
The Digestive, Reproductive, and Urinary Systems

THE DIGESTIVE SYSTEM

Your body is constantly using energy, even when you're at rest. Your cells use energy to carry out the normal functions of protein synthesis, cell maintenance and repair, and their own particular functions. On a larger scale, processes such as breathing, pumping of the heart, maintenance of normal levels of substances within the body, and digestion and absorption of foods are vital to life. All these processes continue while you're sleeping. Because your body can't manufacture energy, it must obtain that energy from elsewhere.

In all animals, energy comes from food. Food also provides the body with fresh raw materials for growth, maintenance, and repair of body structures. The *digestive system* deals with the intake, physical breakdown, chemical digestion, and absorption of food, along with the elimination of waste products created by this process. The digestive system also eliminates certain toxic substances and secretes hormones it uses to regulate itself.

The Oral Cavity

The *mouth*, or *oral cavity*, consists of the lips, teeth and gums, tongue, oropharynx, and the associated salivary glands. The lips are a zone of transition from the skin of the face to the *mucous membrane* (a general term denoting the surface of an organ lubricated by moisture) lining the gums and the inside of your cheeks. Several layers of muscle help the lips grab and retain food and water within the mouth.

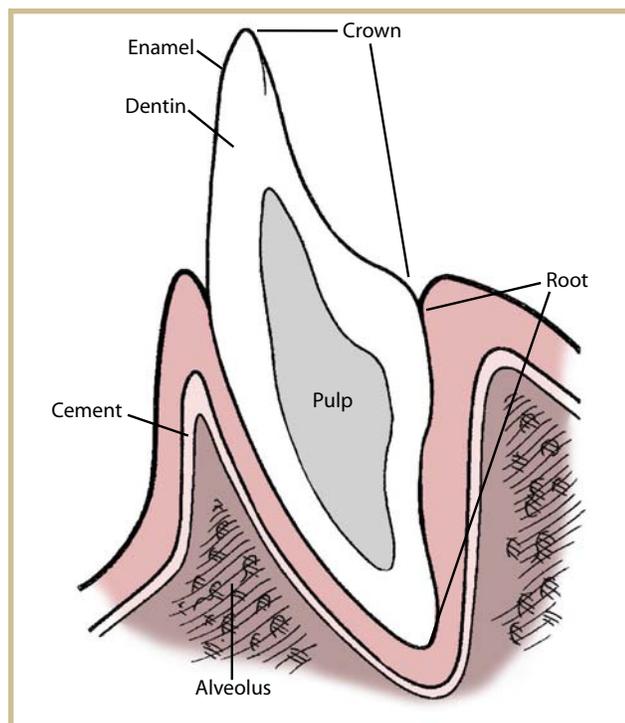
Different animals have different degrees of lip muscle development. Grazing animals like cattle, sheep, and horses have muscular lips that are *prehensile* (i.e., adapted to grasp plant material). Most other mammals tend to have lip muscles that aren't as well-developed. In these animals, the lips are used more for facial expressions such as snarling.

The mucous membranes start at the lips, fold in, and then reverse course to cover the surface of the gums. The gums attach to the teeth or travel between the teeth to line the inner gums. The inner gums are continuous with the roof of the mouth, underside of the tongue, and eventually with the lining of the pharynx.

Teeth

Teeth are among the most specialized of organs within the mouth. The crown is the visible portion of the tooth that projects out of the gum line. Beyond the gum line and embedded in the jaw is the *root*; some teeth have two or more roots. Between the root and crown, some teeth have a slight narrowing called the *neck*, which is approximately where the gums attach to the tooth. Inside each tooth you'll find three or four layers of tissue (Figure 1).

FIGURE 1—A Feline Tooth



The inside layer, or *core*, of each tooth is called the *pulp* and contains connective tissue, blood vessels, and nerves. The pulp is the sensitive part of the tooth that becomes painful when a cavity develops. Covering the pulp cavity is a material called *dentin*, an *inorganic* (nonliving) material somewhat like the inorganic material in bone that constitutes the bulk of the tooth.

The outermost layer of the tooth is called the *enamel*. This inorganic substance is extremely hard and arranged in parallel rods cemented together with a calcified inorganic substrate. Enamel is the hardest substance in the body. Despite being extremely hard and calcified, enamel is somewhat *translucent* (light passes through partially). The tooth's root is embedded into a jaw socket called an *alveolus* by naturally occurring *cement* that forms a fourth layer over the roots.

Plaque is bacteria and salivary material that can accumulate at the junction of the gum and tooth. Bacteria can invade the space between the gum and tooth, eventually causing loss of cement and bone around the tooth root. The tooth becomes loose, may be painful or cause difficulty chewing, and needs to be extracted.

The teeth of horses and the *cheek teeth* (premolars and molars) of *ruminants* (herbivores, like cows, sheep and goats) are constantly growing. As the animal ages, the socket below the root fills with bone and pushes the tooth upward; the tooth stays about the same height above the gum because of the constant wearing down from grinding food.

The teeth in some horses wear unevenly due to occlusive problems. *Occlusion* refers to where upper and lower teeth meet and touch. Factors that affect this process are (1) the way the upper and lower teeth come together, (2) how the animal chews, and (3) how fast the individual teeth erupt. As a result, the teeth may develop sharp edges that become painful to the lips and gums when the horse chews. This requires the teeth to be *float*ed, a process in which a file is used to grind the sharp edges of the teeth down enough to make them less painful.

Teeth in most animals come in two sets: a *deciduous* (temporary or “baby”) set and a permanent set. In general, deciduous teeth are smaller, less numerous, and softer than permanent

teeth. Deciduous teeth are often present below the gum line at birth and erupt during the first six months to three years of life, depending on the species. As the animal matures into an adult, the permanent teeth, which have been developing in the alveoli of the bone, erupt. They gradually push the deciduous teeth out of the jaw. In some animals, an abnormal condition occurs in which a deciduous tooth isn't shed. This condition is called a *retained deciduous tooth*, and it causes problems with occlusion and chewing. The solution is to pull the deciduous tooth.

Most domestic animals have four types of teeth, which are arranged in two arches called *dental arcades*, one on the upper jaw and one on the lower jaw.

These four teeth types are

- *Incisors* (to cut food)
- *Canines* (to tear food)
- *Premolars* (to grind food into smaller particles for swallowing)
- *Molars* (to grind food into smaller particles for swallowing)

Ruminant—an animal (such as a cow or sheep) that has more than one stomach and that swallows food and then brings it back up again to continue chewing it

You'll find all four types of teeth in carnivores, horses, and pigs. Ruminants lack upper incisors and canine teeth. The *dental formula* is the typical number of each type of tooth found in the upper and lower arcades of an animal's mouth (Figure 2). The formula uses the letter "I" for incisor, "C" for canine, "P" for premolar, and "M" for molar. Capitalized letters represent adult teeth, and lowercase letters represent deciduous teeth. The letter is followed by a fraction; the first number represents the number of teeth in *half* of the upper arcade, and the second number represents the number of teeth in *half* of the lower arcade. To determine the total number of teeth, you must add the numbers and multiply by 2 since the formula represents only half of the upper and lower arcades.

Dental Formulas for Several Domestic Species		
Species	Dental Formula	Total Number Teeth
Dog—puppy	i3/3 c1/1 p3/3	28
Dog—adult	I3/3 C1/1 P4/4 M2/3	42
Cat—kitten	i3/3 c1/1 p3/2	26
Cat—adult	I3/3 C1/1 P3/2 M1/1	30
Horse—adult	I3/3 C1/1 P3-4/3 M3/3	40 or 42
Pig—adult	I3/3 C1/1 P4/4 M3/3	44
Cow—adult	I0/3 C0/1 P3/3 M3/3	32

FIGURE 2—Dental Formula Chart

Let's look at the dental formula for the adult cat. It shows 3 incisors in each half of the upper and lower arcades for a total of *12 incisors* ($3 + 3 = 6$; $6 \times 2 = 12$); 1 canine in each half of the upper and lower arcades for a total of *4 canines* ($1 + 1 = 2$; $2 \times 2 = 4$); 3 premolars in half of the upper arcade but only 2 premolars in half of the lower arcade for a total of *10 premolars* ($3 + 2 = 5$; $5 \times 2 = 10$); and 1 molar in each half of the upper and lower arcades for a total of *4 molars* ($1 + 1 = 2$; $2 \times 2 = 4$). Adding these numbers, we can calculate the total teeth for an adult cat to be 30 ($12 + 4 + 10 + 4 = 30$).

As mentioned, ruminants lack upper incisors; instead, a *dental pad* consisting of hardened mucous membrane tissue is present in the rostral upper jaw opposite the lower incisors. The teeth of each species are adapted to the type of diet eaten by that species. Dogs and cats, for example, are *carnivores* that need to cut and tear their food; incisors and canine teeth are important. Cows, on the other hand, eat plant material that must be ground up before being swallowed, so the molars and premolars are their most prominent teeth. Pigs and people are *omnivores*, eating both animal and plant material, so all types of teeth are present and equally prominent in their mouths.

Tongue

The *tongue* is a muscular organ used for manipulating food within the mouth. It possesses *taste buds*, which allow you to taste food. The interior of the tongue is composed of many interlocking muscle bundles. These allow the tongue to move in many directions. These muscle fiber bundles are held together by connective tissue. Scattered throughout the connective tissue are blood vessels, nerves, and small accessory salivary glands.

The tongue's surface is covered with squamous epithelial tissue just like the rest of the mouth, but on the surface of the tongue are small projections called *papillae* (singular, *papilla*) that help the tongue control the food. Some papillae are specially modified to carry the taste buds. In cats, the papillae are especially prominent (if you touch the top of a cat's tongue, you'll note it feels like sandpaper) and are used like the bristles of a brush for grooming.

Salivary glands are located throughout the oral cavity—in the tongue, on the inside of the lips and cheeks, below the tongue, and in the walls of the pharynx. Most of these glands are very small, consisting of a cluster of cells that produce saliva and a small tube called a *duct*. The duct carries the saliva from the secreting cells to the oral cavity's surface.

These smaller salivary glands are called *accessory salivary glands*, and they secrete saliva in a continuous manner to keep the surface of the mouth moist. A few glands are much larger and more complex in structure, and these secrete the majority of saliva in response to the presence of food and other stimuli (usually substances that have a bad taste). These reactions are controlled by the nervous system.

Three pairs of the larger salivary glands exist:

1. *Parotid salivary glands*—located in the angle between the ear and the back of the lower jawbone
2. *Submandibular* (sometimes referred to as *mandibular salivary glands*)—located just inside and forward of the parotid salivary glands between the caudal borders of the mandibles

3. *Sublingual* (sometimes referred to as *lingual*) *salivary glands*—located beneath the tongue

Saliva performs the following functions:

- Moistens the food to make it easier to chew and form a *bolus* (rounded mass of food)
- Keeps the lining of the oral cavity moistened
- Brings food particles in contact with taste buds

Oropharynx/Pharynx

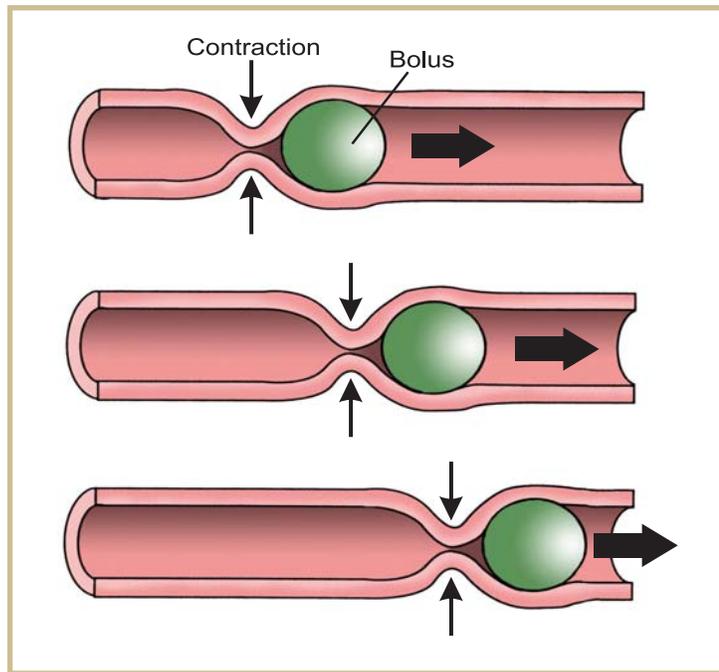
The *oropharynx* (opening at the back of the throat) is a muscular walled area that opens to both the digestive system and the respiratory system. The *pharynx* (throat) opens into the nasal cavity, the oral cavity, the esophagus, and the trachea. The pharynx serves as a conduit to transport food and liquid from the oral cavity to the esophagus and air from the mouth or nasal cavity to the trachea.

There are four layers of the basic “tube” of the intestinal tract. Food moves through the center lumen of the tube. The innermost layer adjacent to the lumen is the *mucosal layer* that’s comprised of epithelial cells. The next layer is the *submucosa*, which contains glands and connective tissue. The third layer is the *muscle layer* that makes movement possible. The outermost layer is the *serosa*, which is a thin, tough layer of connective tissue. The basic anatomy of this tube is similar for all the segments of the intestinal tract—the esophagus, the stomach, the small intestine, and the large intestine.

The Esophagus

The *esophagus* is basically a muscular tube that transports food from the pharynx to the stomach. The bulk of the esophagus consists of muscle tissue that contracts in a coordinated fashion to push food in the distal direction. It accomplishes this task by contracting one area while relaxing an adjacent area; these actions force the food into the relaxed area. This process is known as *peristalsis* (Figure 3).

FIGURE 3—Waves of peristalsis move food through the GI tract.



The lining of the esophagus is stratified squamous epithelium that's fairly resistant to physical trauma from food and foreign objects that are swallowed. Folds in the mucosa are present when the esophagus is relaxed, but these folds flatten out when the lumen is expanded by the presence of a food bolus. When a foreign object such as a bone or needle is accidentally swallowed, it pierces the mucosa, gets stuck, and must be removed either surgically or through endoscopy.

Sometimes acidic fluid from the stomach *refluxes* (or squirts) back up into the esophagus. If this process occurs repeatedly, the acid can damage the mucosa of the esophagus, creating a condition called *esophagitis* (inflammation of the esophagus). Scar tissue may form, leading to a constriction of the esophagus called an *esophageal stricture*; strictures make passage of solid materials difficult.

A condition called *megaesophagus* can occur in some dogs, cats, and people. In this condition, the muscles of the esophagus fail to contract. As a result, the esophagus becomes very dilated and doesn't push food downward; instead, the food sits in the esophagus or *regurgitates* (flows backward passively) into the oropharynx, where it may be *aspirated* (sucked) into the trachea during breathing.

The esophagus has two *muscle sphincters*, which are rings of muscle surrounding an opening, with one sphincter at each end of the esophagus. In the esophagus, sphincters keep food from flowing out of the esophagus and into the pharynx and also keep stomach contents from entering the esophagus. However, the sphincters aren't foolproof; if enough pressure is exerted on one side of the sphincter, the food will reflux.

The outer surface of the esophagus is the *serosa*. The serosa is a thin tissue layer that covers the entire gastrointestinal tract, including the esophagus, stomach, small intestine, and colon. The serosa is continuous with the tissue that lines the inside of the chest cavity, lungs, and heart. Blood vessels, nerves, and *lymphatics* (lymph vessels) run through the serosa.

The Ruminant (Compound) Stomach

Ruminants are animals that swallow their food and then regurgitate it back through the esophagus into the mouth to chew on it again before swallowing it once more. This process is called *rumination*. Ruminants have compound stomachs that are much more complex than simple stomachs. The functions of the compound stomach are similar to those of the simple stomach, but the diet being digested is much different.

Ruminants eat plant material, which is more difficult to digest than the protein ingested by carnivores and omnivores. Plant material's fiber content is much higher than that of animal material. This fiber is the component of food that's the hardest to digest. Therefore, the ruminant stomach is designed to digest plant material, which explains some of the differences between compound and simple stomachs. Ruminants have one stomach with four compartments (Figure 4).

These compartments are the

1. Reticulum
2. Rumen
3. Omasum
4. Abomasum

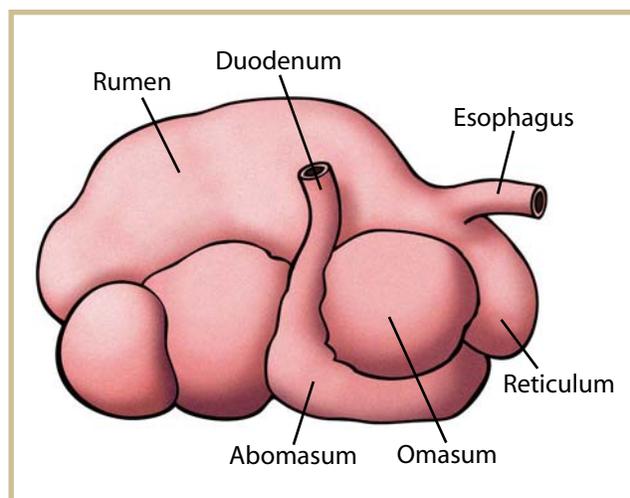


FIGURE 4—The Components of a Cow's Stomach

The first three compartments are sometimes collectively called the *forestomach* (or *prestomach*). The *reticulum* is the smallest and most cranial part of the ruminant stomach. The reticulum's mucosa has a honeycomb pattern of folds that function to increase the surface area of the organ. This increased surface area provides greater area for absorption of nutrients. Because of the location of the reticulum, swallowed heavy (usually metal) objects can drop into the reticulum and may pierce the wall of the organ, causing damage to the diaphragm and other nearby organs. This condition is known as "hardware disease" (or *traumatic reticulitis*). Sometimes, when the animal is young, a magnet is surgically placed in the forestomach to bind to these metal objects and prevent their migration through the wall of the reticulum. The magnet remains and helps prevent recurrence.

The *rumen* is the largest part of the forestomach and takes up most of the abdomen's left side. The rumen is the most important part of the ruminant stomach because it's where *fermentation* occurs. In the process of fermentation, bacteria and *protozoa* (one-celled organisms) as well as digestive enzymes act on plant material to break down *cellulose* (the primary component of plant fiber) into volatile fatty acids (VFAs), proteins, and vitamins. By-products of fermentation, such as carbon dioxide and methane gases, are also released; these by-products must be released either through the mouth or anus. The rumen also digests bacteria and absorbs the breakdown products of both cellulose and bacteria.

The *omasum* is a ball-shaped cavity with many muscular folds. VFAs that aren't absorbed in the rumen are absorbed in the omasum. Bicarbonate ions and some water are also removed from the *ingesta* (food and drink taken into the stomach) in the omasum.

The *abomasum*, also known as the *true stomach*, is similar to the simple stomach of nonruminant animals in organization and function. Both the omasum and abomasum lie on the right side of the abdomen. Occasionally, the abomasum displaces to the left or to the right, pivoting at the opening at each end of the abomasum.

As a result of this abomasal displacement, ingested material can't enter or exit the abomasum. This creates an obstruction that leads to abdominal discomfort for the animal. Surgical correction of the displaced abomasum is needed, followed by surgical attachment of the abomasal wall to the abdominal wall to prevent future displacement.

The Monogastric Stomach

The *monogastric stomach* is similar to the esophagus in basic tubular anatomy, but the similarity ends there. The stomach begins the process of digestion in earnest, mixes the food with digestive fluids, and stores food until it has been digested into particles small enough to enter the small intestine.

Thus, the stomach differs from the esophagus in the following three ways:

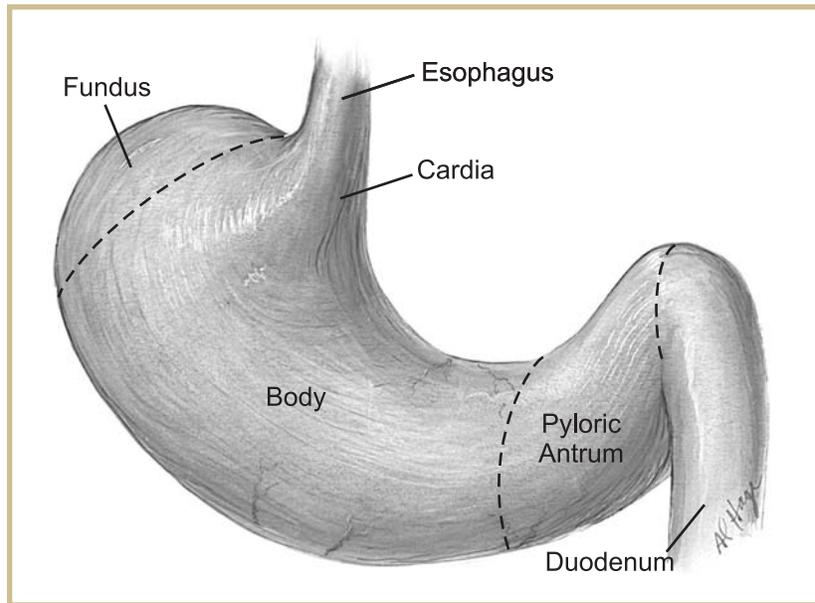
1. The stomach can expand to a much larger diameter than the esophagus, so the stomach's capacity to store food is much greater.
2. The muscular layers of the stomach differ from those of the esophagus because the stomach must not only eventually propel food in the distal direction, but also churn and mix the food that's being stored in it. The stomach has an additional muscle layer, called the *oblique layer*, to accomplish this.
3. The mucosa of the stomach consists of a variety of glandular epithelial structures that secrete digestive fluids, mucus, and acid.

A human stomach's mucosa has many folds called *rugae*. When relaxed, the rugae flatten out as the stomach expands, much like the esophagus. The human stomach is very similar to that of the dog, cat, pig, and horse. This form of stomach is called a *simple stomach*. Simple stomachs are roughly J-shaped.

A simple stomach is essentially a large, dilated tube containing the following regions (Figure 5):

- Esophageal region
- Cardia
- Fundus
- Body
- Pyloric antrum
- Pylorus

FIGURE 5—The Monogastric Stomach



The esophageal region of the stomach lies most cranial and contains the *cardia*, a small area near the opening of the esophagus. Just caudal to the esophageal region is the *cardiac region*, which contains mucous glands that secrete mucus but not digestive enzymes.

The bulk of the simple stomach consists of the next region, the *fundus*. This region contains most of the *gastric glands*, which are the digestive glands that secrete a variety of substances to chemically break down food.

The *body* is a glandular, distensible area, and the *pyloric antrum* functions to grind food and control the amount of hydrochloric acid (discussed in the next section) produced.

At the distal end of the stomach is a muscle sphincter, the *pylorus*, which helps retain food in the stomach until that food is sufficiently digested to enter the small intestine.

The *mucus layer* covering the stomach's surface prevents the mucosa from being damaged by the acid and pepsin (discussed in the next section) in the gastric juice. In cases in which mucus production is decreased or hydrochloric acid production is increased, this protection may break down, resulting in damage to the mucosa commonly known as an *ulcer*.

The *pyloric antrum* has glands that primarily secrete mucus and a hormone called *gastrin*. Gastrin has three major functions:

1. Stimulates the production of hydrochloric acid and pepsin in the stomach
2. Stimulates contraction of stomach muscles to increase stomach emptying
3. Decreases pyloric tone to allow food to enter the small intestine

Gastric Motility and Secretions

The digestive process in the stomach differs for ruminants and nonruminants. In nonruminants, the process is similar to that for humans. Food enters the stomach and is exposed to *gastric juice* (contains mucus from cells in almost all areas of the stomach), digestive enzymes such as pepsin from peptic cells in the gastric glands of the fundus and body, and hydrochloric acid from *parietal cells* (stomach epithelial cells) in the gastric glands. Like saliva, mucus softens and lubricates the food. Mucus also coats the stomach mucosa and helps prevent acid and pepsin from damaging the mucosa.

Pepsinogen secreted from the peptic cells isn't an active enzyme (it's an inactive enzyme called a *proenzyme*). However, once pepsinogen enters the stomach lumen, it's exposed to stomach acid, which converts it to pepsin, its active form. *Pepsin* attacks protein molecules in food and breaks them into peptides and polypeptides.

Hydrochloric acid, which plays an important role in digestion, functions to

- Activate pepsinogen to pepsin
- Act as an antimicrobial chemical to partially sterilize the stomach
- Further break down the food into smaller particles

Gastrin is secreted by mucosal cells in the stomach's pyloric region in response to the presence of food in the pylorus. Gastrin stimulates the secretion of hydrochloric acid and pepsin, increases stomach contractions to promote emptying of the stomach, and decreases the tone of the pyloric sphincter to allow food to pass.

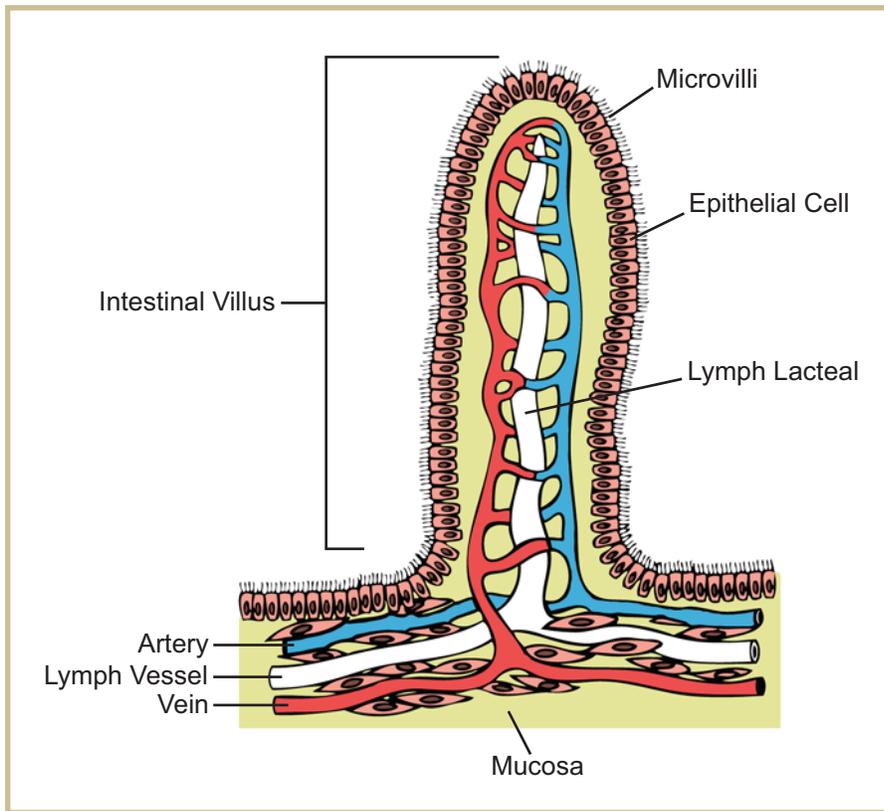
Waves of peristalsis in the stomach mix these secretions with the food in the stomach to aid in the digestive process (refer to Figure 3). The degree of stomach distention and the level of gastrin determine when and how forcefully stomach peristalsis occurs to force food through the pylorus.

The Small Intestine

The *small intestine* is remarkably similar in all species. The three major divisions are the *jejunum*, *ileum*, and *duodenum*. Each of these structures has the general tubular arrangement already described, including a mucosa, submucosa, muscularis, and serosa. The small intestinal mucosa is shaped into numerous small folds called *villi* (singular, *villus*). Columnar epithelial cells, also called *enterocytes*, are tall, thin cells lining the surface of the villi. These cells have small finger-like projections on their surface called *microvilli*, which create the appearance of a “brush border” on the villus (Figure 6).

Inside the villi are small blood vessels and *lacteals*, small lymphatic vessels that help absorb certain fats from the diet. In depressions between the villi, called *crypts*, new cells are constantly produced to replace cells lost from the tips of the villi. As cells are shed, the cells lining the sides of the villus are pushed toward the tip of the villus by new cells made in the crypts.

FIGURE 6—Intestinal Villus



Interspersed with the enterocytes, which perform the digestive and absorptive functions, are *goblet cells*. These cells secrete mucus to lubricate the intestine and the food contained within it. Digestion is both a physical and chemical process. Food must be broken down physically through the process of chewing, softening of the food by water and acid in the gastrointestinal tract, and the churning action of the stomach and intestines. Physical breakdown makes the food particles smaller. This breakdown, in turn, makes the food easier to pass farther down the digestive system and exposes more of the food to the digestive juices.

Digestive juices perform a chemical breakdown of the food into the basic nutrients that the body can absorb into the bloodstream. The three most basic nutrients used by almost all animals are

- Proteins
- Carbohydrates (sugars and starches)
- Fats

The nutrients in food are too big to be absorbed directly into the body. Therefore, the digestive system must take in the food, break it down into the simplest forms available for absorption, and absorb these products into the blood.

Proteins are composed of building blocks called *amino acids*. Amino acids link end to end or side to side to form *peptides*. Peptides in turn can link together to form *polypeptides*. Polypeptides are long chains of amino acids twisted and looped together to form the specific configuration needed for that protein. The digestive process breaks down protein from the largest substance to the smallest.

Carbohydrates are formed from *monosaccharides*. Two monosaccharides can be linked together to form a *disaccharide*, which in turn can be linked multiple times to form a three chain *polysaccharide*. Generally, sugars are simple carbohydrates, whereas starches are more complex carbohydrates. More complex carbohydrates can store more energy than simpler molecules.

Triglycerides, the building blocks of fats, are composed of an alcohol molecule (*glycerol*) bound to three fatty-acid chains. The length of the fatty acid chains and the types of bonds between the atoms in the fatty acid chain determine the type of fat and its physical characteristics.

Molecules in foods typically consist of the most complex of each of these nutrients, so the digestive process must break down a lot of bonds between carbon molecules to retrieve the simplest form of the nutrient. The process by which the carbon bonds are broken is called *hydrolysis*, and this is the most basic process of digestion. All forms of digestion use hydrolysis, but the means by which hydrolysis is achieved varies with the type of nutrient being digested.

Enzymes are proteins produced throughout the body. They perform a variety of functions involving the manipulation of other molecules. In the digestive system, enzymes are essential to the chemical digestion of food. Enzymes are produced by glandular tissue in various parts of the digestive system, including the salivary glands, stomach, intestine, and accessory organs, such as the pancreas.

Digestive enzymes recognize specific molecules or types of molecules in food and act upon those molecules to perform hydrolysis. The three categories of enzymes in the digestive tract are

1. *Proteases*—break down proteins
2. *Lipases*—break down fat molecules
3. *Amylases*—break down carbohydrates

Enzymes are present in the cell membrane of the enterocytes lining the mucosa. These enzymes digest food particles that come in contact with the mucosa but have no effect on particles floating free in the lumen. Damage to the mucosa can lead to poor digestion because of damage to the cell membranes and the associated enzymes.

The majority of digestion and absorption of food in dogs, cats, and pigs occurs in the small intestine. The presence of villi and microvilli, as well as the extreme length of the small intestine (several feet even in the smallest dog or cat), all serve to increase the surface area of intestine exposed to ingested food. This large surface area in the small intestine facilitates the absorption and digestion of food.

The Large Intestine

Although the anatomy of the large intestine varies widely depending on an animal's diet, it has the same basic features in all domestic animals. The *large intestine* has three main parts: the *colon*, *rectum*, and *anus*. The *cecum* is a blind sac projecting from the colon that technically isn't part of the large intestine. The cecum is similar to a human's appendix.

The large intestine functions mostly as a site for absorption of water and *electrolytes* (e.g., sodium and chloride) from the ingested material, which is converted to *feces* (waste material). The exception to this rule is the horse, which has a very large cecum and a large colon, both of which serve as sites for fermentation very much like the rumen in ruminant animals. Horses and similar species are thus sometimes known as *hindgut fermenters* because fermentation occurs in the

large intestine (i.e., the “hindgut”). The cecum and large intestine in these species absorb the products of fermentation along with digested bacteria and protozoa.

Sodium is actively reabsorbed in the large intestine of all species, which facilitates the absorption of water and chloride. Mucus is secreted by goblet cells within the mucosa, and this mucus helps lubricate the feces as it passes through the colon, anus, and rectum. The rectum serves only as a storage site for the feces until evacuation. The anus contains a muscle sphincter that controls when feces are evacuated. Contractions of the colon and rectum are under the influence of the nervous system, which is signaled by distention of the colon. That is, when the colon becomes full, stretching of the colon wall is detected by various nerve sensors, and this stimulates a reflex series of muscle contractions in the colon and relaxation of the anal sphincter, which empties the colon.

Accessory Digestive Organs

Several organs lying near the gastrointestinal organs aid in the digestive process. These include the

- Pancreas
- Liver
- Gallbladder
- Biliary ducts

These organs secrete, store, or transport substances that promote digestion, lubricate food, and aid in food absorption. The liver also serves a variety of other functions not directly related to digestion.

The Pancreas

The *pancreas* is composed mostly of clumps of glandular secretory tissue and tubules carrying the pancreatic digestive secretions to the small intestine. Intermixed with the secretory cells of the pancreas are different cells arranged in clusters called the *islets of Langerhans*. Cells in the islets secrete

hormones such as *insulin* and *glucagon*. This secretion is considered *endocrine* in nature, meaning the cells secrete into the bloodstream. (The islets of Langerhans will be discussed in a later part of your program.) The secretory cells also carry out an *exocrine* function (meaning they secrete into a lumen) by secreting digestive enzymes (trypsin, chymotrypsin, lipase, and amylase) that mix with the food in the small intestine. *Trypsin* and *chymotrypsin* help digest proteins and are secreted as inactive forms—*trypsinogen* and *chymotrypsinogen*, respectively—to prevent them from digesting the proteins of the pancreas itself. Once in the lumen, *enterokinase*, an enzyme secreted by the duodenal enterocytes, converts trypsinogen into trypsin. This in turn activates chymotrypsinogen into chymotrypsin. *Lipase* digests fats, whereas amylase digests carbohydrates.

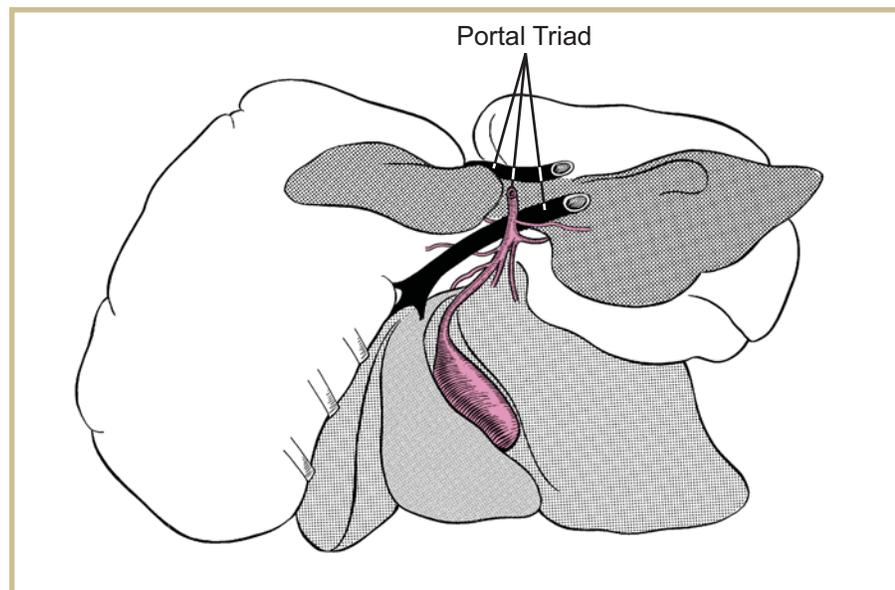
People, dogs, and cats can develop inflammation of the pancreas, called *pancreatitis*. In this condition, inflammation breaks down some of the protective barriers in the pancreatic ducts that prevent trypsin and chymotrypsin from entering into, and digesting, the pancreatic tissue. This damages the pancreas further, leading to a vicious and sometimes fatal cycle of damage and leakage. Treatment consists of minimizing the amount of food and water entering the intestine to avoid stimulation of pancreatic secretion, allowing the pancreas to quiet down with time.

The Liver

The *liver* is one of the largest organs in the body. Located immediately caudal to the diaphragm, the liver is *convex* (bowing out) on its cranial surface and somewhat *concave* (bowing in) on its caudal aspect. The liver is divided into several lobes by clefts; the number of lobes and the subdivisions of the lobes vary with the species. Liver tissue contains numerous blood vessels and ducts. Each arrangement of the vessels and ducts is called a *portal triad* (Figure 7). Each portal triad contains

1. A *portal vein* that carries blood from the intestines to the liver
2. A *hepatic artery* that carries blood from the heart to the liver
3. A *bile duct* that carries bile from the liver to the gallbladder or duodenum

FIGURE 7—Portal Triad of a Canine Liver



The liver performs a wide variety of functions, one of which is detoxification of materials in the blood. Blood coming from the intestines often carries bacteria and a large volume of toxic substances produced by bacteria during digestion. The liver filters this blood.

Liver cells called *hepatocytes* also store a starchy compound called *glycogen*. Glycogen acts as an energy supply when blood sugar levels become low; the liver can break glycogen down into *glucose*, a sugar molecule used by almost all body cells for energy production. Many proteins, like *albumin* (a water-soluble transport protein), are also synthesized by hepatocytes for secretion into the central vein.

Another important function of the hepatocytes is to secrete *bile* (an emulsifier that functions to digest lipids) into the bile ducts, where it's carried to the gallbladder or duodenum.

With so many functions, it's understandable that a severely damaged liver can cause many serious and sometimes fatal consequences. Among the problems faced by patients with liver failure are exposure to toxins that affect the brain, infections, poor digestion and absorption of fats and vitamins, and an inability to store and use long-term energy sources such as glycogen.

The Gallbladder and Biliary Ducts

Exiting from the liver on its caudal surface is the *hepatic duct*. This duct is the collective continuation of the millions of small bile ducts in the portal triad. The hepatic duct carries bile from the liver to the gallbladder and duodenum. The *gallbladder* is closely associated with the liver, both anatomically and functionally. It's a relatively simple, muscular, thin-walled sack that sits tucked between the lobes of the liver on the right side. When empty, the gallbladder mucosa has many folds; when filled with bile, these folds flatten out.

A small duct called the *cystic duct* connects the gallbladder to the hepatic duct. This connection serves as a means for bile to enter and leave the gallbladder. The *common bile duct* starts where the hepatic duct and cystic duct join. This duct ends where the bile duct empties into the duodenum at the major duodenal papilla, where the pancreatic duct empties. Thus, the common bile duct must pass through, or very near, the pancreas before entering the duodenum.

In some cases of pancreatitis, the inflammation spreads to the common bile duct, resulting in swelling of the bile duct wall and a narrowing of the lumen, sometimes to the point of obstructing the flow of bile. The condition of bile duct obstruction can lead to *jaundice*, also called *icterus*, in which yellow bile pigment accumulates in the blood and leads to yellowing of the gums, skin, and whites of the eyes.

The gallbladder serves as a storage site for bile; while the bile is stored, water is reabsorbed from it by the gallbladder, making the bile more concentrated. Under the right conditions after eating, the gallbladder wall contracts, forcing bile down the common bile duct to the duodenum. Bile helps break fat globules into smaller fat globules, a process known as *emulsification*. Emulsification increases the surface area of fat exposed to lipases, increasing the speed and efficiency of fat digestion. It's interesting to note that the horse doesn't have a gallbladder.

Summary

In this part of your program, you've learned how the body's digestive system works as a unit to break food down physically and chemically, absorb the products of digestion, and eliminate the body's waste products. Different species of animals feature unique digestive systems designed to digest specific foods. The gastrointestinal system, pancreas, and liver digest almost any organic material.

Bacterial and protozoal fermentation, enzymes, acids, and bile are all used to digest the food into components small enough to be absorbed by the stomach and intestines. The products of digestion are later used for energy and raw materials as well as to build and repair tissues and maintain the proper internal environment. Any breakdown in these processes can lead to potentially fatal malnutrition.

Now, review the material you've studied here. Once you feel you understand the material, complete the self-check that follows. Then check your answers with those provided at the end of this study unit. If you've missed any answers or you feel unsure of the material, review the material until you feel that you understand the information presented.



Self-Check 1

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

Questions 1–10: Match the following terms with their definitions below by placing the letter of the best definition in the blank space next to each term.

- | | |
|-------------------------|--|
| _____ 1. Fermentation | a. Muscular tube located between the pharynx and stomach |
| _____ 2. Pylorus | b. Outer lining of the gastrointestinal system, composed of connective tissue, blood vessels, and nerves |
| _____ 3. Pulp | c. Inorganic calcified layer of the tooth |
| _____ 4. Serosa | d. Muscular sphincter between the stomach and duodenum |
| _____ 5. Rumen | e. Largest compartment of a compound stomach; site of fermentation |
| _____ 6. Emulsification | f. Process of bacterial digestion of plant material |
| _____ 7. Esophagus | g. Process of breaking up fat globules to improve fat digestion |
| _____ 8. Incisors | h. Sensitive core of the tooth |
| _____ 9. Hydrolysis | i. Basic process of intestinal digestion |
| _____ 10. Enamel | j. Teeth used to cut food |

(Continued)



Self-Check 1

Questions 11–15: Choose the letter of the correct answer.

11. The small intestine is divided into three parts, namely, the
 - a. jejunum, cecum, and ileum.
 - b. jejunum, pylorus, and duodenum.
 - c. jejunum, pancreas, and duodenum.
 - d. jejunum, ileum, and duodenum.
12. The four layers of the gastrointestinal wall, from inside to outside, are
 - a. mucosa, serosa, muscularis, and submucosa.
 - b. mucosa, submucosa, muscularis, and serosa.
 - c. submucosa, mucosa, muscularis, and serosa.
 - d. serosa, muscularis, submucosa, and mucosa.
13. In which area of the gastrointestinal tract does most digestion and absorption occur in a dog?
 - a. Small intestine
 - b. Cecum
 - c. Stomach
 - d. Colon
14. Which enzymes are secreted by the pancreas?
 - a. Trypsinogen, enterokinase, amylase, and lipase
 - b. Lipase, amylase, pepsinogen, and chymotrypsinogen
 - c. Chymotrypsinogen, trypsinogen, lipase, and amylase
 - d. Chymotrypsinogen, enterokinase, pepsinogen, and lipase
15. The portal triad in the liver contains which three structures?
 - a. Hepatic artery, portal vein, and bile duct
 - b. Hepatic vein, portal vein, and bile duct
 - c. Hepatic artery, portal vein, and hepatic vein
 - d. Hepatic artery, central vein, and bile duct

(Continued)



Self-Check 1

Questions 16–19: Fill in the blanks or provide short answers.

16. Digestive _____ are proteins that help break down molecules of proteins, carbohydrates, and fats.

17. What are four functions of the liver?

18. Tall, thin cells lining the surface of villi are _____ that are covered with finger-like projections called _____.

19. Name the four layers of a tooth.

Check your answers with those on page 55.
