PART

II

Maintenance of the Human Body

All of the systems of the body help maintain homeostasis, resulting in a dynamic equilibrium of the internal environment. Our internal environment is the blood within blood vessels and the fluid that surrounds the cells of the tissues. The heart pumps the blood and sends it in vessels to the tissues, where materials are exchanged with tissue fluid. The composition of blood tends to remain relatively constant as a result of the actions of the digestive, respiratory, and urinary systems. Nutrients enter the blood at the small intestine, external gas exchange occurs in the lungs, and metabolic waste products are excreted at the kidneys. The immune system prevents pathogens from taking over the body and interfering with its proper functioning.

Chapter 5

Digestive System and Nutrition

Chapter Concepts

Enjoying the summer night at an outdoor cafe, Sam washes down his last piece of pizza with a sip of wine. Even before Sam swallows his food, the enzymes in his mouth's saliva begin to break starch molecules apart. The wine's alcohol is absorbed in the stomach, where the process of transforming Sam's meal into a nutrient-laden liquid begins. In the small intestine, wormlike projections from the intestinal wall absorb sugars, amino acids, and other needed molecules into Sam's bloodstream. Even the large intestine contributes by taking in needed water and salts. His body now refueled, Sam heads off for a night of dancing.

In this chapter, you will learn how the body digests food, and the importance of proper nutrition. Science is beginning to find the cellular basis for believing that fruits and vegetables, and yes, especially broccoli, can ensure a brighter and healthier life. Sam—and all of us—can play a part by being aware of these findings. Avoiding sugars and fats and consuming protein in moderate amounts can help us maintain a normal weight and avoid certain illnesses.

5.1 The Digestive Tract

Digestion takes place within a tube called the digestive tract, which begins with the mouth and ends with the anus (Fig. 5.1). The functions of the digestive system are to ingest food, digest it to nutrients that can cross plasma membranes, absorb nutrients, and eliminate indigestible remains.

The Mouth

The mouth, which receives food, is bounded externally by the lips and cheeks. The lips extend from the base of the nose to the start of the chin. The red portion of the lips is poorly keratinized, and this allows blood to show through.

Most people enjoy eating food, largely because they like its texture and taste. Sensory receptors called taste buds occur primarily on the tongue. They communicate with the brain where the sensation of taste occurs. The tongue is composed of skeletal muscle whose contraction changes the shape of the tongue. Muscles exterior to the tongue cause it to move about. A fold of mucous membrane attaches the underside of the tongue to the floor of the mouth.

The mouth has a roof that separates it from the nasal cavities. The roof has two parts: an anterior (toward the front) **hard palate** and a posterior (toward the back) **soft palate** (Fig. 5.2*a*). The hard palate contains several bones, while the soft palate does not. The soft palate ends in a finger-shaped projection called the uvula.

The tonsils are in the back of the mouth, on either side of the tongue and in the nasopharynx (where they are called adenoids). If the tonsils become inflamed, the person has **tonsillitis.** If tonsillitis keeps on recurring, the tonsils may be surgically removed (called a tonsillectomy).

Three pairs of **salivary glands** send juices (saliva) by way of ducts to the mouth. One pair of salivary glands lies at the sides of the face immediately below and in front of the ears. These glands swell when a person has the mumps, a disease caused by a viral infection. Salivary glands have ducts that open on the inner surface of the cheek at the location of

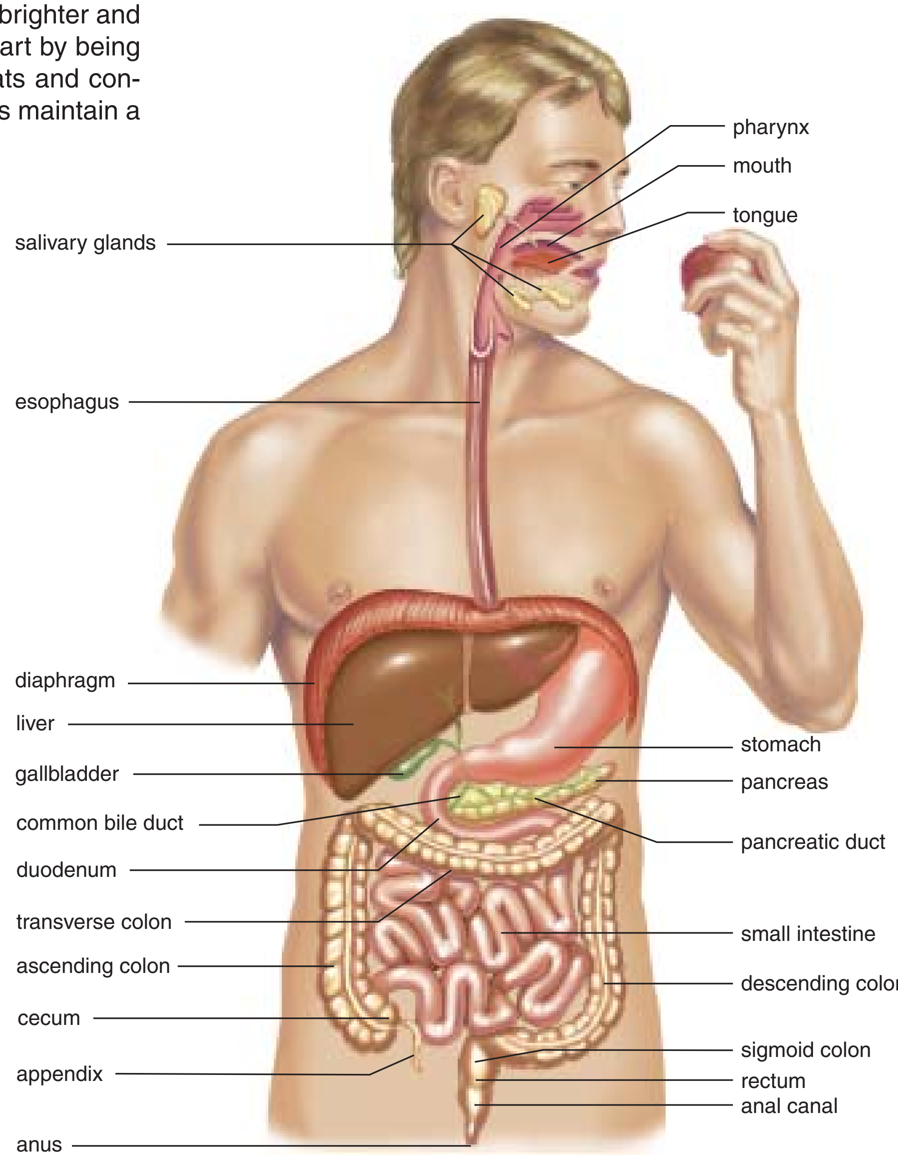


Figure 5.1 **Digestive system.**
Trace the path of food from the mouth to the anus. The large intestine consists of the cecum, the colon (composed of the ascending, transverse, descending, and sigmoid colon), and the rectum and anal canal. Note also the location of the accessory organs of digestion: the pancreas, the liver, and the gallbladder.

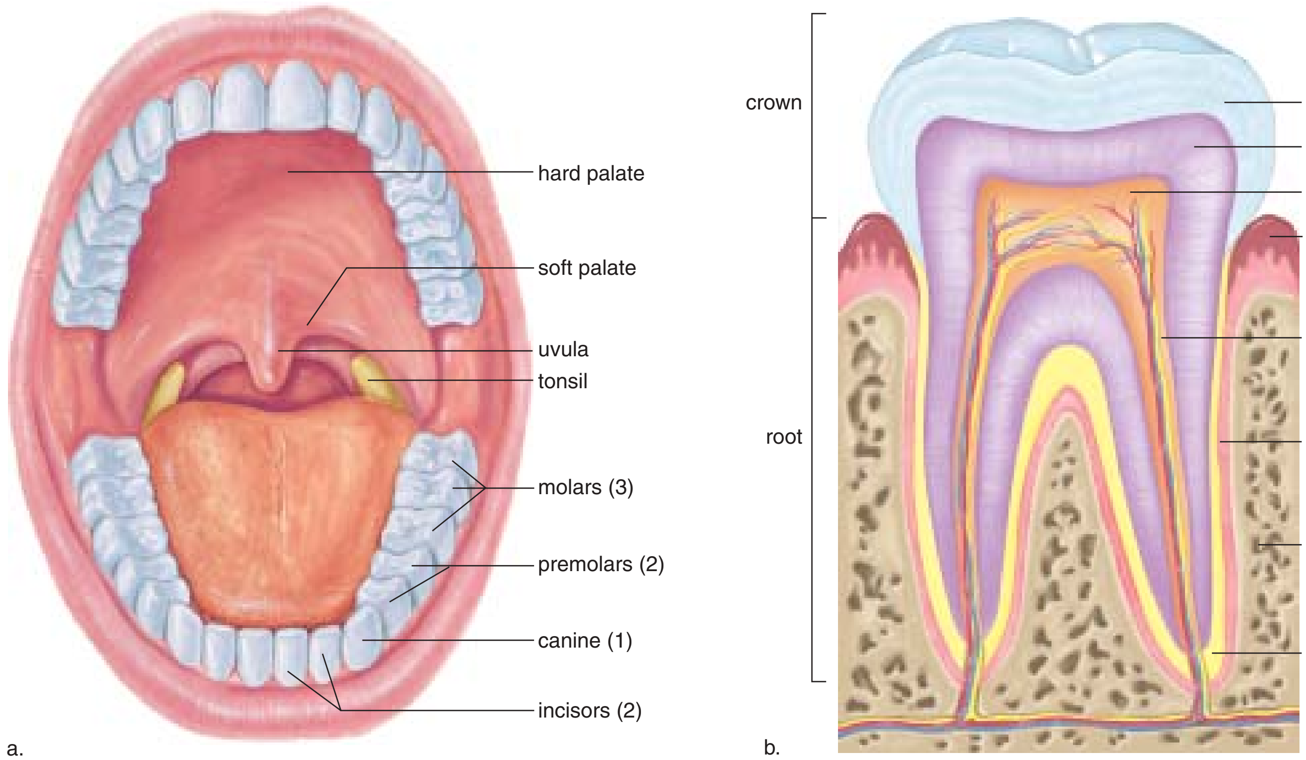


Figure 5.2 **Adult mouth and teeth.**
a. The chisel-shaped incisors bite; the pointed canines tear; the fairly flat premolars grind; and the flattened molars crush food. The last molar, called a wisdom tooth, may fail to erupt, or if it does, it is sometimes crooked and useless. Often dentists recommend the extraction of the wisdom teeth. **b.** Longitudinal section of a tooth. The crown is the portion that projects above the gum line and can be replaced by a dentist if damaged. When a “root canal” is done, the nerves are removed. When the periodontal membrane is inflamed, the teeth can loosen.

the second upper molar. Another pair of salivary glands lies beneath the tongue, and still another pair lies beneath the floor of the mouth. The ducts from these salivary glands open under the tongue. You can locate the openings if you use your tongue to feel for small flaps on the inside of your cheek and under your tongue. Saliva contains bicarbonate and an enzyme called **salivary amylase** that begins the process of digesting starch.

The Teeth

With our teeth, we chew food into pieces convenient for swallowing. During the first two years of life, the smaller 20 deciduous, or baby, teeth appear. These are eventually replaced by 32 adult teeth (Fig. 5.2*a*). The third pair of molars, called the wisdom teeth, sometimes fail to erupt. If they push on the other teeth and/or cause pain, they can be removed by a dentist or oral surgeon.

Each tooth has two main divisions, a crown and a root (Fig. 5.2*b*). The crown has a layer of enamel, an extremely hard outer covering of calcium compounds; dentin, a thick layer of bonelike material; and an inner pulp, which contains the nerves and the blood vessels. Dentin and pulp are also found in the root.

Tooth decay, called **dental caries,** or cavities, occurs when bacteria within the mouth metabolize sugar and give off acids, which erode teeth. Two measures can prevent tooth decay: eating a limited amount of sweets and daily brushing and flossing of teeth. Fluoride treatments, particularly in children, can make the enamel stronger and more resistant to decay. Gum disease is more apt to occur with aging. Inflammation of the gums (gingivitis) can spread to the periodontal membrane, which lines the tooth socket. A person then has periodontitis, characterized by a loss of bone and loosening of the teeth so that extensive dental work may be required. Stimulation of the gums in a manner advised by your dentist is helpful in controlling this condition. Medications are also available.

The tongue mixes the chewed food with saliva. It then forms this mixture into a mass called a bolus in preparation for swallowing.

The salivary glands send saliva into the mouth, where the teeth chew the food and the tongue forms it into a bolus for swallowing.

Table 5.1 Path of Food

Organ	Function of Organ	Special Feature(s)	Function of Special Feature(s)
Mouth	Receives food; starts digestion of starch	Teeth Tongue	Chew food Forms bolus
Pharynx	Passageway	———	———
Esophagus	Passageway	———	———
Stomach	Storage of food; acidity kills bacteria; starts digestion of protein	Gastric glands	Release gastric juices
Small intestine	Digestion of all foods; absorption of nutrients	Intestinal glands Villi	Release intestinal juices Absorb nutrients
Large intestine	Absorption of water; storage of indigestible remains	———	———

The Pharynx

The **pharynx** is a region that receives air from the nasal cavities and food from the mouth. The soft palate has a projection called the uvula, which projects into the pharynx and which people often confuse with the tonsils. The tonsils, however, are embedded in the mucous membrane of the pharynx.

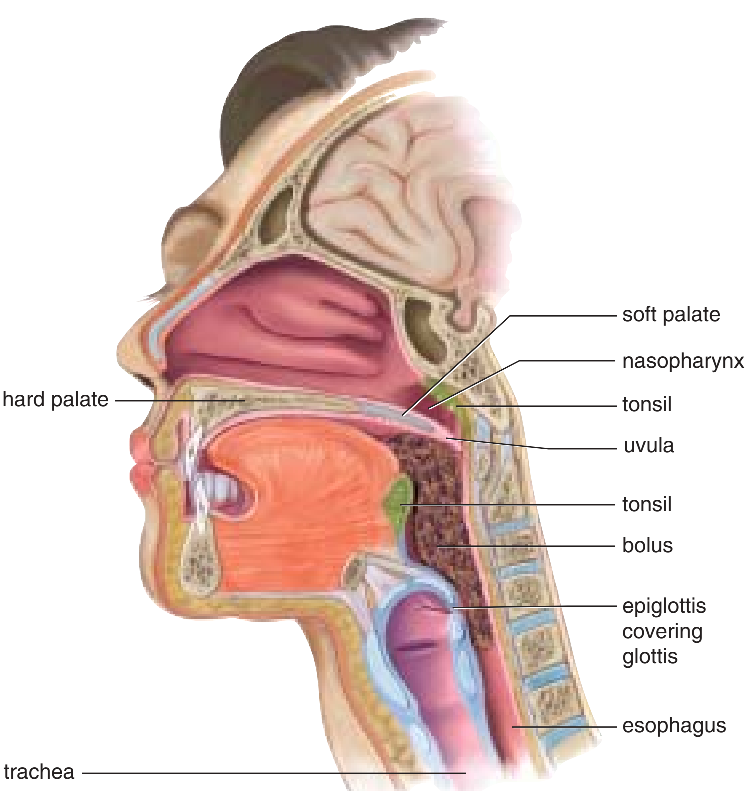


Figure 5.3 **Swallowing.**
When food is swallowed, the soft palate closes off the nasopharynx, and the epiglottis covers the glottis, forcing the bolus to pass down the esophagus. Therefore, a person does not breathe while swallowing.

Table 5.1 traces the path of food. From the mouth, food passes through the pharynx and esophagus to the stomach, small intestine, and large intestine. The food passage and air passage cross in the pharynx because the trachea (windpipe) is anterior to (in front of) the esophagus, a long muscular tube that takes food to the stomach. Swallowing, a process that occurs in the pharynx (Fig. 5.3), is a **reflex action** performed automatically, without conscious thought. Usually during swallowing, the soft palate moves back to close off the **nasopharynx,** and the trachea moves up under the **epiglottis** to cover the glottis. The **glottis** is the opening to the larynx (voice box) and therefore the air passage. During swallowing, food normally enters the esophagus because the air passages are blocked. We do not breathe when we swallow.

Unfortunately, we have all had the unpleasant experience of having food "go the wrong way." The wrong way may be either into the nasal cavities or into the trachea. If it is the latter, coughing will most likely force the food up out of the trachea and into the pharynx again. The up-and-down movement of the Adam's apple, the front part of the larynx, is easy to observe when a person swallows.

The Esophagus

The **esophagus** is a muscular tube that passes from the pharynx through the thoracic cavity and diaphragm into the abdominal cavity, where it joins the stomach. The esophagus is ordinarily collapsed, but it opens and receives the bolus when swallowing occurs.

A rhythmic contraction called **peristalsis** pushes the food along the digestive tract. Peristalsis begins in the esophagus and continues in all the organs of the digestive tract.

Occasionally, peristalsis begins even though there is no food in the esophagus. This produces the sensation of a lump in the throat.

The esophagus plays no role in the chemical digestion of food. Its sole purpose is to conduct the food bolus from the mouth to the stomach. **Sphincters** are muscles that encircle tubes and act as valves; tubes close when sphincters contract, and they open when sphincters relax. The entrance of the esophagus to the stomach is marked by a constriction, often called a sphincter, although the muscle is not as developed as in a true sphincter. Relaxation of the sphincter allows the bolus to pass into the stomach, while contraction prevents the acidic contents of the stomach from backing up into the esophagus.

Heartburn, which feels like a burning pain rising up into the throat, occurs during reflux when some of the stomach contents escape into the esophagus. When vomiting occurs, a contraction of the abdominal muscles and diaphragm propels the contents of the stomach upward through the esophagus.

> The air passage and food passage cross in the pharynx, which takes food to the esophagus. The esophagus conducts the bolus of food from the pharynx to the stomach. Peristalsis begins in the esophagus and occurs along the entire length of the digestive tract.

The Wall of the Digestive Tract

The wall of the esophagus in the abdominal cavity is comparable to that of the digestive tract, which has these layers (Fig. 5.4):

Mucosa (mucous membrane layer) A layer of epithelium supported by connective tissue and smooth muscle lines the **lumen** (central cavity) and contains glandular epithelial cells that secrete digestive enzymes and goblet cells that secrete mucus.

Submucosa (submucosal layer) A broad band of loose connective tissue that contains blood vessels lies beneath the mucosa. Lymph nodules, called Peyer's patches, are in the submucosa. Like the tonsils, they help protect us from disease.

Muscularis (smooth muscle layer) Two layers of smooth muscle make up this section. The inner, circular layer encircles the gut; the outer, longitudinal layer lies in the same direction as the gut. (The stomach also has oblique muscles.)

Serosa (serous membrane layer) Most of the digestive tract has a serosa, a very thin, outermost layer of squamous epithelium supported by connective tissue. The serosa secretes a serous fluid that keeps the outer surface of the intestines moist so that the organs of the abdominal cavity slide against one another. The esophagus has an outer layer composed only of loose connective tissue called the adventitia.

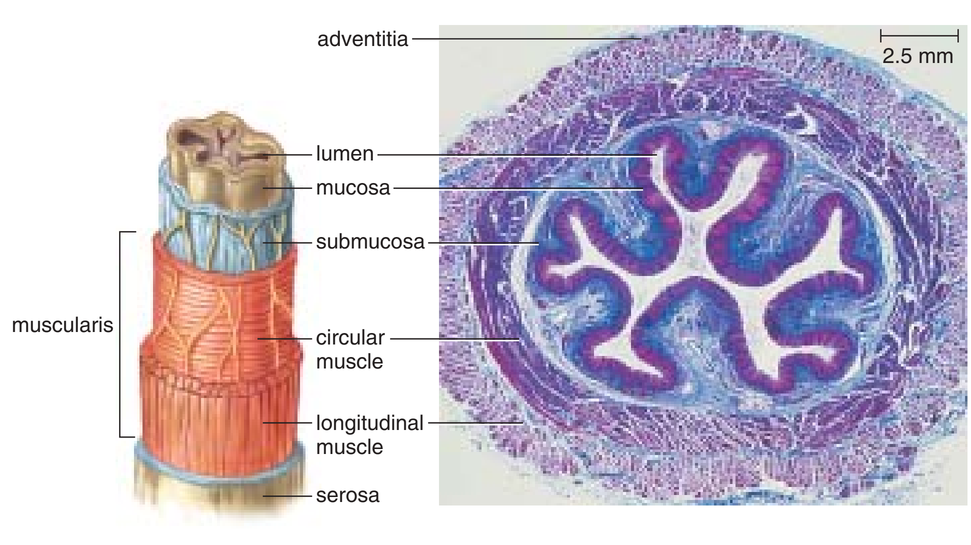


Figure 5.4 **Wall of the digestive tract.**
a. Several different types of tissues are found in the wall of the digestive tract. Note the placement of circular muscle inside longitudinal muscle.
b. Micrograph of the wall of the esophagus.

The Stomach

The **stomach** (Fig. 5.5) is a thick-walled, J-shaped organ that lies on the left side of the body beneath the diaphragm. The stomach is continuous with the esophagus above and the duodenum of the small intestine below. The stomach stores food and aids in digestion. The wall of the stomach has deep folds, which disappear as the stomach fills to an approximate capacity of one liter. Its muscular wall churns, mixing the food with gastric juice. The term *gastric* always refers to the stomach.

The columnar epithelial lining of the stomach has millions of gastric pits, which lead into **gastric glands.** The gastric glands produce gastric juice. Gastric juice contains an enzyme called **pepsin,** which digests protein, plus hydrochloric acid (HCl) and mucus. HCl causes the stomach to have a high acidity with a pH of about 2, and this is beneficial because it kills most bacteria present in food. Although HCl does not digest food, it does break down the connective tissue of meat and activate pepsin. The wall of the stomach is protected by a thick layer of mucus secreted by goblet cells in its lining. If, by chance, HCl penetrates this mucus, the wall can begin to break down, and an ulcer results. An **ulcer** is an open sore in the wall caused by the gradual disintegration of tissue. It now appears that most ulcers are due to a bacterial infection *(Helicobacter pylori)* that impairs the ability of epithelial cells to produce protective mucus.

Alcohol is absorbed in the stomach, but food substances are not. Normally, the stomach empties in about 2–6 hours. When food leaves the stomach, it is a thick, soupy liquid called **chyme.** Chyme enters the small intestine in squirts by way of a sphincter that repeatedly opens and closes.

The stomach can expand to accommodate large amounts of food. When food is present, the stomach churns, mixing food with acidic gastric juice.

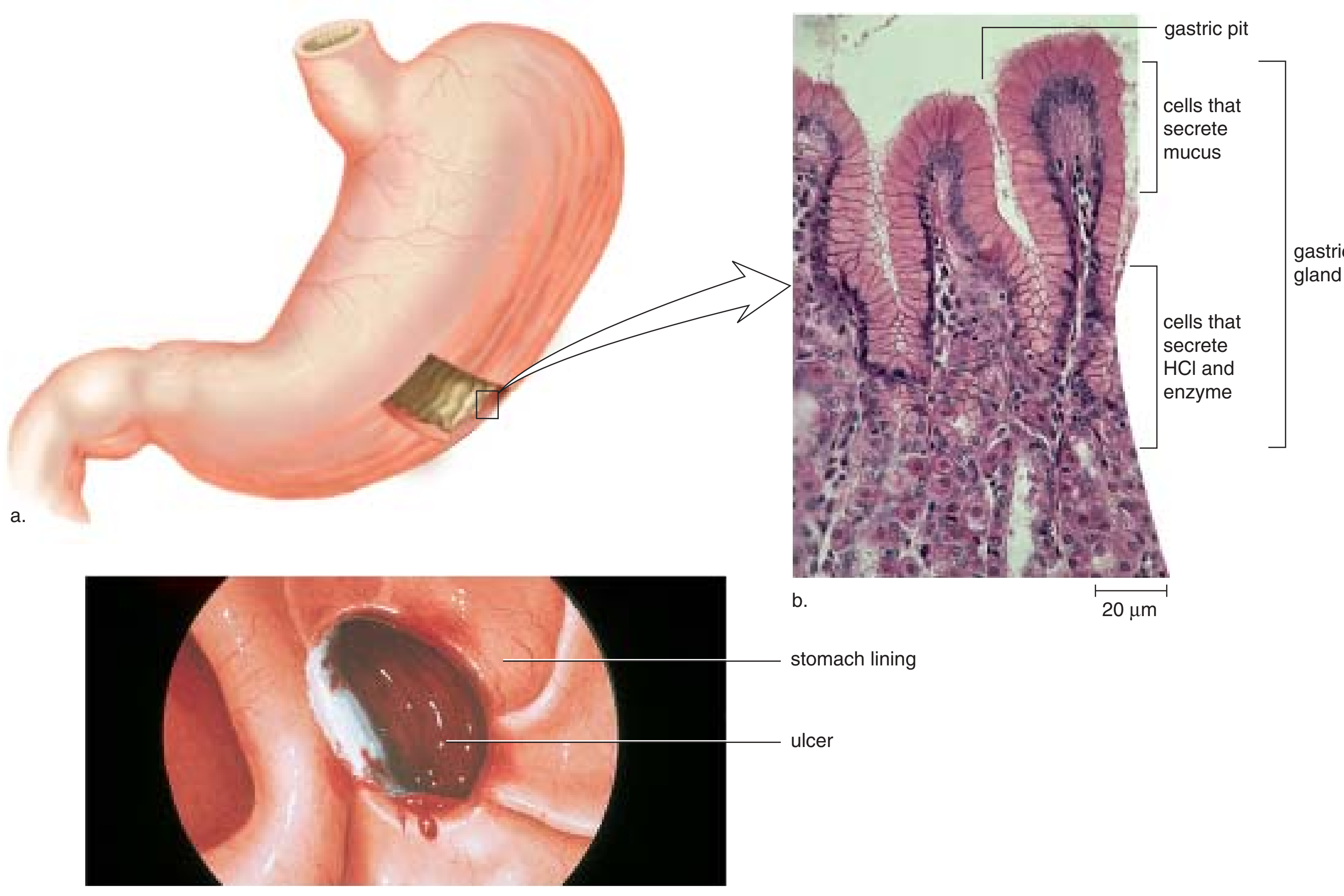


Figure 5.5 Anatomy and histology of the stomach.
a. The stomach has a thick wall with folds that allow it to expand and fill with food. **b.** The lining contains gastric glands, which secrete mucus and a gastric juice active in protein digestion. **c.** A bleeding ulcer viewed through an endoscope (a tubular instrument bearing a tiny lens and a light source) inserted into the abdominal cavity.

The Small Intestine

The **small intestine** is named for its small diameter (compared to that of the large intestine), but perhaps it should be called the long intestine. The small intestine averages about 6 m (18 ft) in length, compared to the large intestine, which is about 1.5 m (4½ ft) in length.

The first 25 cm of the small intestine is called the **duodenum.** A duct brings bile from the liver and gallbladder, and pancreatic juice from the pancreas, into the small intestine (see Fig. 5.1). **Bile** emulsifies fat—emulsification causes fat droplets to disperse in water. The intestine has a slightly basic pH because pancreatic juice contains sodium bicarbonate ($NaHCO_3$), which neutralizes chyme. The enzymes in pancreatic juice and the enzymes produced by the intestinal wall complete the process of food digestion.

It has been suggested that the surface area of the small intestine is approximately that of a tennis court. What factors contribute to increasing its surface area? The wall of the small intestine contains fingerlike projections called villi (sing., **villus**), which give the intestinal wall a soft, velvety appearance (Fig. 5.6). A villus has an outer layer of columnar epithelial cells, and each of these cells has thousands of microscopic extensions called microvilli. Collectively, in electron micrographs, microvilli give the villi a fuzzy border known as a "brush border." Since the microvilli bear the intestinal enzymes, these enzymes are called brush-border enzymes. The microvilli greatly increase the surface area of the villus for the absorption of nutrients.

Nutrients are absorbed into the vessels of a villus. A villus contains blood capillaries and a small lymphatic capillary, called a **lacteal.** The lymphatic system is an adjunct to the cardiovascular system; its vessels carry a fluid called lymph to the cardiovascular veins. Sugars (digested from carbohydrates) and amino acids (digested from proteins) enter the blood capillaries of a villus. Glycerol and fatty acids (digested from fats) enter the epithelial cells of the villi, and within these cells are joined and packaged as lipoprotein droplets, which enter a lacteal. After nutrients are absorbed, they are eventually carried to all the cells of the body by the bloodstream.

The large surface area of the small intestine facilitates absorption of nutrients into the cardiovascular system (sugars and amino acids) and the lymphatic system (fats).

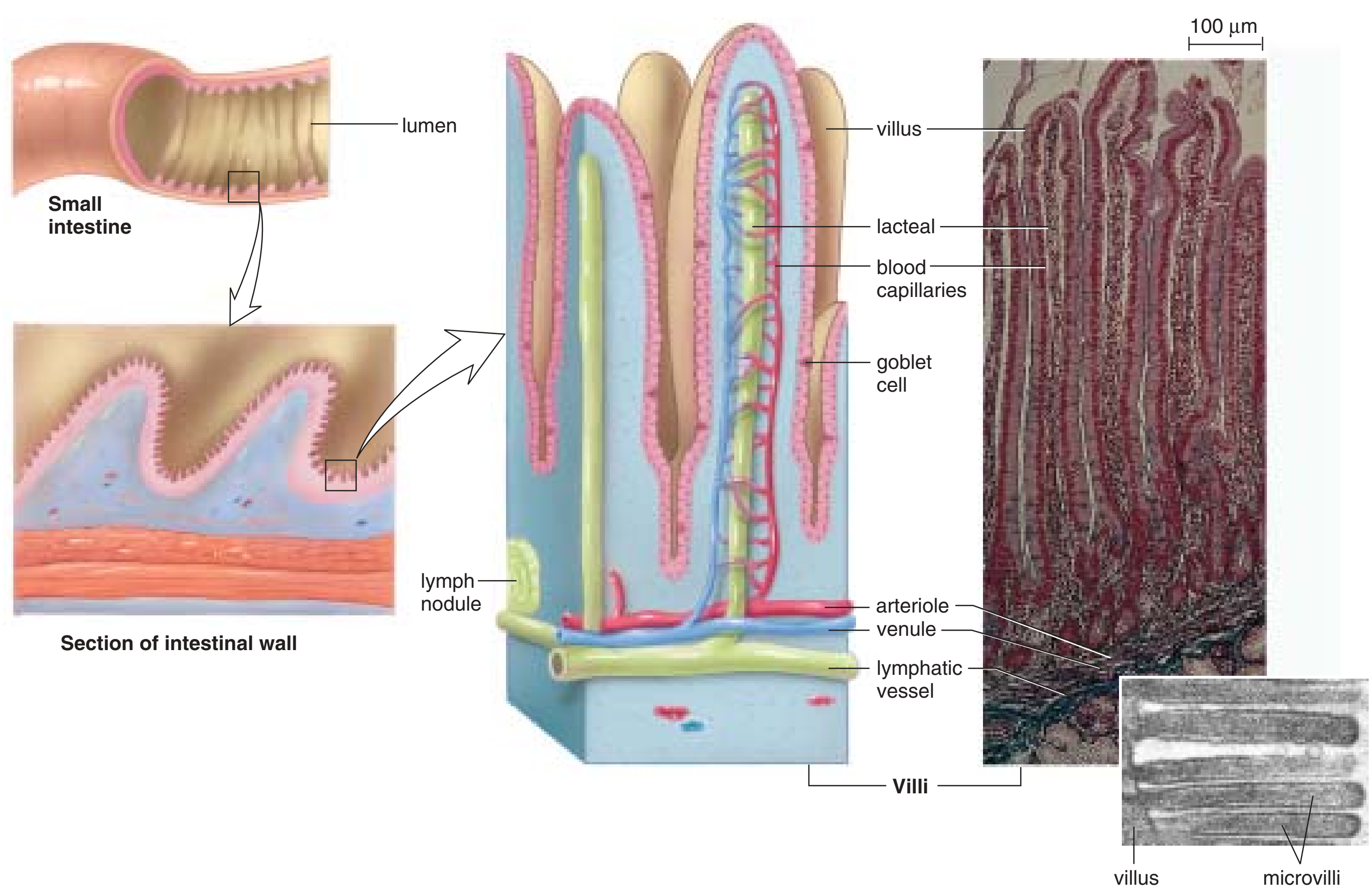


Figure 5.6 **Anatomy of the small intestine.**
The wall of the small intestine has folds that bear fingerlike projections called villi. The products of digestion are absorbed into the blood capillaries and the lacteals of the villi by microvilli which project from the villi.

Regulation of Digestive Secretions

The secretion of digestive juices is promoted by the nervous system and by hormones. A **hormone** is a substance produced by one set of cells that affects a different set of cells, the so-called target cells. Hormones are usually transported by the bloodstream. For example, when a person has eaten a meal particularly rich in protein, the stomach produces the hormone gastrin. Gastrin enters the bloodstream, and soon the stomach is churning, and the secretory activity of gastric glands is increasing. A hormone produced by the duodenal wall, GIP (gastric inhibitory peptide), works opposite to gastrin: It inhibits gastric gland secretion.

Cells of the duodenal wall produce two other hormones that are of particular interest—secretin and CCK (cholecystokinin). Acid, especially hydrochloric acid (HCl) present in chyme, stimulates the release of secretin, while partially digested protein and fat stimulate the release of CCK. Soon after these hormones enter the bloodstream, the pancreas increases its output of pancreatic juice, which helps digest food, and the gallbladder increases its output of bile. The gallbladder contracts to release stored bile. Figure 5.7 summarizes the actions of gastrin, secretin, and CCK.

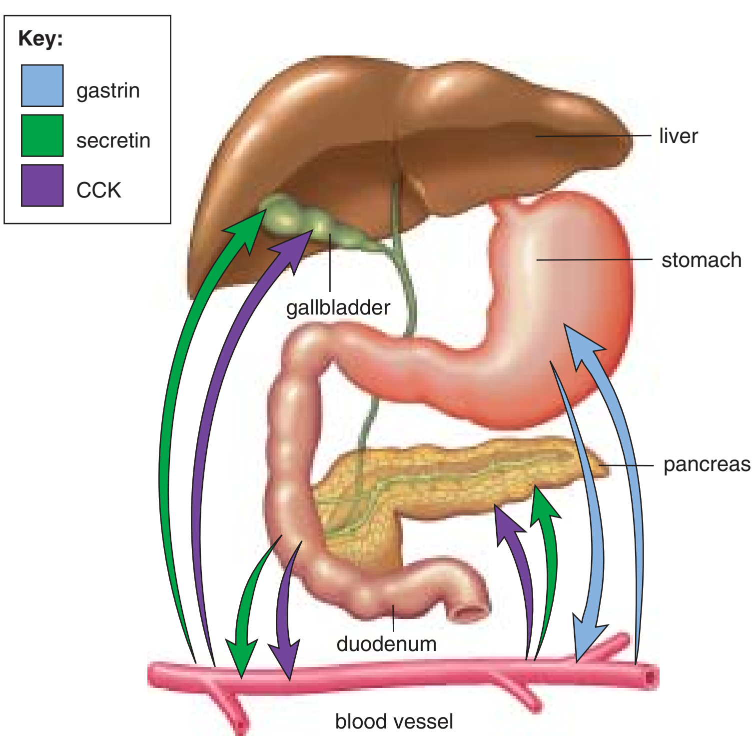


Figure 5.7 Hormonal control of digestive gland secretions. Gastrin (blue), produced by the lower part of the stomach, enters the bloodstream and thereafter stimulates the upper part of the stomach to produce more gastric juice. Secretin (green) and CCK (purple), produced by the duodenal wall, stimulate the pancreas to secrete its juice and the gallbladder to release bile.

The Large Intestine

The **large intestine,** which includes the cecum, the colon, the rectum, and the anal canal, is larger in diameter than the small intestine (6.5 cm compared to 2.5 cm), but it is shorter in length (see Fig. 5.1). The large intestine absorbs water, salts, and some vitamins. It also stores indigestible material until it is eliminated at the anus.

The **cecum,** which lies below the junction with the small intestine, is the blind end of the large intestine. The cecum has a small projection called the **vermiform appendix** (*vermiform* means wormlike) (Fig. 5.8). In humans, the appendix also may play a role in fighting infections. This organ is subject to inflammation, a condition called appendicitis. If inflamed, the appendix should be removed before the fluid content rises to the point that the appendix bursts, a situation that may cause **peritonitis,** a generalized infection of the lining of the abdominal cavity. Peritonitis can lead to death.

The **colon** includes the ascending colon, which goes up the right side of the body to the level of the liver; the transverse colon, which crosses the abdominal cavity just below the liver and the stomach; the descending colon, which passes down the left side of the body; and the sigmoid colon, which enters the **rectum,** the last 20 cm of the large intestine. The rectum opens at the **anus,** where **defecation,** the expulsion of feces, occurs. When feces are forced into the rectum by peristalsis, a defecation reflex occurs. The stretching of the rectal wall initiates nerve impulses to the spinal cord, and shortly thereafter the rectal muscles contract and the anal sphincters relax (Fig. 5.9). Ridding the body of indigestible remains is another way the digestive system helps maintain homeostasis.

Feces are three-quarters water and one-quarter solids. Bacteria, **fiber** (indigestible remains), and other indigestible materials are in the solid portion. Bacterial action on indigestible materials causes the odor of feces and also accounts for the presence of gas. A breakdown product of bilirubin (see page 86) and the presence of oxidized iron cause the brown color of feces.

For many years, it was believed that facultative bacteria (bacteria that can live with or without oxygen), such as *Escherichia coli,* were the major inhabitants of the colon, but new culture methods show that over 99% of the colon bacteria are obligate anaerobes (bacteria that die in the presence of oxygen). Not only do the bacteria break down indigestible material, but they also produce B complex vitamins and most of the vitamin K needed by our bodies. In this way, they perform a service for us.

Water is considered unsafe for swimming when the coliform (nonpathogenic intestinal) bacterial count reaches a certain number. A high count indicates that a significant amount of feces has entered the water. The more feces present, the greater the possibility that disease-causing bacteria are also present.

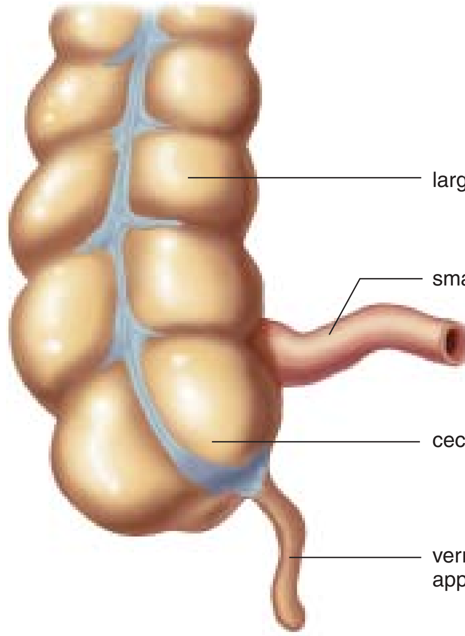


Figure 5.8 Junction of the small intestine and the large intestine.
The cecum is the blind end of the ascending colon. The vermiform appendix is attached to the cecum.

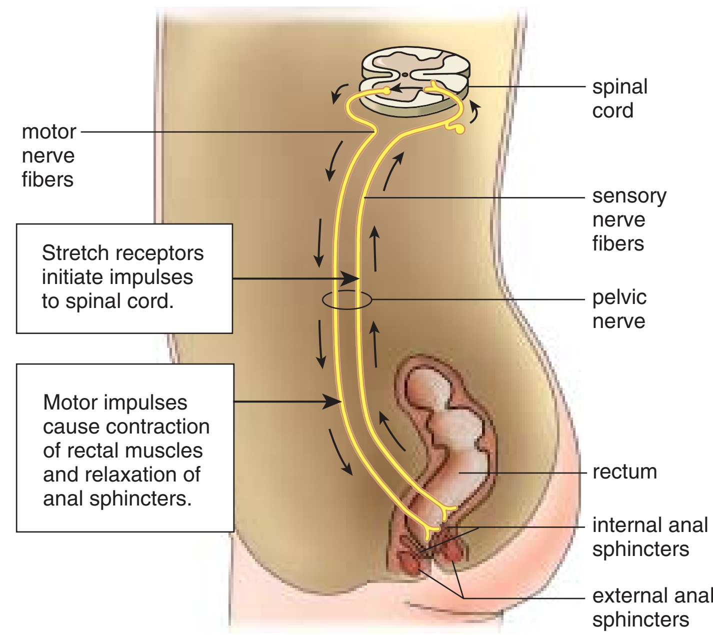


Figure 5.9 Defecation reflex.
The accumulation of feces in the rectum causes it to stretch, which initiates a reflex action resulting in rectal contraction and expulsion of the fecal material.

Polyps

The colon is subject to the development of **polyps,** small growths arising from the epithelial lining. Polyps, whether benign or cancerous, can be removed surgically. If colon cancer is detected while still confined to a polyp, the expected outcome is a complete cure. Some investigators believe that dietary fat increases the likelihood of colon cancer because dietary fat causes an increase in bile secretion. It could be that intestinal bacteria convert bile salts to substances that promote the development of cancer. On the other hand, fiber in the diet seems to inhibit the development of colon cancer. Dietary fiber absorbs water and adds bulk, thereby diluting the concentration of bile salts and facilitating the movement of substances through the intestine. Regular elimination reduces the time that the colon wall is exposed to any cancer-promoting agents in feces.

Diarrhea and Constipation

Two common everyday complaints associated with the large intestine are **diarrhea** and **constipation.** The major causes of diarrhea are infection of the lower intestinal tract and nervous stimulation. In the case of infection, such as food poisoning caused by eating contaminated food, the intestinal wall becomes irritated, and peristalsis increases. Water is not absorbed, and the diarrhea that results rids the body of the infectious organisms. In nervous diarrhea, the nervous system stimulates the intestinal wall, and diarrhea results. Prolonged diarrhea can lead to dehydration because of water loss and to disturbances in the heart's contraction due to an imbalance of salts in the blood.

When a person is constipated, the feces are dry and hard. One reason for this condition is that socialized persons have learned to inhibit defecation to the point that the urge to defecate is ignored. Two components of the diet that can help prevent constipation are water and fiber. Water intake prevents drying out of the feces, and fiber provides the bulk needed for elimination. The frequent use of laxatives is discouraged. If, however, it is necessary to take a laxative, a bulk laxative is the most natural because, like fiber, it produces a soft mass of cellulose in the colon. Lubricants, such as mineral oil, make the colon slippery; saline laxatives, such as milk of magnesia, act osmotically—they prevent water from being absorbed and, depending on the dosage, may even cause water to enter the colon. Some laxatives are irritants, meaning that they increase peristalsis to the degree that the contents of the colon are expelled.

Chronic constipation is associated with the development of hemorrhoids, enlarged and inflamed blood vessels at the anus.

The large intestine does not produce digestive enzymes; it does absorb water, salts, and some vitamins.

5.2 Three Accessory Organs

The pancreas, liver, and gallbladder are accessory digestive organs. Figure 5.1 shows how the pancreatic duct from the pancreas and the common bile duct from the liver and gallbladder join before entering the duodenum.

The Pancreas

The **pancreas** lies deep in the abdominal cavity, resting on the posterior abdominal wall. It is an elongated and somewhat flattened organ that has both an endocrine and an exocrine function. As an endocrine gland, it secretes insulin and glucagon, hormones that help keep the blood glucose level within normal limits. In this chapter, however, we are interested in its exocrine function. Most pancreatic cells produce pancreatic juice, which contains sodium bicarbonate ($NaHCO_3$) and digestive enzymes for all types of food. Sodium bicarbonate neutralizes chyme from the stomach. Whereas the enzyme pepsin acts best in the acid pH of the stomach, pancreatic enzymes require a slightly basic pH. **Pancreatic amylase** digests starch, **trypsin** digests protein, and **lipase** digests fat. In cystic fibrosis, a thick mucus blocks the pancreatic duct, and the patient must take supplemental pancreatic enzymes by mouth for proper digestion to occur.

The Liver

The **liver,** which is the largest gland in the body, lies mainly in the upper right section of the abdominal cavity, under the diaphragm (see Fig. 5.1). The liver has two main lobes, the right lobe and the smaller left lobe, which crosses the midline and lies above the stomach. The liver contains approximately 100,000 lobules that serve as its structural and functional units (Fig. 5.10). Triads consisting of these three structures are located between the lobules: a bile duct that takes bile away from the liver; a branch of the hepatic artery that brings O_2-rich blood to the liver; and a branch of the hepatic portal vein that transports nutrients from the intestines to the liver. In contrast, the central veins of lobules enter a hepatic vein. In Figure 5.11, trace the path of blood from the intestines to the liver via the hepatic portal vein and from the liver to the inferior vena cava via the hepatic veins.

In some ways, the liver acts as the gatekeeper to the blood. As the blood from the hepatic portal vein passes through the liver, it removes poisonous substances and detoxifies them. The liver also removes and stores iron and the fat-soluble vitamins A, D, E, and K. The liver makes certain types of the plasma proteins, and helps regulate the quantity of cholesterol in the blood.

The liver maintains the blood glucose level at about 100 mg/100 ml (0.1%), even though a person eats intermittently. When insulin is present, any excess glucose in blood is removed and stored by the liver as glycogen. Between meals, glycogen is broken down to glucose, which enters the hepatic veins, and in this way, the blood glucose level remains constant.

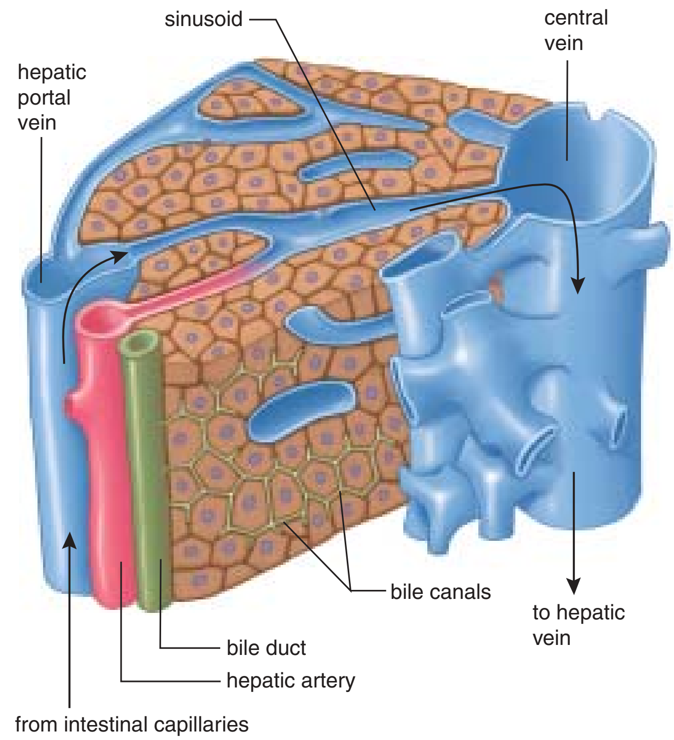


Figure 5.10 **Hepatic lobules.**
The liver contains over 100,000 lobules. Each lobule contains many cells that perform the various functions of the liver. They remove materials from and/or add materials to the blood, and deposit bile in bile ducts.

If the supply of glycogen is depleted, the liver converts glycerol (from fats) and amino acids to glucose molecules. The conversion of amino acids to glucose necessitates deamination, the removal of amino groups and the production of ammonia. By a complex metabolic pathway, the liver then combines ammonia with carbon dioxide to form urea:

$$\underset{\text{ammonia}}{2\,NH_3} + \underset{\text{carbon dioxide}}{CO_2} \longrightarrow \underset{\text{urea}}{H_2N-\overset{\overset{\displaystyle O}{\|}}{C}-NH_2}$$

Urea is the usual nitrogenous waste product from amino acid breakdown in humans. After its formation in the liver, urea is excreted by the kidneys.

The liver produces bile, which is stored in the gallbladder. Bile has a yellowish-green color because it contains the bile pigment bilirubin, derived from the breakdown of hemoglobin, the red pigment of red blood cells. Bile also contains bile salts. Bile salts are derived from

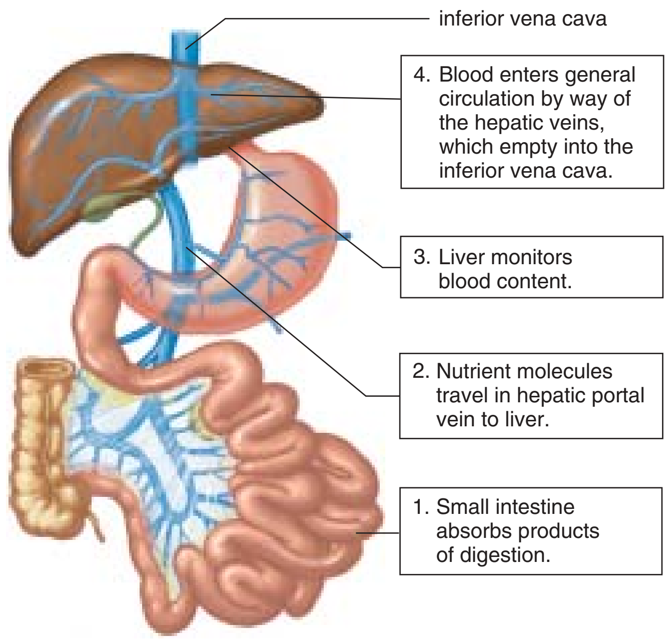


Figure 5.11 **Hepatic portal system.**
The hepatic portal vein takes the products of digestion from the digestive system to the liver, where they are processed before entering a hepatic vein.

cholesterol, and they emulsify fat in the small intestine. When fat is emulsified, it breaks up into droplets, providing a much larger surface area, which can be acted upon by a digestive enzyme from the pancreas.

Altogether, the following are significant ways in which the liver helps maintain homeostasis:

1. Detoxifies blood by removing and metabolizing poisonous substances.
2. Stores iron (Fe^{2+}) and the fat-soluble vitamins A, D, E, and K.
3. Makes plasma proteins, such as albumins and fibrinogen, from amino acids.
4. Stores glucose as glycogen after a meal, and breaks down glycogen to glucose to maintain the glucose concentration of blood between eating periods.
5. Produces urea after breaking down amino acids.
6. Destroys old red blood cells, excretes bilirubin, a breakdown product of hemoglobin, in bile, a liver product.
7. Helps regulate blood cholesterol level, converting some to bile salts.

Liver Disorders

Hepatitis and cirrhosis are two serious diseases that affect the entire liver and hinder its ability to repair itself. Therefore, they are life-threatening diseases. When a person has a liver ailment, jaundice may occur. **Jaundice** is a yellowish tint to the whites of the eyes and also to the skin of light-pigmented persons. Bilirubin is deposited in the skin due to an abnormally large amount in the blood. In hemolytic jaundice, red blood cells have been broken down in abnormally large amounts; in obstructive jaundice, bile ducts are blocked or liver cells are damaged.

Jaundice can also result from **hepatitis,** inflammation of the liver. Viral hepatitis occurs in several forms. Hepatitis A is usually acquired from sewage-contaminated drinking water. Hepatitis B, which is usually spread by sexual contact, can also be spread by blood transfusions or contaminated needles. The hepatitis B virus is more contagious than the AIDS virus, which is spread in the same way. Thankfully, however, a vaccine is now available for hepatitis B. Hepatitis C, which is usually acquired by contact with infected blood and for which there is no vaccine, can lead to chronic hepatitis, liver cancer, and death.

Cirrhosis is another chronic disease of the liver. First the organ becomes fatty, and then liver tissue is replaced by inactive fibrous scar tissue. Cirrhosis of the liver is often seen in alcoholics due to malnutrition and the excessive amounts of alcohol (a toxin) the liver is forced to break down.

The liver has amazing regenerative powers and can recover if the rate of regeneration exceeds the rate of damage. During liver failure, however, there may not be enough time to let the liver heal itself. Liver transplantation is usually the preferred treatment for liver failure, but artificial livers have been developed and tried in a few cases. One type is a cartridge that contains liver cells. The patient's blood passes through the cellulose acetate tubing of the cartridge and is serviced in the same manner as with a normal liver. In the meantime, the patient's liver has a chance to recover.

The Gallbladder

The **gallbladder** is a pear-shaped, muscular sac attached to the surface of the liver (see Fig. 5.1). About 1,000 ml of bile are produced by the liver each day, and any excess is stored in the gallbladder. Water is reabsorbed by the gallbladder so that bile becomes a thick, mucuslike material. When needed, bile leaves the gallbladder and proceeds to the duodenum via the common bile duct.

The cholesterol content of bile can come out of solution and form crystals. If the crystals grow in size, they form gallstones. The passage of the stones from the gallbladder may block the common bile duct and cause obstructive jaundice. Then the gallbladder may have to be removed.

The pancreas produces pancreatic juice, which contains enzymes for the digestion of food. Among the liver's many functions is the production of bile, which is stored in the gallbladder.

5.3 Digestive Enzymes

The digestive enzymes are **hydrolytic enzymes,** which break down substances by the introduction of water at specific bonds. Digestive enzymes, like other enzymes, are proteins with a particular shape that fits their substrate. They also have an optimum pH, which maintains their shape, thereby enabling them to speed up their specific reaction.

The various digestive enzymes present in the gastric, pancreatic, and intestinal juices, mentioned previously, help break down carbohydrates, proteins, nucleic acids, and fats, the major components of food. Starch is a carbohydrate, and its digestion begins in the mouth. Saliva from the salivary glands has a neutral pH and contains **salivary amylase,** the first enzyme to act on starch:

$$\text{starch} + H_2O \xrightarrow{\text{salivary amylase}} \text{maltose}$$

In this equation, salivary amylase is written above the arrow to indicate that it is neither a reactant nor a product in the reaction. It merely speeds the reaction in which its substrate, starch, is digested to many molecules of maltose, a disaccharide. Maltose molecules cannot be absorbed by the intestine; additional digestive action in the small intestine converts maltose to glucose, which can be absorbed.

Protein digestion begins in the stomach. Gastric juice secreted by gastric glands has a very low pH—about 2—because it contains hydrochloric acid (HCl). Pepsinogen, a precursor that is converted to the enzyme **pepsin** when exposed to HCl, is also present in gastric juice. Pepsin acts on protein to produce peptides:

$$\text{protein} + H_2O \xrightarrow{\text{pepsin}} \text{peptides}$$

Peptides vary in length, but they always consist of a number of linked amino acids. Peptides are usually too large to be absorbed by the intestinal lining, but later they are broken down to amino acids in the small intestine.

Starch, proteins, nucleic acids, and fats are all enzymatically broken down in the small intestine. Pancreatic juice, which enters the duodenum, has a basic pH because it contains sodium bicarbonate ($NaHCO_3$). Sodium bicarbonate neutralizes chyme, producing the slightly basic pH that is optimum for pancreatic enzymes. One pancreatic enzyme, **pancreatic amylase,** digests starch:

$$\text{starch} + H_2O \xrightarrow{\text{pancreatic amylase}} \text{maltose}$$

Another pancreatic enzyme, **trypsin,** digests protein:

$$\text{protein} + H_2O \xrightarrow{\text{trypsin}} \text{peptides}$$

Trypsin is secreted as trypsinogen, which is converted to trypsin in the duodenum.

Lipase, a third pancreatic enzyme, digests fat molecules in the fat droplets after they have been emulsified by bile salts:

$$\text{fat} \xrightarrow{\text{bile salts}} \text{fat droplets}$$

$$\text{fat droplets} + H_2O \xrightarrow{\text{lipase}} \text{glycerol} + \text{fatty acids}$$

The end products of lipase digestion, glycerol and fatty acid molecules, are small enough to cross the cells of the intestinal villi, where absorption takes place. As mentioned previously, glycerol and fatty acids enter the cells of the villi, and within these cells, they are rejoined and packaged as lipoprotein droplets before entering the lacteals (see Fig. 5.6).

Peptidases and **maltase,** enzymes produced by the small intestine, complete the digestion of protein to amino acids and starch to glucose, respectively. Amino acids and glucose are small molecules that cross the cells of the villi and enter the blood. Peptides, which result from the first step in protein digestion, are digested to amino acids by peptidases:

$$\text{peptides} + H_2O \xrightarrow{\text{peptidases}} \text{amino acids}$$

Maltose, a disaccharide that results from the first step in starch digestion, is digested to glucose by maltase:

$$\text{maltose} + H_2O \xrightarrow{\text{maltase}} \text{glucose} + \text{glucose}$$

Other disaccharides, each of which has its own enzyme, are digested in the small intestine. The absence of any one of these enzymes can cause illness. For example, many people, including as many as 75% of African Americans, cannot digest lactose, the sugar found in milk, because they do not produce lactase, the enzyme that converts lactose to its components, glucose and galactose. Drinking untreated milk often gives these individuals the symptoms of **lactose intolerance** (diarrhea, gas, cramps), caused by a large quantity of nondigested lactose in the intestine. In most areas, it is possible to purchase milk made lactose-free by the addition of synthetic lactase or *Lactobacillus acidophilus* bacteria, which break down lactose.

Each type of food is broken down by specific enzymes. Table 5.2 lists some of the major digestive enzymes produced by the digestive tract, salivary glands, or the pancreas.

> Digestive enzymes present in digestive juices help break down food to the nutrient molecules: glucose, amino acids, fatty acids, and glycerol. The first two are absorbed into the blood capillaries of the villi, and the last two re-form within epithelial cells before entering the lacteals as lipoprotein droplets.

Table 5.2 Major Digestive Enzymes

Enzyme	Produced By	Site of Action	Optimum pH	Digestion
Salivary amylase	Salivary glands	Mouth	Neutral	Starch + H_2O → maltose
Pancreatic amylase	Pancreas	Small intestine	Basic	
Maltase	Small intestine	Small intestine	Basic	Maltose + H_2O → glucose + glucose
Pepsin	Gastric glands	Stomach	Acidic	Protein + H_2O → peptides
Trypsin	Pancreas	Small intestine	Basic	
Peptidases	Small intestine	Small intestine	Basic	Peptide + H_2O → amino acids
Nuclease	Pancreas	Small intestine	Basic	RNA and DNA + H_2O → nucleotides
Nucleosidases	Small intestine	Small intestine	Basic	Nucleotide + H_2O → base + sugar + phosphate
Lipase	Pancreas	Small intestine	Basic	Fat droplet + H_2O → glycerol + fatty acids

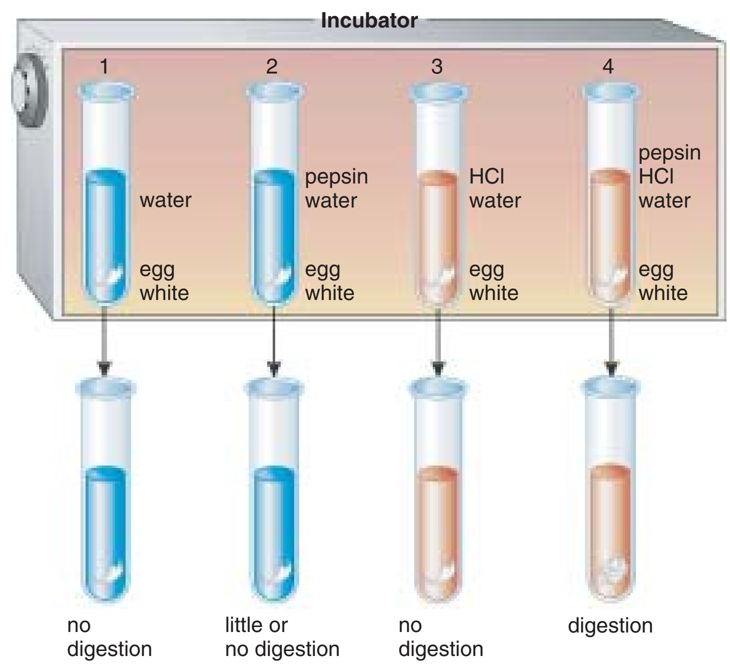


Figure 5.12 **Digestion experiment.**
This experiment is based on the optimum conditions for digestion by pepsin in the stomach. Knowing that the correct enzyme, optimum pH, optimum temperature, and correct substrate must be present for digestion to occur, explain the results of this experiment. Colors indicate pH of test tubes (blue, basic; red, acidic).

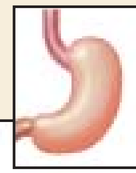
Conditions for Digestion

Laboratory experiments can define the necessary conditions for digestion. For example, the four test tubes shown in Figure 5.12 can be prepared and observed for the digestion of egg white, a protein digested in the stomach by the enzyme pepsin.

After all tubes are placed in an incubator at body temperature for at least one hour, the results depicted are observed. Tube 1 is a control tube; no digestion has occurred in this tube because the enzyme and HCl are missing. (If a control gives a positive result, then the experiment is invalidated.) Tube 2 shows limited or no digestion because HCl is missing, and therefore the pH is too high for pepsin to be effective. Tube 3 shows no digestion because although HCl is present, the enzyme is missing. Tube 4 shows the best digestive action because the enzyme is present and the presence of HCl has resulted in an optimum pH. This experiment supports the hypothesis that for digestion to occur, the substrate and enzyme must be present and the environmental conditions must be optimum. The optimal environmental conditions include a warm temperature and the correct pH.

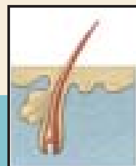
Human Systems Work Together

How the Digestive System works with other body systems



Integumentary System

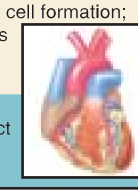
Digestive tract provides nutrients needed by skin.



Skin helps to protect digestive organs; helps to provide vitamin D for Ca^{2+} absorption.

Cardiovascular System

Digestive tract provides nutrients for plasma protein formation and blood cell formation; liver detoxifies blood, makes plasma proteins, destroys old red blood cells.



Blood vessels transport nutrients from digestive tract to body; blood services digestive organs.

Skeletal System

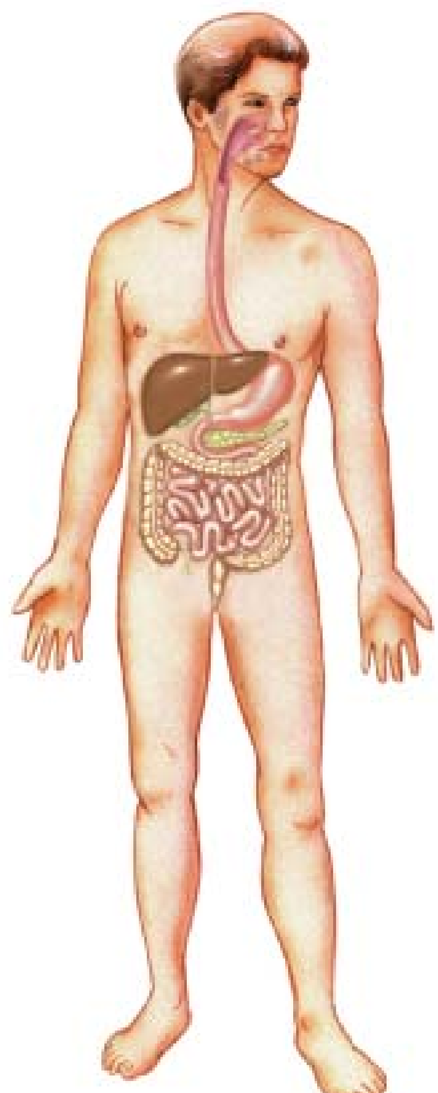
Digestive tract provides Ca^{2+} and other nutrients for bone growth and repair.

Bones provide support and protection; hyoid bone assists swallowing.

Lymphatic System/Immunity

Digestive tract provides nutrients for lymphoid organs; stomach acidity prevents pathogen invasion of body.

Lacteals absorb fats; Peyer's patches prevent invasion by pathogens; appendix contains lymphoid tissue.



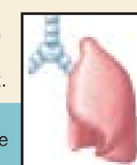
Muscular System

Digestive tract provides glucose for muscle activity; liver metabolizes lactic acid following anaerobic muscle activity.

Smooth muscle contraction accounts for peristalsis; skeletal muscles support and help protect abdominal organs.

Respiratory System

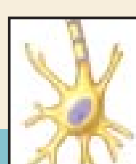
Breathing is possible through the mouth because digestive tract and respiratory tract share the pharynx.



Gas exchange in lungs provides oxygen to digestive tract and excretes carbon dioxide from digestive tract.

Nervous System

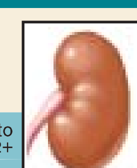
Digestive tract provides nutrients for growth, maintenance, and repair of neurons and neuroglia.



Brain controls nerves, which innervate smooth muscle and permit tract movements.

Urinary System

Liver synthesizes urea; digestive tract excretes bile pigments from liver and provides nutrients.



Kidneys convert vitamin D to active form needed for Ca^{2+} absorption; compensate for any water loss by digestive tract.

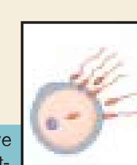
Endocrine System

Stomach and small intestine produce hormones.

Hormones help control secretion of digestive glands and accessory organs; insulin and glucagon regulate glucose storage in liver.

Reproductive System

Digestive tract provides nutrients for growth and repair of organs and for development of fetus.



Pregnancy crowds digestive organs and promotes heartburn and constipation.

5.4 Homeostasis

Human Systems Work Together on page 90 tells how the digestive system works with other systems in the body to maintain homeostasis.

Within the digestive tract, the food we eat is broken down to nutrients small enough to be absorbed by the villi of the small intestine. Digestive enzymes are produced by the salivary glands, gastric glands, and intestinal glands. Three accessory organs of digestion (the pancreas, the liver, and the gallbladder) also contribute secretions that help break down food. The liver produces bile (stored by the gallbladder), which emulsifies fat. The pancreas produces enzymes for the digestion of carbohydrates, proteins, and fat. Secretions from these glands, which are sent by ducts into the small intestine, are regulated by hormones such as secretin produced by the digestive tract. Therefore, the digestive tract is also a part of the endocrine system.

Blood laden with nutrients passes from the region of the small intestine to the liver by way of the hepatic portal vein. The liver is the most important of the metabolic organs. Aside from making bile, the liver regulates the cholesterol content of the blood, makes plasma proteins, stores glucose as glycogen, produces urea, metabolizes poisons, and breaks down old red blood cells. Because the liver is such an important organ, diseases affecting the liver, such as hepatitis and cirrhosis, are extremely dangerous.

5.5 Nutrition

The body requires three major classes of macronutrients in the diet: carbohydrate, protein, and fat. These supply the energy and the building blocks that are needed to synthesize cellular contents. Micronutrients—especially vitamins and minerals—are also required because they are necessary for optimum cellular metabolism.

Several modern nutritional studies suggest that certain nutrients can protect against heart disease, cancer, and other serious illnesses. These studies have analyzed the eating habits of healthy people in the United States and around the world, especially those living in areas that have lower rates of heart disease and cancer. The resulting dietary recommendations can be illustrated by a food pyramid (Fig. 5.13).

The bulk of the diet should consist of bread, cereal, rice, and pasta as energy sources. Whole grains are preferred over those that have been milled because they contain fiber, vitamins, and minerals. Vegetables and fruits are another rich source of fiber, vitamins, and minerals. Notice, then, that a largely vegetarian diet is recommended.

Animal products, especially meat, may be included only minimally in the diet; fats and sweets should be used sparingly. Dairy products and meats tend to be high in saturated fats, and an intake of saturated fats increases the risk of cardiovascular disease (see Lipids, page 94). Low-fat dairy products are available, but there is no way to take much of the fat out of meat. Beef, in particular, contains a relatively high fat content. Ironically, the affluence of people in the United States contributes to a poor diet and, therefore, possible illness. Only comparatively rich people can afford fatty meats from grain-fed cattle and carbohydrates that have been highly processed to remove fiber and to add sugar and salt.

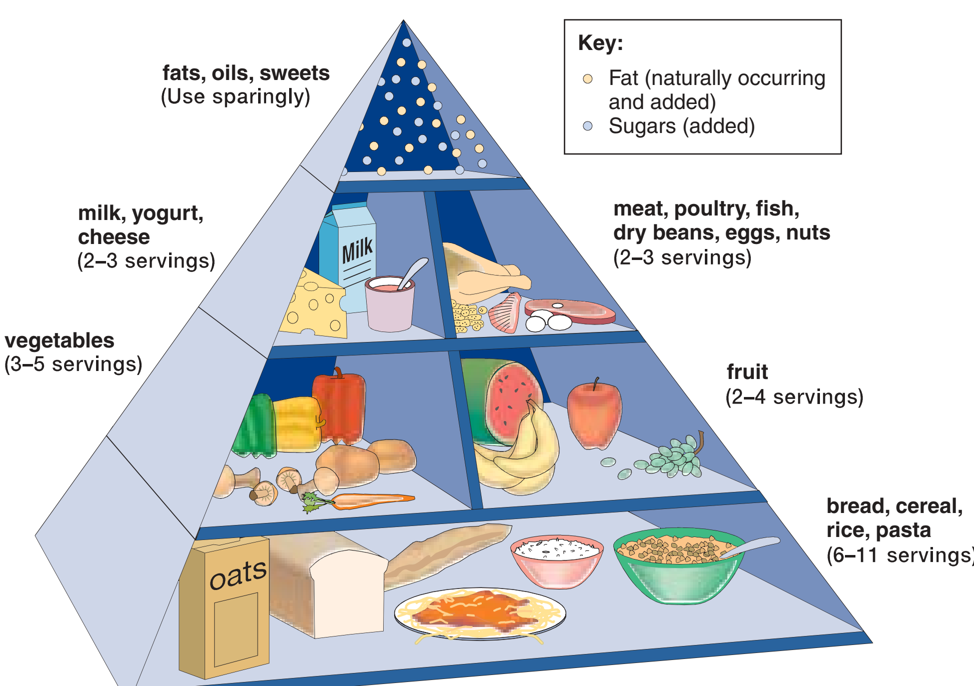


Figure 5.13 Food guide pyramid: A guide to daily food choices. The U.S. Department of Agriculture uses a pyramid to show the ideal diet because it emphasizes the importance of eating grains, fruits, and vegetables. Meats and dairy products are needed in limited amounts; fats, oils, and sweets should be used sparingly.

Source: Data from the U.S. Department of Agriculture.

Carbohydrates

The quickest, most readily available source of energy for the body is glucose. Carbohydrates are digested to simple sugars, which are or can be converted to glucose. As mentioned earlier in this chapter, glucose is stored by the liver in the form of glycogen. Between eating periods, the blood glucose level is maintained at about 0.1% by the breakdown of glycogen or by the conversion of glycerol (from fats) or amino acids to glucose. If necessary, amino acids are taken from the muscles—even from the heart muscle. While body cells can utilize fatty acids as an energy source, brain cells require glucose. For this reason alone, it is necessary to include carbohydrates in the diet. According to Figure 5.13, carbohydrates should make up the bulk of the diet. Further, these should be complex, not simple, carbohydrates. Complex sources of carbohydrates include preferably whole-grain pasta, rice, bread, and cereal (Fig. 5.14). Potatoes and corn, although considered vegetables, are also sources of carbohydrates.

Simple carbohydrates (e.g., sugars) are labeled "empty calories" by some dietitians because they contribute to energy needs and weight gain without supplying any other nutritional requirements. Table 5.3 gives suggestions on how to reduce dietary sugar (simple carbohydrates). In contrast to simple sugars, complex carbohydrates are likely to be accompanied by a wide range of other nutrients and by **fiber,** which is indigestible plant material.

As previously stated, the intake of fiber is recommended because it may decrease the risk of colon cancer, a major type of cancer, and cardiovascular disease, the number one killer in the United States. Insoluble fiber, such as that found in wheat bran, has a laxative effect. Soluble fiber, such as that found in oat bran, combines with bile acids and cholesterol in the intestine and prevents them from being absorbed. The liver then removes cholesterol from the blood and changes it to bile acids, replacing the bile acids that were lost. While the diet should have an adequate amount of fiber, some evidence suggests that a diet too high in fiber can be detrimental, possibly impairing the body's ability to absorb iron, zinc, and calcium.

Complex carbohydrates, which contain fiber and a wide range of nutrients, should form the bulk of the diet.

Table 5.3 Reducing Dietary Sugar

To reduce dietary sugar:

1. Eat fewer sweets, such as candy, soft drinks, ice cream, and pastry.
2. Eat fresh fruits or fruits canned without heavy syrup.
3. Use less sugar—white, brown, or raw—and less honey and syrups.
4. Avoid sweetened breakfast cereals.
5. Eat less jelly, jam, and preserves.
6. Drink pure fruit juices, not imitations.
7. When cooking, use spices, such as cinnamon, instead of sugar to flavor foods.
8. Do not put sugar in tea or coffee.

Figure 5.14 **Complex carbohydrates.**
To meet our energy needs, dietitians recommend consuming foods rich in complex carbohydrates, such as those shown here, rather than foods consisting of simple carbohydrates, such as candy and ice cream. Simple carbohydrates provide monosaccharides but few other types of nutrients.

Proteins

Foods rich in protein include red meat, fish, poultry, dairy products, legumes (i.e., peas and beans), nuts, and cereals. Following digestion of protein, amino acids enter the bloodstream and are transported to the tissues. Ordinarily, amino acids are not used as an energy source. Most are incorporated into structural proteins found in muscles, skin, hair, and nails. Others are used to synthesize such proteins as hemoglobin, plasma proteins, enzymes, and hormones.

Adequate protein formation requires 20 different types of amino acids. Of these, eight are required from the diet in adults (nine in children) because the body is unable to produce them. These are termed the **essential amino acids.** The body produces the other amino acids from metabolites derived from glucose breakdown or by transforming one type into another type. Some protein sources, such as meat, milk, and eggs, are complete; they provide all 20 types of amino acids. Legumes (beans and peas), other types of vegetables, seeds and nuts, and also grains supply us with amino acids, but each of these alone is an incomplete protein source because of a deficiency in at least one of the essential amino acids. Absence of one essential amino acid prevents utilization of the other 19 amino acids. Therefore, vegetarians are counseled to combine two or more incomplete types of plant products to acquire all the essential amino acids. Table 5.4 lists complementary proteins—sources of protein whose amino acid contents complement each other so that all the essential amino acids are present in the diet. Soybeans and tofu, which is made from soybeans, are rich in amino acids, but even so, you have to combine tofu with a complementary protein to acquire all the essential amino acids. Table 5.4 shows how to select various combinations of plant products in order to make sure the diet contains the essential amino acids when it does not contain meat.

Table 5.4 Complementary Proteins*

Legumes	Seeds and Nuts	Grains	Vegetables
Green peas	Sunflower seeds	Wheat	Leafy green (e.g., spinach)
Navy beans	Sesame seeds	Rice	Broccoli
Soybeans	Macadamia nuts	Corn	Cauliflower
Black-eyed peas	Brazil nuts	Barley	Cabbage
Pinto beans	Peanuts	Oats	Artichoke hearts
Lima beans	Cashews	Rye	
Kidney beans	Hazelnuts		
Chickpeas	Almonds		
Black beans	Nut butter		

*Combine foods from any two or more columns to acquire all of the essential amino acids.

Amino acids are not stored in the body, and a daily supply is needed. However, it does not take very much protein to meet the daily requirement. Two servings of meat a day (one serving is equal in size to a deck of cards) are usually enough. Some meats (e.g., hamburger) are high in protein, but also high in fat. Everything considered, it is probably a good idea to depend on protein from plant origins (e.g., whole-grain cereals, dark breads, and legumes) to a greater extent than is often the custom in the United States. A study involving native Hawaiians lends support to the belief that health improves when the diet is rich in protein from plants rather than protein from animals. Only 3% of the ancient Hawaiian diet was animal protein, whereas the modern diet is 12% animal protein (Fig. 5.15). This, in large part, accounts for why the ancient diet was only 10% fat, whereas the modern diet of Hawaiians is 42% fat. A statistical study showed that the rate of cardiovascular disease and cancer is higher than average among Hawaiians who follow the modern diet. Diabetes is also common in persons who follow the modern diet. On the other hand, health has improved immensely among those who have switched back to the ancient diet.

Nutritionists do not recommend using protein and/or amino acid supplements. Protein supplements that athletes take to build muscle cost more than food and can be harmful. When excess protein is broken down, more urea is excreted in the urine. The water needed for excretion of

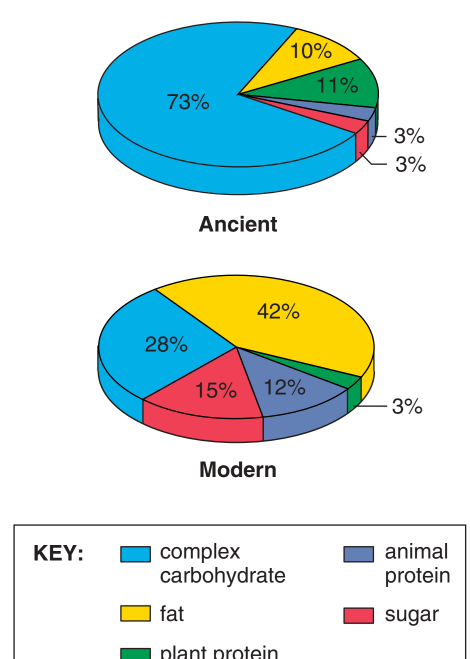


Figure 5.15 Ancient versus modern diet of native Hawaiians.
Among those Hawaiians who have switched back to the native diet, the incidence of cardiovascular disease, cancer, and diabetes has dropped.

urea can cause dehydration when a person is exercising and also losing water by sweating. Also, some studies suggest that protein supplements lead to calcium loss and weakened bones. Amino acid supplements can also be dangerous to your health. Mistaken ideas abound. For example, contrary to popular reports, taking lysine does not relieve or cure herpes sores.

Lipids

Fat and cholesterol are both lipids. Fat is present not only in butter, margarine, and oils, but also in various foods high in animal protein.

The current guidelines suggest that fat should account for no more than 30% of our daily calories. The chief reason is that an intake of fat not only causes weight gain, but also increases the risk of cancer and cardiovascular disease. Dietary fat may increase the risk of colon, hepatic, and pancreatic cancers. Although recent studies suggest no link between dietary fat and breast cancer, other researchers still believe the matter deserves further investigation.

Cardiovascular disease is often due to arteries blocked by fatty deposits, called **plaque,** that contain saturated fats and cholesterol. Cholesterol is carried in the blood by two types of lipoproteins: low-density lipoprotein (LDL) and high-density lipoprotein (HDL). LDL is thought of as "bad" because it carries cholesterol from the liver to the cells, while HDL is thought of as "good" because it carries cholesterol to the liver, which takes it up and converts it to bile salts.

Saturated fatty acids have no double bonds; monounsaturated fatty acids have one double bond; and polyunsaturated fatty acids have many double bonds. Saturated fats, whether in butter or margarine, can raise LDL cholesterol levels, while monounsaturated fats and polyunsaturated fats lower LDL cholesterol levels. Olive oil and canola oil contain mostly monounsaturated fats; corn oil and safflower oil contain mostly polyunsaturated fats. These oils have a liquid consistency and come from plants. Saturated fats, which are solids at room temperature, usually have an animal origin; two well-known exceptions are palm oil and coconut oil, which contain mostly saturated fats and come from the plants mentioned.

Nutritionists suggest that, for optimal health, less than 30% of your calories should come from fat and less than 10% should come from saturated fat. Polyunsaturated fats are nutritionally essential because they are the only type of fat that contains linoleic acid and linolenic acid, two fatty acids the body cannot make. The body needs these two polyunsaturated fatty acids to produce various hormones and the plasma membrane of cells. Since these fatty acids must be supplied by diet, they are called essential fatty acids. These essential fatty acids are found in small amounts in the oils of plants and cold-water fish and are readily stored in the adult body.

Table 5.5 **Reducing Lipids**

TO REDUCE DIETARY FAT:

1. Choose poultry, fish, or dry beans and peas as a protein source.
2. Remove skin from poultry before cooking, and place on a rack so that fat drains off.
3. Broil, boil, or bake rather than frying.
4. Limit your intake of butter, cream, hydrogenated oils, shortenings, and tropical oils (coconut and palm oils).*
5. Use herbs and spices to season vegetables instead of butter, margarine, or sauces. Use lemon juice instead of salad dressing.
6. Drink skim milk instead of whole milk, and use skim milk in cooking and baking.
7. Eat nonfat or low-fat foods.

TO REDUCE DIETARY CHOLESTEROL:

1. Avoid cheese, egg yolks, liver, and certain shellfish (shrimp and lobster). Preferably, eat white fish and poultry.
2. Substitute egg whites for egg yolks in both cooking and eating.
3. Include soluble fiber in the diet. Oat bran, oatmeal, beans, corn, and fruits such as apples, citrus fruits, and cranberries are high in soluble fiber.

*Although coconut and palm oils are from plant sources, they are mostly saturated fats.

Table 5.5 gives suggestions for reducing dietary fat and cholesterol. Everyone should use diet to keep their cholesterol level within normal limits so that medications will not be needed for this purpose.

Fake Fat

Olestra is a substance made to look, taste, and act like real fat, but the digestive system is unable to digest it. It travels down the length of the digestive system without being absorbed or contributing any calories to the day's total. Therefore, it is commonly known as "fake fat." Unfortunately, the fat-soluble vitamins A, D, E, and K tend to be taken up by olestra, and thereafter they are not absorbed by the body. Similarly, people using olestra have reduced amounts of carotenoids in their blood, even as much as 20% less. Manufacturers fortify olestra-containing foods with the vitamins mentioned, but not with carotenoids.

Fake fat has other side effects. Some people who consume olestra have developed anal leakage. Others experience diarrhea, intestinal cramping, and gas. Presently, the FDA has limited the use of olestra to potato chips and other salty snacks, but the manufacturer wants approval to add it to ice cream, salad dressings, and cheese.

Dietary protein supplies the essential amino acids; proteins from plant origins generally have less accompanying fat. A diet composed of no more than 30% fat calories is recommended because fat intake, particularly saturated fats, is associated with various health problems.

Health Focus

Weight Loss the Healthy Way

People who wish to lose weight need to reduce their caloric intake and/or increase their level of exercise. For a woman 19 to 22 years of age and 5 feet 4 inches tall, who exercises lightly, the normal recommendation is 2,100 Cal* per day. For a man the same age, 5 feet 10 inches tall, who exercises lightly, the recommendation is 2,900 Cal. Exercising is a good idea, because to maintain good nutrition, the caloric intake per day should probably not go below 1,200 Cal. Also, for the reasons discussed in this chapter, carbohydrates should still make up at least 58% of these calories, proteins should be no more than 25%, and the rest can be fats. A deficit of 500 Cal a day (through intake reduction or increased exercise) is sufficient to lose a pound of body fat in a week.

A diet needs to be judged according to the principles of adequate nutrients; balanced carbohydrates, proteins, and fats; a moderate number of calories; and a variety of food sources. Thus, it is easy to see that many of the diets and gimmicks people use to lose weight are bad for their health. Some unhealthy approaches are described here.

Pills

The most familiar pills, and the only ones approved by the United States Food and Drug Administration (FDA), are those that claim to suppress the appetite. They may work at first, but the appetite soon returns to normal, and the lost weight is regained. Then the user has the problem of trying to stop taking the drug without gaining additional weight. Other types of pills are under investigation and sometimes can be obtained illegally. But, as yet, there is no known drug that is both safe and effective for weight loss.

Liquid Diets

Despite the fact that liquid diets provide proteins and vitamins, the number of Calories is so restricted that the body cannot burn fat quickly enough to compensate, and muscle is still broken down to provide energy. A few people on this regime have died, probably because even the heart muscle was not spared by the body.

Low-Carbohydrate Diets

The dramatic weight loss that occurs with a low-carbohydrate diet is not due to a loss of fat; it is due to a loss of muscle mass and water. Glycogen and important minerals are also lost. When a normal diet is resumed, so is the normal weight.

Single-Category Diets

These diets rely on the intake of only one kind of food, either a fruit or vegetable or rice alone. However, no single type of food provides the balance of nutrients needed to maintain health. Some dieters on strange diets suffer the consequences—in one instance, an individual lost hair and fingernails.

*Cal = 1,000 calories

Questions to Ask About a Weight-Loss Diet

1. Does the diet have a reasonable number of Calories?
   (10 Cal per pound of current weight is suggested. In any case, no fewer than 1,000–1,200 Cal are recommended for a normal-sized person.)
2. Does the diet provide enough protein?
   (For a 120-lb woman, 44 grams of protein each day are recommended. For a 154-lb man, 56 grams are recommended. More than twice this amount is too much. For reference, 1 c milk and 1 oz meat each have 8 grams of protein.)
3. Does the diet provide too much fat?
   (No more than 20–30% of total Cal is recommended. For reference, a pat of butter has 45 Cal; 1 gram fat = 9 Cal.)
4. Does the diet provide enough carbohydrates?
   (100 grams = 400 Cal is the very least recommended per day; 50% of total Cal should be carbohydrates. For reference, a slice of bread contains 14 grams of carbohydrates.)
5. Does the diet provide a balanced assortment of foods?
   (The diet should include breads, cereals, legumes, vegetables (especially dark-green and yellow ones), low-fat milk products, and meats or a meat substitute.)
6. Does the diet make use of ordinary foods that are available locally?
   (Diets should not require the purchase of unusual or expensive foods.)

Figure 5A **Fruit is a healthy and low-calorie snack.**

Vitamins

Vitamins are organic compounds (other than carbohydrate, fat, and protein) that the body uses for metabolic purposes but is unable to produce in adequate quantity. Many vitamins are portions of coenzymes, which are enzyme helpers. For example, niacin is part of the coenzyme NAD, and riboflavin is part of another dehydrogenase, FAD. Coenzymes are needed in only small amounts because each can be used over and over again. Not all vitamins are coenzymes; vitamin A, for example, is a precursor for the visual pigment that prevents night blindness. If vitamins are lacking in the diet, various symptoms develop (Fig. 5.16). Altogether, there are 13 vitamins, which are divided into those that are fat-soluble (Table 5.6) and those that are water-soluble (Table 5.7).

Antioxidants

Over the past 20 years, numerous statistical studies have been done to determine whether a diet rich in fruits and vegetables can protect against cancer. Cellular metabolism generates free radicals, unstable molecules that carry an extra electron. The most common free radicals in cells are superoxide (O_2^-) and hydroxide (OH^-). In order to stabilize themselves, free radicals donate an electron to DNA, to proteins, including enzymes, or to lipids, which are found in plasma membranes. Such donations most likely damage these cellular molecules and thereby may lead to disorders, perhaps even cancer.

Vitamins C, E, and A are believed to defend the body against free radicals, and therefore they are termed antioxidants. These vitamins are especially abundant in fruits and vegetables. The dietary guidelines shown in Figure 5.13 suggest that we eat a minimum of five servings of fruits and vegetables a day. To achieve this goal, we should include salad greens, raw or cooked vegetables, dried fruit, and fruit juice, in addition to traditional apples and oranges and such.

Dietary supplements may provide a potential safeguard against cancer and cardiovascular disease, but nutritionists do not think people should take supplements instead of improving their intake of fruits and vegetables. There are many beneficial compounds in fruits that cannot be obtained from a vitamin pill. These compounds enhance each other's absorption or action and also perform independent biological functions.

Vitamin D

Skin cells contain a precursor cholesterol molecule that is converted to vitamin D after UV exposure. Vitamin D leaves the skin and is modified first in the kidneys and then in the liver until finally it becomes calcitriol. Calcitriol promotes the absorption of calcium by the intestines. The lack of vitamin D leads to rickets in children (Fig. 5.16*a*). Rickets, characterized by bowing of the legs, is caused by defective mineralization of the skeleton. Most milk today is fortified with vitamin D, which helps prevent the occurrence of rickets.

Vitamins are essential to cellular metabolism; many protect against identifiable illnesses and conditions.


a. b. c.

Figure 5.16 **Illnesses due to vitamin deficiency.**
a. Bowing of bones (rickets) due to vitamin D deficiency. **b.** Dermatitis (pellagra) of areas exposed to light due to niacin (vitamin B_3) deficiency.
c. Bleeding of gums (scurvy) due to vitamin C deficiency.

Table 5.6 Fat-Soluble Vitamins

Vitamin	Functions	Food Sources	Conditions With	
			Too Little	***Too Much***
Vitamin A	Antioxidant synthesized from beta-carotene; needed for healthy eyes, skin, hair, and mucous membranes, and for proper bone growth	Deep yellow/orange and leafy, dark green vegetables, fruits, cheese, whole milk, butter, eggs	Night blindness, impaired growth of bones and teeth	Headache, dizziness, nausea, hair loss, abnormal development of fetus
Vitamin D	A group of steroids needed for development and maintenance of bones and teeth	Milk fortified with vitamin D, fish liver oil; also made in the skin when exposed to sunlight	Rickets, decalcification and weakening of bones	Calcification of soft tissues, diarrhea, possible renal damage
Vitamin E	Antioxidant that prevents oxidation of vitamin A and polyunsaturated fatty acids	Leafy green vegetables, fruits, vegetable oils, nuts, whole-grain breads and cereals	Unknown	Diarrhea, nausea, headaches, fatigue, muscle weakness
Vitamin K	Needed for synthesis of substances active in clotting of blood	Leafy green vegetables, cabbage, cauliflower	Easy bruising and bleeding	Can interfere with anticoagulant medication

Table 5.7 Water-Soluble Vitamins

Vitamin	Functions	Food Sources	Conditions With	
			Too Little	***Too Much***
Vitamin C	Antioxidant; needed for forming collagen; helps maintain capillaries, bones, and teeth	Citrus fruits, leafy green vegetables, tomatoes, potatoes, cabbage	Scurvy, delayed wound healing, infections	Gout, kidney stones, diarrhea, decreased copper
Thiamine (vitamin B_1)	Part of coenzyme needed for cellular respiration; also promotes activity of the nervous system	Whole-grain cereals, dried beans and peas, sunflower seeds, nuts	Beriberi, muscular weakness, enlarged heart	Can interfere with absorption of other vitamins
Riboflavin (vitamin B_2)	Part of coenzymes, such as FAD; aids cellular respiration, including oxidation of protein and fat	Nuts, dairy products, whole-grain cereals, poultry, leafy green vegetables	Dermatitis, blurred vision, growth failure	Unknown
Niacin (nicotinic acid)	Part of coenzymes NAD and NADP; needed for cellular respiration, including oxidation of protein and fat	Peanuts, poultry, whole-grain cereals, leafy green vegetables, beans	Pellagra, diarrhea, mental disorders	High blood sugar and uric acid, vasodilation, etc.
Folacin (folic acid)	Coenzyme needed for production of hemoglobin and formation of DNA	Dark leafy green vegetables, nuts, beans, whole-grain cereals	Megaloblastic anemia, spina bifida	May mask B_{12} deficiency
Vitamin B_6	Coenzyme needed for synthesis of hormones and hemoglobin; CNS control	Whole-grain cereals, bananas, beans, poultry, nuts, leafy green vegetables	Rarely, convulsions, vomiting, seborrhea, muscular weakness	Insomnia, neuropathy
Pantothenic acid	Part of coenzyme A needed for oxidation of carbohydrates and fats; aids in the formation of hormones and certain neurotransmitters	Nuts, beans, dark green vegetables, poultry, fruits, milk	Rarely, loss of appetite, mental depression, numbness	Unknown
Vitamin B_{12}	Complex, cobalt-containing compound; part of the coenzyme needed for synthesis of nucleic acids and myelin	Dairy products, fish, poultry, eggs, fortified cereals	Pernicious anemia	Unknown
Biotin	Coenzyme needed for metabolism of amino acids and fatty acids	Generally in foods, especially eggs	Skin rash, nausea, fatigue	Unknown

Minerals

In addition to vitamins, various **minerals** are required by the body. Minerals are divided into macrominerals and microminerals. The body contains more than 5 grams of each macromineral and less than 5 grams of each micromineral (Fig. 5.17). The macrominerals are constituents of cells and body fluids and are structural components of tissues. For example, calcium (present as Ca^{2+}) is needed for the construction of bones and teeth and for nerve conduction and muscle contraction. Phosphorus (present as PO_4^{3-}) is stored in the bones and teeth and is a part of phospholipids, ATP, and the nucleic acids. Potassium (K^+) is the major positive ion inside cells and is important in nerve conduction and muscle contraction, as is sodium (Na^+). Sodium also plays a major role in regulating the body's water balance, as does chloride (Cl^-). Magnesium (Mg^{2+}) is critical to the functioning of hundreds of enzymes. Sulfer (S^{2-}) helps proteins maintain their normal shape.

The microminerals are parts of larger molecules. For example, iron (Fe^{2+}) is present in hemoglobin, and iodine (I^-) is a part of thyroxine and triiodothyronine, hormones produced by the thyroid gland. Zinc (Zn^{2+}), copper (Cu^{2+}), and manganese (Mn^{2+}) are present in enzymes that catalyze a variety of reactions. Proteins, called zinc-finger proteins because of their characteristic shapes, bind to DNA when a particular gene is to be activated. As research continues, more and more elements are added to the list of microminerals considered essential. During the past three decades, for example, very small amounts of selenium, molybdenum, chromium, nickel, vanadium, silicon, and even arsenic have been found to be essential to good health. Table 5.8 lists the functions of various minerals and gives their food sources and signs of deficiency and toxicity.

Occasionally, individuals do not receive enough iron (especially women), calcium, magnesium, or zinc in their diets. Adult females need more iron in the diet than males (18 mg compared to 10 mg) because they lose hemoglobin each month during menstruation. Stress can bring on a magnesium deficiency, and due to its high-fiber content, a vegetarian diet may make zinc less available to the body. However, a varied and complete diet usually supplies enough of each type of mineral.

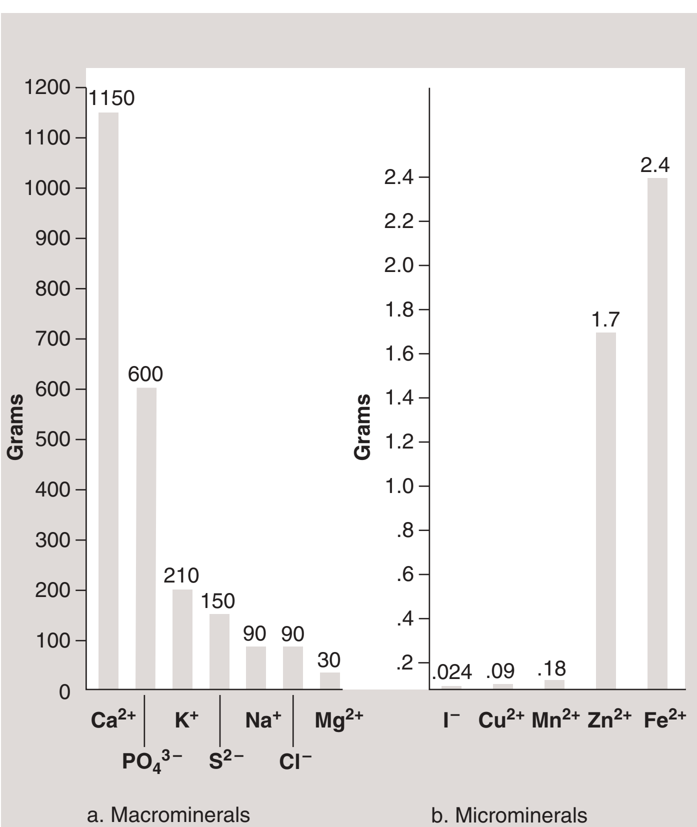


Figure 5.17 Minerals in the body.
a. The macrominerals are present in amounts larger than 5 grams (about a teaspoon). **b.** Microminerals are present in lesser amounts.

Calcium

Many people take calcium supplements to counteract **osteoporosis,** a degenerative bone disease that afflicts an estimated one-fourth of older men and one-half of older women in the United States. Osteoporosis develops because bone-eating cells called osteoclasts are more active than bone-forming cells called osteoblasts. Therefore, the bones are porous, and they break easily because they lack sufficient calcium. Due to recent studies that show consuming more calcium does slow bone loss in elderly people, the guidelines have been revised. A calcium intake of 1,000 mg a day is recommended for men and for women who are premenopausal, and 1,300 mg a day is recommended for postmenopausal women. To achieve this amount, supplemental calcium is most likely necessary.

Vitamin D is an essential companion to calcium in preventing osteoporosis. Other vitamins may also be helpful; for example, magnesium has been found to suppress the cycle that leads to bone loss. In addition to adequate calcium and vitamin intake, exercise helps prevent osteoporosis. Risk factors for osteoporosis include drinking more than nine cups of caffeinated coffee per day and smoking. Medications are also available that slow bone loss while increasing skeletal mass. These are still being studied for their effectiveness and possible side effects.

Sodium

The recommended amount of sodium intake per day is 500 mg, although the average American takes in 4,000–4,700 mg every day. In recent years, this imbalance has caused concern because sodium in the form of salt intensifies hypertension (high blood pressure) if you already have it. About one-third of the sodium we consume occurs

Table 5.8 Minerals

Mineral	Functions	Food Sources	Conditions With: *Too Little*	Conditions With: *Too Much*
MACROMINERALS (MORE THAN 100 MG/DAY NEEDED)				
Calcium (Ca^{2+})	Strong bones and teeth, nerve conduction, muscle contraction	Dairy products, leafy green vegetables	Stunted growth in children, low bone density in adults	Kidney stones; interferes with iron and zinc absorption
Phosphorus (PO_4^{3-})	Bone and soft tissue growth; part of phospholipids, ATP, and nucleic acids	Meat, dairy products, sunflower seeds, food additives	Weakness, confusion, pain in bones and joints	Low blood and bone calcium levels
Potassium (K^+)	Nerve conduction, muscle contraction	Many fruits and vegetables, bran	Paralysis, irregular heartbeat, eventual death	Vomiting, heart attack, death
Sulfur (S^{2-})	Stabilizes protein shape, neutralizes toxic substances	Meat, dairy products, legumes	Not likely	In animals, depresses growth
Sodium (Na^+)	Nerve conduction, pH and water balance	Table salt	Lethargy, muscle cramps, loss of appetite	Edema, high blood pressure
Chloride (Cl^-)	Water balance	Table salt	Not likely	Vomiting, dehydration
Magnesium (Mg^{2+})	Part of various enzymes for nerve and muscle contraction, protein synthesis	Whole grains, leafy green vegetables	Muscle spasm, irregular heartbeat, convulsions, confusion, personality changes	Diarrhea
MICROMINERALS (LESS THAN 20 MG/DAY NEEDED)				
Zinc (Zn^{2+})	Protein synthesis, wound healing, fetal development and growth, immune function	Meats, legumes, whole grains	Delayed wound healing, night blindness, diarrhea, mental lethargy	Anemia, diarrhea, vomiting, renal failure, abnormal cholesterol levels
Iron (Fe^{2+})	Hemoglobin synthesis	Whole grains, meats, prune juice	Anemia, physical and mental sluggishness	Iron toxicity disease, organ failure, eventual death
Copper (Cu^{2+})	Hemoglobin synthesis	Meat, nuts, legumes	Anemia, stunted growth in children	Damage to internal organs if not excreted
Iodine (I^-)	Thyroid hormone synthesis	Iodized table salt, seafood	Thyroid deficiency	Depressed thyroid function, anxiety
Selenium (SeO_4^{2-})	Part of antioxidant enzyme	Seafood, meats, eggs	Vascular collapse, possible cancer development	Hair and fingernail loss, discolored skin
Manganese (Mn^{2+})	Part of enzymes	Nuts, legumes, green vegetables	Weakness and confusion	Confusion, coma, death

naturally in foods; another one-third is added during commercial processing; and we add the last one-third either during home cooking or at the table in the form of table salt.

Clearly, it is possible to cut down on the amount of sodium in the diet. Table 5.9 gives recommendations for doing so.

> Both macro- and microminerals play specific roles in the body. Calcium is needed for strong bones, for example. Excess sodium in the diet can lead to hypertension; therefore, excess sodium intake should be avoided.

Table 5.9 Reducing Dietary Sodium

To reduce dietary sodium:

1. Use spices instead of salt to flavor foods.
2. Add little or no salt to foods at the table, and add only small amounts of salt when you cook.
3. Eat unsalted crackers, pretzels, potato chips, nuts, and popcorn.
4. Avoid hot dogs, ham, bacon, luncheon meats, smoked salmon, sardines, and anchovies.
5. Avoid processed cheese and canned or dehydrated soups.
6. Avoid brine-soaked foods, such as pickles or olives.
7. Read nutrition labels to avoid high-salt products.

Persons with obesity have

- weight 20% or more above appropriate weight for height.
- body fat content in excess of that consistent with optimal health, probably due to a diet rich in fats.
- low levels of exercise.

Figure 5.18 **Recognizing obesity.**

Eating Disorders

Authorities recognize three primary eating disorders: obesity, bulimia nervosa, and anorexia nervosa. Although they exist in a continuum as far as body weight is concerned, they all represent an inability to maintain normal body weight because of eating habits.

Obesity

As indicated in Figure 5.18, **obesity** is most often defined as a body weight 20% or more above the ideal weight for a person's height. By this standard, 28% of women and 10% of men in the United States are obese. Moderate obesity is 41–100% above ideal weight, and severe obesity is 100% or more above ideal weight.

Obesity is most likely caused by a combination of hormonal, metabolic, and social factors. It is known that obese individuals have more fat cells than normal, and when they lose weight, the fat cells simply get smaller; they don't disappear. The social factors that cause obesity include the eating habits of other family members. Consistently eating fatty foods, for example, will make you gain weight. Sedentary activities, such as watching television instead of exercising, also determine how much body fat you have. The risk of heart disease is higher in obese individuals, and this alone tells us that excess body fat is not consistent with optimal health.

The treatment depends on the degree of obesity. Surgery to remove body fat may be required for those who are moderately or greatly overweight. But for most people, a knowledge of good eating habits along with behavior modification may suffice, particularly if a balanced diet is accompanied by a sensible exercise program. A lifelong commitment to a properly planned program is the best way to prevent a cycle of weight gain followed by weight loss. Such a cycle is not conducive to good health.

Bulimia Nervosa

Bulimia nervosa can coexist with either obesity or anorexia nervosa, which is discussed next. People with this condition have the habit of eating to excess (called binge eating) and then purging themselves by some artificial means, such as self-induced vomiting or use of a laxative. Bulimic individuals are overconcerned about their body shape and weight, and therefore they may be on a very restrictive diet. A restrictive diet may bring on the desire to binge, and typically the person chooses to consume sweets, such as cakes, cookies, and ice cream (Fig. 5.19). The amount of food consumed is far beyond the normal number of calories for one meal, and the person keeps on eating until every bit is gone. Then, a feeling of guilt most likely brings on the next phase, which is a purging of all the calories that have been taken in.

Bulimia can be dangerous to your health. Blood composition is altered, leading to an abnormal heart rhythm, and damage to the kidneys can even result in death. At the very least, vomiting can lead to inflammation of the pharynx and esophagus, and stomach acids can cause the teeth to erode. The esophagus and stomach may even rupture and tear due to strong contractions during vomiting.

The most important aspect of treatment is to get the patient on a sensible and consistent diet. Again, behavioral modification is helpful, and so perhaps is psychotherapy to help the patient understand the emotional causes of the behavior. Medications, including antidepressants, have sometimes helped to reduce the bulimic cycle and restore normal appetite.

Obesity and bulimia nervosa have complex causes and may be damaging to health. Therefore, they require competent medical attention.

Anorexia Nervosa

In **anorexia nervosa,** a morbid fear of gaining weight causes the person to be on a very restrictive diet. Athletes such as distance runners, wrestlers, and dancers are at risk of anorexia nervosa because they believe that being thin gives them a competitive edge. In addition to eating only low-calorie foods, the person may induce vomiting and use laxatives to bring about further weight loss. No matter how thin they have become, people with anorexia nervosa think they are overweight (Fig. 5.20). Such a distorted self-image may prevent recognition of the need for medical help.

Actually, the person is starving and has all the symptoms of starvation, including low blood pressure, irregular heartbeat, constipation, and constant chilliness. Bone density decreases and stress fractures occur. The body begins to shut down; menstruation ceases in females; the internal organs, including the brain, don't function well; and the skin dries up. Impairment of the pancreas and digestive tract means that any food consumed does not provide nourishment. Death may be imminent. If so, the only recourse may be hospitalization and force-feeding. Eventually, it is necessary to use behavior therapy and psychotherapy to enlist the cooperation of the person to eat properly. Family therapy may be necessary, because anorexia nervosa in children and teens is believed to be a way for them to gain some control over their lives.

In anorexia nervosa, the individual has a distorted body image and always feels fat. Competent medical help is often necessary.

Figure 5.19 **Recognizing bulimia nervosa.**

Figure 5.20 **Recognizing anorexia nervosa.**

Summarizing the Concepts

5.1 The Digestive Tract

The digestive tract consists of the mouth, pharynx, esophagus, stomach, small intestine, and large intestine. Only these structures actually contain food, while the salivary glands, liver, and pancreas supply substances that aid in the digestion of food.

The salivary glands send saliva into the mouth, where the teeth chew the food and the tongue forms a bolus for swallowing. Saliva contains salivary amylase, an enzyme that begins the digestion of starch.

The air passage and food passage cross in the pharynx. When a person swallows, the air passage is usually blocked off, and food must enter the esophagus, where peristalsis begins.

The stomach expands and stores food. While food is in the stomach, the stomach churns, mixing food with the acidic gastric juices. Gastric juices contain pepsin, an enzyme that digests protein.

The duodenum of the small intestine receives bile from the liver and pancreatic juice from the pancreas. Bile, which is produced in the liver and stored in the gallbladder, emulsifies fat and readies it for digestion by lipase, an enzyme produced by the pancreas. The pancreas also produces enzymes that digest starch (pancreatic amylase) and protein (trypsin). The intestinal enzymes finish the process of chemical digestion.

The walls of the small intestine have fingerlike projections called villi where small nutrient molecules are absorbed. Amino acids and glucose enter the blood vessels of a villus. Glycerol and fatty acids are joined and packaged as lipoproteins before entering lymphatic vessels called lacteals in a villus.

The large intestine consists of the cecum, the colon (including the ascending, transverse, descending, and sigmoid colon), and the rectum, which ends at the anus. The large intestine does not produce digestive enzymes; it does absorb water, salts, and some vitamins. Reduced water absorption results in diarrhea. The intake of water and fiber help prevent constipation.

5.2 Three Accessory Organs

Three accessory organs of digestion—the pancreas, liver, and gallbladder—send secretions to the duodenum via ducts. The pancreas produces pancreatic juice, which contains digestive enzymes for carbohydrate, protein, and fat.

The liver produces bile, which is stored in the gallbladder. The liver receives blood from the small intestine by way of the hepatic portal vein. It has numerous important functions, and any malfunction of the liver is a matter of considerable concern.

5.3 Digestive Enzymes

Digestive enzymes are present in digestive juices and break down food into the nutrient molecules glucose, amino acids, fatty acids, and glycerol (see Table 5.2). Salivary amylase and pancreatic amylase begin the digestion of starch. Pepsin and trypsin digest protein to peptides. Lipase digests fat to glycerol and fatty acids. Intestinal enzymes finish the digestion of starch and protein.

Digestive enzymes have the usual enzymatic properties. They are specific to their substrate and speed up specific reactions at optimum body temperature and pH.

5.4 Homeostasis

The digestive system works with the other systems of the body in the ways described in Human Systems Work Together on page 90.

5.5 Nutrition

The nutrients released by the digestive process should provide us with an adequate amount of energy, essential amino acids and fatty acids, and all necessary vitamins and minerals.

The bulk of the diet should be carbohydrates (e.g., bread, pasta, and rice) and fruits and vegetables. These are low in saturated fatty acids and cholesterol molecules, whose intake is linked to cardiovascular disease. Aside from carbohydrates, proteins, and fats, the body requires vitamins and minerals. The vitamins C, E, and A are antioxidants that protect cell contents from damage due to free radicals. The mineral calcium is needed for strong bones.

The reasons for eating disorders, including obesity, bulimia nervosa, and anorexia, are being explored in order to help people maintain a normal weight for their height.

Studying the Concepts

1. List the organs of the digestive tract, and state the contribution of each to the digestive process. 78–84
2. Discuss the absorption of the products of digestion into the lymphatic and cardiovascular systems. 83
3. Name and state the functions of the hormones that assist the nervous system in regulating digestive secretions. 84
4. Name the accessory organs, and describe the part they play in the digestion of food. 86–87
5. Choose and discuss any three functions of the liver. 86–87
6. Name and discuss two serious illnesses of the liver. 87
7. Discuss the digestion of starch, protein, and fat, listing all the steps that occur with each of these. 88–89
8. How does the digestive system help maintain homeostasis? 90–91
9. How does the cardiovascular system assist the digestive system in maintaining homeostasis? 90–91
10. What is the chief contribution of each of these constituents of the diet: a. carbohydrates; b. proteins; c. fats; d. fruits and vegetables? 92–94, 96–97
11. Why should the amount of saturated fat be curtailed in the diet? 94
12. Name and discuss three eating disorders. 100–101

Testing Your Knowledge of the Concepts

Choose the best answer for each question.

1. Tracing the path of food in the following list (a–f), which step is out of order first?
   a. mouth
   b. pharynx
   c. esophagus
   d. small intestine
   e. stomach
   f. large intestine
2. The appendix connects to the
   a. cecum.
   b. small intestine.
   c. esophagus.
   d. large intestine.
   e. liver.
   f. All of these are correct.
3. Which association is incorrect?
   a. mouth—starch digestion
   b. esophagus—protein digestion
   c. small intestine—starch, lipid, protein digestion

d. stomach—food storage
e. liver—production of bile

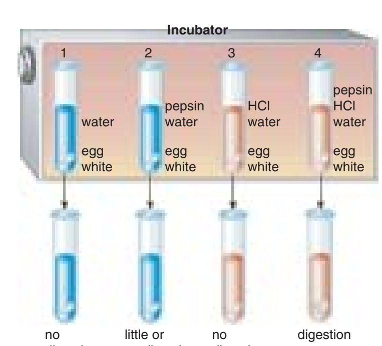
4. Why can a person not swallow food and talk at the same time?
   a. In order to swallow, the epiglottis must close off the trachea.
   b. The brain cannot control two activities at once.
   c. In order to speak, air must come through the larynx to form sounds.
   d. A swallowing reflex is only initiated when the mouth is closed.
   e. Both a and c are correct.
5. Which association is incorrect?
   a. pancreas—produces alkaline secretions and enzymes
   b. salivary glands—produce saliva and amylase
   c. gallbladder—produces digestive enzymes
   d. liver—produces bile
6. Which of the following could be absorbed directly without need of digestion?
   a. glucose
   b. fat
   c. polysaccharides
   d. protein
   e. nucleic acid
7. Peristalsis occurs
   a. from the mouth to the small intestine.
   b. from the beginning of the esophagus to the anus.
   c. only in the stomach.
   d. only in the small and large intestine.
   e. only in the esophagus and stomach.
8. An organ is a structure made of two or more tissues performing a common function. Which of the four tissue types are present in the wall of the digestive tract?
   a. epithelium
   b. connective tissue
   c. nervous tissue
   d. muscle tissue
   e. All of these are correct.
9. Which association is incorrect?
   a. protein—trypsin
   b. fat—bile
   c. fat—lipase
   d. maltose—pepsin
   e. starch—amylase
10. Most of the products of digestion are absorbed across the
    a. squamous epithelium of the esophagus.
    b. striated walls of the trachea.
    c. convoluted walls of the stomach.
    d. fingerlike villi of the small intestine.
    e. smooth wall of the large intestine.
11. Bile
    a. is an important enzyme for the digestion of fats.
    b. cannot be stored.
    c. is made by the gallbladder.
    d. emulsifies fat.
    e. All of these are correct.
12. Which of the following is not a function of the liver in adults?
    a. Produces bile.
    b. Detoxifies alcohol.
    c. Stores glucose.
    d. Produces urea.
    e. Makes red blood cells.
13. The large intestine
    a. digests all types of food.
    b. is the longest part of the intestinal tract.
    c. absorbs water.
    d. is connected to the stomach.
    e. is subject to hepatitis.

In questions 14–18, match each function to an organ in the key.

Key:

a. mouth
b. esophagus
c. stomach
d. small intestine
e. large intestine

14. Stores nondigestible remains.
15. Serves as a passageway.
16. Stores food.
17. Absorbs nutrients.
18. Receives food.
19. How many small servings of meat are sufficient in the daily diet?
    a. 6–11
    b. 2–4
    c. 2–3
    d. 3–4
20. The amino acids that must be consumed in the diet are called essential. Nonessential amino acids
    a. can be produced by the body.
    b. are only needed occasionally.
    c. are stored in the body until needed.
    d. can be taken in by supplements.
21. Which of the following are often organic portions of important coenzymes?
    a. minerals
    b. vitamins
    c. protein
    d. carbohydrates
22. Bulimia nervosa is not characterized by
    a. a restrictive diet often with excessive exercise.
    b. binge eating followed by purging.
    c. an obsession about body shape and weight.
    d. a distorted body image so person feels fat even when emaciated.
    e. a health risk due to this complex.
23. Predict and explain the expected digestive results per test tube for this experiment.



24. The products of digestion are
    a. large macromolecules needed by the body.
    b. enzymes needed to digest food.

c. small nutrient molecules that can be absorbed.
d. regulatory hormones of various kinds.
e. the food we eat.

In questions 25–29, match each statement to a layer of the wall of the esophagus in the key.

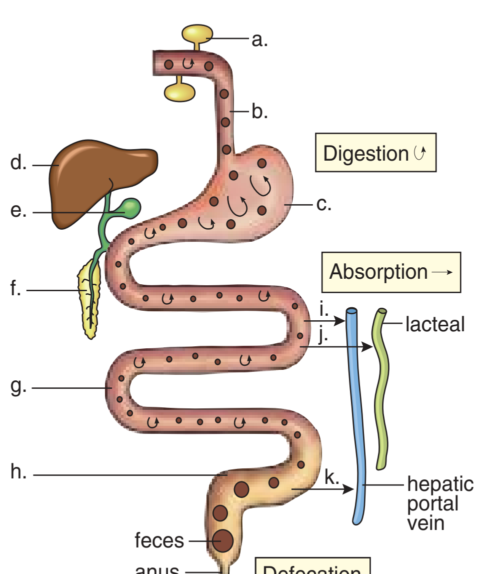
Key:
a. mucosa
b. submucosa
c. muscularis
d. serosa

25. Loose connective tissue that contains lymph nodules.
26. Contains a layer of epithelium that lines lumen.
27. Very thin layer of squamous epithelium that secretes a fluid, keeping the organ moist.
28. Contains digestive glands and mucus-secreting goblet cells.
29. Two layers of smooth muscle.

In questions 30–36, match each statement to an answer in the key. Answers are used more than once.

Key:
a. gastrin
b. secretin
c. CCK
d. All of these are correct.
e. None of these are correct.

30. Stimulates gallbladder to release bile.
31. Hormone carried in bloodstream.
32. Stimulates the stomach to digest protein.
33. Enzyme that digests food.
34. Secreted by duodenum.
35. Stimulates the salivary glands to release saliva.
36. Secreted by the stomach.
37. Label each organ indicated in the diagram (a–h). For the arrows (i–k), use either glucose, amino acids, lipids, or water.



Understanding Key Terms

Match the key terms to these definitions.

a. __________ Essential requirement in the diet, needed in small amounts. Often a part of a coenzyme.
b. __________ Fat-digesting enzyme secreted by the pancreas.
c. __________ Lymphatic vessel in an intestinal villus; it aids in the absorption of fats.
d. __________ Muscular tube for moving swallowed food from the pharynx to the stomach.
e. __________ Organ attached to the liver that serves to store and concentrate bile.

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