teeth
decision tree series of steps considered to make sound decisions
degenerative joint disease when a joint becomes so worn that the cartilage lining the joint thins and roughens
dehiscence breaking of wound edges
diabetes disorder evidence by elevated blood sugar levels; more correctly, diabetes mellitus
diabetes insipidus lack of antidiuretic hormone, which results in very diluted urine, uncontrolled thirst, and excessive urination
diabetes mellitus disease in which the animal is consistently hyperglycemic (elevated blood sugar)
diastole relaxation phase of the cardiac cycle
diffusion process that allows molecules to move across a membrane in an effort to equalize the concentration
dilate open
diplomate a doctor certified by a board of examiners as a specialist
disinfectant germicides that are too harsh to be used on skin but can be used on inanimate objects or surfaces
displaced abomasum condition commonly called a twisted stomach in which the fourth stomach of a cow fills with gas and is pulled upward; commonly occurs shortly after calving
doe female goat
dorsal toward, on, or in the back
dosimetry measurement of radiation dosage

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dry matter amount of a feed that remains when all the water is removed

E

edema swelling due to an accumulation of fluid
electrocardiogram tracing made by the electrocardiograph
electrocardiograph electronic instrument that picks up the small electrical signal that runs through the body
ELISA test enzyme-linked immunosorbent assay
–emia suffix used to describe levels in the bloodstream
endocytosis process that allows the cell membrane to wrap around a particle and then section it into the cytoplasm as a vacuole
endotracheal tube tube, often used in administering anesthesia that is passed through the trachea
enzymes protein molecules that speed chemical reactions in the body
epidural injection of local anesthetic into fluid around the spinal cord
epilepsy seizure activity
epithelial tissues collection of cells that line the body's surface and openings
equine infectious anemia viral disease causing fever, red blood cell breakdown, depression, and weight loss
equine protozoal myeloencephalitis disease in which a protozoan causes brain infection and clinical neurologic signs
erythropoiesis production of red blood cells
eructate belch
estrous cycle series of events that occurs in females in preparation for pregnancy
estrus state of sexual excitement in which the female is receptive to the male
eukaryotic cells with membrane-bound organelles such as a nucleus, mitochondria, and endoplasmic reticulum
euthanasia practice of assisted death used to provide relief to hopelessly injured, ill, or dying animals, often referred to as "putting an animal to sleep"
exocytosis the process that takes a membrane-bound sac, joins it to the cell membrane, and then releases it to the extracellular fluid
expiration when air is forced from the lungs

F

fibrosarcoma cancer of the connective tissue
first intention healing wound closure that occurs when repaired during the first six to eight hours after trauma, when bacterial levels at the site remain low, allowing wound to heal
flatulence an accumulation of gas in the intestinal tract
float filing of a horse's teeth to prevent discomfort from the edges of molars that sharpen with age
fomite inanimate object capable of becoming contaminated and transferring infectious organisms
foot-and-mouth disease highly infectious viral disease that selectively attacks epithelial tissue in cloven-hoofed animals
forage high-fiber feed such as grasses, hay, or silages
formalin solution of water and formaldehyde used to preserve tissues and specimens
free catch urine urine caught outside the body while the animal urinates
free choice diet having food available to the animal at all times
free radicals atoms having a single free electron, which attracts another electron from neighboring atoms

G

gastric dilatation–volvulus syndrome condition typically occurring in large, deep-chested dogs that have consumed a large meal and large volumes of water, which causes the accumulation of gas and rotation of the stomach; also called gastric torsion
gestation (gestating) pregnancy; carrying a pregnancy
glucose blood sugar
glycogen polysaccharide, which is used to store cellular energy
golden period time during the first six to eight hours after trauma when bacterial numbers remain at a moderate level, allowing the wound to be closed
gout painful disease resulting from high serum levels of uric acid
granulation tissue combination of capillaries and connective tissue in an open wound that takes on a fleshy red appearance
grazing consumption of forages such as grasses at a leisurely pace
grief a normal emotional response to the death of a pet; this process varies with each individual

H

hardware disease occurs when ruminants inadvertently consume metal, which migrates through their bodies, causing infection
heart failure condition in which the heart cannot meet the demands of the animal
heart murmur leakage within the heart, creating an abnormal heart sound
heaves noncontagious condition in horses that results in coughing, nasal discharge, labored breathing, and rapid fatigue; often caused by inhaling dust and molds
hematoma accumulation of blood in the dead space between tissues
hemolysis breakdown of red blood cells
hemophilia chromosomal defect resulting in a deficiency of one of the clotting factors

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herbivore animal that requires a plant-based diet
herd check reproductive exams and health maintenance work routinely done by veterinarians
high-rise syndrome occurs when cats fracture their lower jaws during falls from tall buildings
hip dysplasia diseased ball-and-socket joint resulting from a shallow rather than normally deep socket
homeostasis maintenance of the extracellular fluid
Horner's syndrome nerve damage that causes several eye malfunctions, including pupil constriction, eyelid drooping, protrusion of the third eyelid, and sunken eyes
humoral immunity production of antibody in response to an antigen
hydrolysis process in which water is added to a molecule to cleave it into smaller parts
hydrophilic attracted to or soluble in water
hydrophobic repelled by water
hyper- prefix that indicates above normal
hypo- prefix that indicates below normal
hypocalcemia condition commonly referred to as milk fever; caused by low blood calcium occurring at parturition
hypoglycemia low blood sugar

I

iatrogenic disease condition resulting from a treatment
idiopathic disease condition not explained by current medical knowledge
inspiration when air is taken into the lungs
integument skin
intern individual gaining experience from assisting a professional: position is either paid or unpaid
intervertebral disk disease occurs when the center of the disk becomes less pliable and pressure between the vertebrae causes the disk center to rupture through the fibrous outer layer
intestinal anastomosis procedure in which two regions of intestine are joined
intramedullary pin method of repairing broken bone in which a stainless steel pin is inserted into the medullary cavity
intranasally in the nose
intravenous in the vein
intussusception condition that occurs when a region of the intestine telescopes into itself
involution process by which the uterus returns to a normal state
isotonic the same concentration

J

joint ill occurs when bacteria enters a newborn's body through the umbilical opening and settles in the joints, with lameness resulting

K

kennel cough disease involving severe cough, which commonly occurs in dogs kept in close quarters
keratin specialized protein deposited in cells, giving a typical hardness and durability
killed vaccines immunizations that are manufactured from dead versions of pathogens
Koch's postulates four principles, developed by Robert Koch, that help define infectious disease

L

lacerations cuts
lidocaine anesthetic
ligaments connective tissue that attaches bones to bones
ligated tied
lipid fat
listeriosis (circling disease) brain infection commonly seen in cattle, sheep, and goats
Lyme disease bacterial infection that in humans and animals can cause symptoms such as fatigue and joint pain
lymph transparent yellowish fluid that travels through the lymphatic system, which helps to remove bacteria and proteins, transport fat, and supply lymphocytes

M

mad cow disease transmissible spongiform encephalopathy disease condition in cattle that causes the degeneration of the brain to a spongelike appearance
maintenance energy requirement (MER) amount of energy required by an animal at rest plus any additional energy required for the normal activity
malignant description of a tumor that will invade other parts of the body
management team group of professionals who assist in decision making
mastitis infection of the mammary gland
Material Safety Data Sheets (MSDS) data that provide essential information about working with and around potentially hazardous materials; requirements vary by country
metabolism all reactions conducted in the cells
metaphylaxis prophylactic use of antibiotics at times of high risk
metastasis spread of cancer cells to other sites in the body
mixed animal practice veterinary practice treating large and small animals
modified live vaccines immunizations that are manufactured from altered versions of pathogens
monogastric single stomached
myelinated nerves nerves with a myelin sheath

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myelogram procedure in which dye is injected into the epidural space, followed by a radiograph to trace the path of the dye
myofiber muscle cell

N

necropsy (postmortem) examination to determine cause of death
necrotic dead
neoplasm tumor that develops when cells grow in an uncontrolled manner
neuron nerve cell
nystagmus condition in which the eyes jerk back and forth in a rhythmic manner

O

obstetric having to do with pregnancy and delivery
Occupational Safety and Health Administration (OSHA) federal agency charged with enforcing laws enacted regarding safety and health in the workplace
ophthalmoscope instrument used to observe the structures in the interior of the eye, such as the optic nerve, retina, and retinal blood vessels
organs collections of tissue
orthopedic surgeon veterinarian or doctor who specializes in surgery of the bones
osmosis process that allows a solvent to move across a membrane in an effort to equalize concentration but will not allow large molecules of the solute to pass
ossification process in which bone is formed

P

pacemaker system maintains the regular rhythm of the heart
packed cell volume rapid test that provides the percentage of the blood composed of red blood cells
palpated felt
parasympathetic system part of the autonomic system that slows the body from the flight-or-fight mode, lowering heart rate and blood pressure
parturition giving birth
parvovirus viral disease that causes severe vomiting and diarrhea in dogs
passive immunity disease resistance resulting from transfer of antibodies from one animal to another
pasteurization a process used to sterilize milk by heating it to a high temperature for a short time
pathologists scientists who interpret and diagnose changes in cells and tissues
peripheral nervous system all nerves outside the brain and spinal column
peristalsis organized set of muscle contractions in a hollow organ that propels the contents
peritonitis inflammation throughout the abdominal area
phagocytosis process in which a cell engulfs and ingests particles
phenobarbital drug used to control seizures
pheromone chemical emitted by an animal that serves as a means of sexual communication
pleural friction rub noise heard when listening to lungs with irritated pleura
plexus network of nerves
pneumonia inflammation of the lungs
pneumothorax condition in which air becomes trapped between the lungs and the chest wall
polarization condition in which one region of a cell has a different charge than an adjacent region
polydipsia excessive drinking
polyestrous constant continuation of the estrous cycle
polyuria excessive urination
porcine stress syndrome swine condition in which calcium leaks from the endoplasmic reticulum, causing pigs to shake involuntarily
primary response initial antibody production that occurs when an antigen is first introduced to the body
private practitioner veterinarians who practice independently and not part of a larger organization such as a university or pharmaceutical company
prodromal phase stage of disease when first signs of illness occur
prokaryotic cells that lack membrane-bound organelles
prolapsed uterus condition in which the uterus turns inside out and is pushed through the vulva
proud flesh overgrowth of granulation tissue that prevents epithelial cells from growing across the wound
pruritus severe itchiness
puberty start of sexual maturation
pus accumulation of infection-fighting cells, destroyed pathogens, dying tissue cells, and tissue fluid that results at the site of infection
pyometra uterine infection that commonly occurs in older dogs and cats

Q

Q fever a disease condition caused by *Coxiella burnetii*, which results in abortions in sheep and goats and a sudden onset of flulike symptoms in humans
quarantine confinement of an animal separate from the herd in an effort to prevent spread of disease

R

rabies viral disease that infects the central nervous system
radiograph photograph taken when streams of x-rays pass through the body and expose film
radiology study of radiographs

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referral practice specialty veterinary practices such as oncology
refractometer instrument that measures specific gravity
respiration exchange of gases between the animal and its environment
resting energy rate (RER) amount of energy required by an animal at rest
retching strong, rapid abdominal contractions
retro- behind
rickets disease condition of deformed and weakened bones resulting from childhood deficiency of calcium
rigor mortis muscle stiffness occurring after death
ringworm fungal infection of the skin
RNA viruses group of viruses that cause inflammation in the brain
roaring horse condition in which one of the vocal folds fails to open, thus causing an ensuing roaring noise when the horse breathes heavily during exertion
rodenticide poison used to control rodents such as rats and mice
rumination process in which the rumen and reticulum contract in a manner that forces some of the stomach contents back through the esophagus and into the mouth, where they are chewed

S

schistosomus reflexus congenital abnormality in which the affected fetus develops inside out, with internal organs exposed
scrapie transmissible spongiform encephalopathy disease condition in sheep and goats that causes the degeneration of the brain to a spongelike appearance
seasonal polyestrous continuation of the estrous cycle until pregnancy during only certain times of the year
second intention healing wound closure occurring after the first six to eight hours after trauma, when granulation tissue must first fill the gap between the skin edges and subsequently allow epithelial cells to grow
secondary response quick response mounted against a second exposure to an antigen, which typically prevents disease development
sensory somatic system operates the voluntary motor activity of the body
seroconversion change in titer reading by four times
serology measurement of the presence of antibodies against a specific organism
seroma accumulation of fluid in a dead space between tissues; similar to serum, with a small number of red blood cells
serum clear yellow substance obtained when separating blood components
shock condition in which not enough blood is pumped to vital tissues, associated with a drop in blood pressure
shunting moving
signalment basic description of an animal presented for evaluation
simple fracture clean bone break
skin turgor measure of hydration, which tests how quickly the skin returns to its normal position after being pinched
spay (ovariohysterectomy) removal of ovaries and uterus
spayed indicates a female animal with reproductive organs removed
specific gravity weight of a liquid as compared with distilled water
sterilization procedures such as application of pressurized steam and chemicals in which all microorganisms are destroyed
stocking up term used to describe an accumulation of fluid in the legs of horses that have been tied for excessive periods
subcutaneous under the skin
subluxate partially dislocate
sweeny nerve damage and resultant shoulder muscle shrinkage occurring in draft horses from pulling harnesses
symbiosis mutually beneficial relationship
sympathetic system part of the autonomic system that stimulates organs for flight or fight
systemic affecting the entire body
systole contraction phase of the cardiac cycle

T

tachycardia elevated heart rate
tendons connective tissue that attaches muscles to bones
tetanus acute bacterial infection causing muscle stiffness and rigidity; often called lockjaw
tissue collection of cells organized for a particular function
titer measure of antibody levels in the bloodstream
total mixed ration (TMR) the mixing of all feedstuffs in a diet
toxoplasmosis protozoal parasitic disease in which cats serve as the definitive host; of concern to humans, especially pregnant women and persons with compromised immune systems
treatment protocol plan of action often requiring medication to achieve wellness in animal
tuberculosis bacterial disease that affects the lungs and respiratory system
tunnel ventilation system with air inlets at one end of a building and fans for outlet at the other
tying up (Monday-morning disease) cramping with potential muscle damage in working horses that occurs the Monday after a weekend of rest and full feed

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U

uremia clinical signs associated with azotemia
urinalysis evaluation of urine
urinary incontinence leakage of urine at inappropriate times

V

vector organism that transmits disease
veins vessels that transport blood back to the heart
ventilation exchange of air from within a building and the outside
ventral below
vestibular system balance center
veterinary assistant helper in veterinary practice who is not required to have post-secondary education
veterinary specialist veterinary who has advance training and certification in any number of areas such as internal medicine
veterinary technician individual in veterinary practice with either a two or four year degree and also has passed a licensing exam
visceral larva migrans condition in humans in which roundworm larvae migrate through the body, causing damage to internal organs
volt unit of electrical measurement

W

weaned removal from nursing
West Nile fever viral disease causing flulike symptoms in humans (mosquitoes often act as a vector)
wet dewlap skin infection in the lower neck of rabbits
whelping birthing in dogs

X

x-ray electromagnetic radiation, which can pass through living tissue

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