Chapter 3 The Human Body: From Meals to Molecules

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Chapter Outline

Chapter Concepts

- ✔ All plant and animal life is made up of atoms bound together to form molecules that are organized into cells. Cells form tissues that compose the organs and organ systems of a living organism.
- ✔ The food we eat is digested in the gastrointestinal tract, and nutrients are absorbed into the body.
- ✔ Hormones released into the blood and enzymes released into the gastrointestinal tract facilitate the digestion of food and the absorption of nutrients.
- ✔ The small intestine is the primary site of digestion and absorption.
- ✔ Water-soluble materials are absorbed into the blood. Most fat-soluble materials are absorbed into the lymph.
- ✔ Nutrients delivered to the cells can be used to produce energy in the form of ATP and to synthesize molecules for immediate use or for storage.
- ✔ Materials that are consumed but not absorbed are excreted in feces. The waste products generated inside the body by metabolism are eliminated via the lungs, skin, and kidneys.

Just a Taste

Can simply seeing or smelling food activate digestion?

Why are you hungry very soon after eating some meals while others stick with you longer?

Is it healthy to have bacteria living in your gastrointestinal tract?

No matter what food choices you make, the processes by which your body uses the nutrients in food are the same. After being consumed, food must be broken into smaller components, absorbed into the body, and then converted into forms that the body can use. Converting the meals we eat into energy or molecules that are a part of our body involves the integration of a number of processes and interaction among almost all the systems of the body. Digestion breaks food into its component parts; absorption brings these components into the body; and metabolism uses the nutrients for energy production, building new tissues, maintaining and repairing existing tissues, and regulating these processes. Whether you choose to eat a burrito, a mango, and arroz con leche (rice with milk), or a turkey sandwich, an apple, and a glass of milk—if the food cannot be properly digested, absorbed, and metabolized by the body, it will be of little benefit.

An understanding of nutrition requires comprehending the processes by which food provides fuel and function to the human body. The unique features of the digestion, absorption, and metabolism of specific nutrients will be more thoroughly discussed in subsequent chapters.

• The Chemistry of Life

The organization of life, as of all matter, begins with **atoms**. Atoms are units of matter that cannot be further broken down by chemical means. Atoms of different **elements** have different characteristics. Carbon, hydrogen, oxygen, and nitrogen are the most abundant elements in our bodies and in the foods we eat. These atoms can be linked by forces called **chemical bonds** to form **molecules**. The chemistry of all life on earth is based on **organic molecules**, which are those that contain carbon. Carbohydrates, lipids, proteins, and vitamins are nutrient classes that are made up of organic molecules. Substances that do not contain carbon, such as water and minerals, are referred to as **inorganic**.

In any living system, whether a broccoli plant, a cow, or a human being, molecules are organized into structures that form cells, the smallest unit of life (Figure 3.1). **Cells** of similar structure and function are organized into tissues. The human

Atoms The smallest units of an element that still retain the properties of that element.

Elements Substances that cannot be broken down into products with different properties.

Chemical bonds Forces that hold atoms together.

Molecules Units of two or more atoms of the same or different elements bonded together.

Organic molecules Molecules that contain carbon atoms.

Inorganic Substances that contain no carbon atoms.

Cells The basic structural and functional units of plant and animal life.

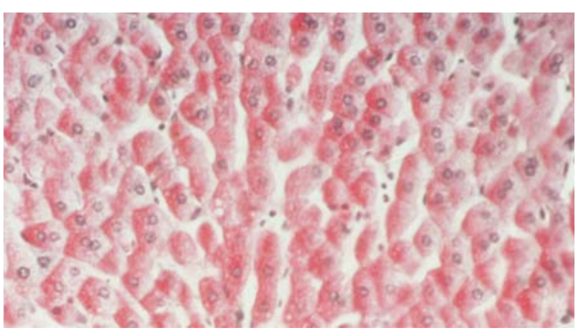

Figure 3.1
Living things are made up of cells such as these human liver cells. (Courtesy Dr. Roger Wagner)

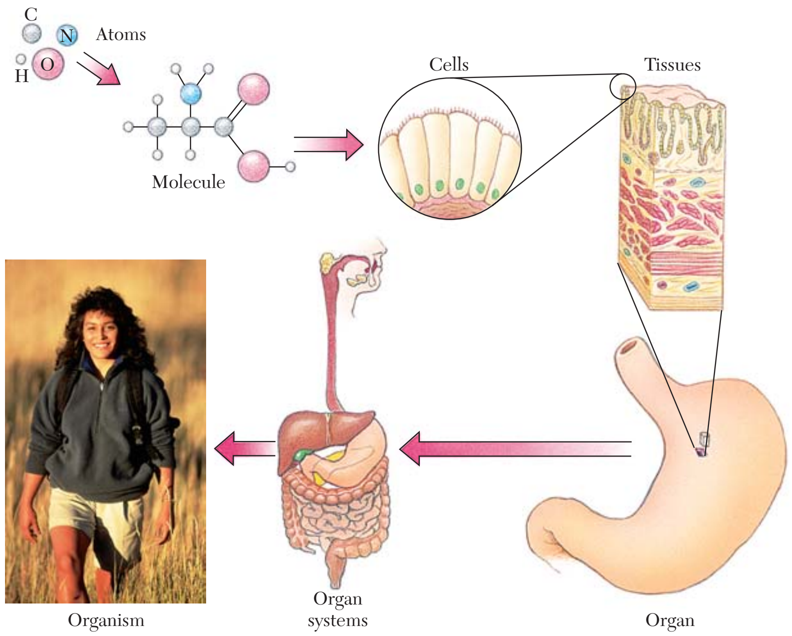

Figure 3.2
The organization of life begins with atoms that form molecules, which are then organized into cells to form tissues, organs, and organisms. (Photo, © Brian Bailey/Stone)

Table 3.1 *The Role of Body Organ Systems*

Organ System	Components	Functions
Nervous	Nerves, sense organs, brain, and spinal cord	Responds to stimuli from the external and internal environments; conducts impulses to activate muscles and glands; integrates activities of other systems.
Respiratory	Lungs, trachea, and air passageways	Supplies the blood with oxygen and removes carbon dioxide.
Urinary	Kidneys and associated structures	Eliminates wastes and regulates the balance of water, electrolytes, and acid in the blood.
Reproductive	Testes, ovaries, and associated structures	Produces offspring.
Cardiovascular	Heart and blood vessels	Transports blood, which carries oxygen, nutrients, and wastes.
Lymphatic/ Immune	Lymph and lymph structures, leukocytes	Defends against foreign invaders; picks up fluid leaked from blood vessels; transports fat-soluble nutrients.
Muscular	Skeletal muscles	Provides movement and structure.
Skeletal	Bones and joints	Protects and supports the body, provides a framework for the muscles to use for movement.
Endocrine	Pituitary, adrenal, thyroid, and other ductless glands	Secretes hormones that regulate processes such as growth, reproduction, and nutrient use.
Integumentary	Skin, hair, nails, and sweat glands	Covers and protects the body; helps control body temperature.
Digestive	Mouth, esophagus, stomach, intestines, pancreas, liver, and gallbladder	Ingests and digests food; absorbs nutrients into the blood; eliminates nonabsorbed food residues.

Adapted from E. N. Marieb, *Human Anatomy and Physiology*, 5th ed. Redwood City, Calif.: Benjamin/Cummings Publishing Co., 2000.

body contains four types of tissues: muscle, nerve, epithelial, and connective. These tissues are organized in varying combinations into **organs**, which are discrete structures that perform specialized functions in the body (Figure 3.2).

Organ A discrete structure composed of more than one tissue that performs a specialized function.

Most organs do not function alone but are part of a group of cooperative organs called an organ system. The organ systems in humans include the nervous system, respiratory system (lungs), urinary system (kidneys and bladder), reproductive system, cardiovascular system (heart and blood vessels), lymphatic/immune system, muscular system, skeletal system, endocrine system (hormones), integumentary system (skin and body linings), and digestive system (Table 3.1). An organ may be part of more than one organ system. For example, the pancreas is part of the endocrine system as well as the digestive system.

The digestive system is the organ system primarily responsible for the movement of nutrients into the body; however, several other organ systems are also important in the process of using these nutrients. The endocrine system secretes chemical messengers that help regulate food intake and absorption. The nervous system aids in digestion by sending nerve signals that help control the passage of food through the digestive tract. Once absorbed, nutrients are transported to individual cells by the cardiovascular system. The body's urinary, respiratory, and integumentary systems allow for the elimination of metabolic waste products.

• THE DIGESTIVE SYSTEM: AN OVERVIEW

The digestive system provides two major functions: **digestion** and **absorption**. Carbohydrate, fat, and protein are digested and absorbed as sugars, fatty acids, and amino acids, respectively. Some substances, such as water, can be absorbed without digestion, and others, such as dietary fiber, cannot be digested by humans and therefore cannot be absorbed. These unabsorbed substances pass through the digestive tract and are excreted in the **feces**.

The main part of the digestive system is the **gastrointestinal tract**. It is also referred to as the GI tract, gut, digestive tract, intestinal tract, or alimentary canal. It can be thought of as a hollow tube that runs from the mouth to the anus. The organs of the gastrointestinal tract include the mouth, pharynx, esophagus, stomach, small intestine, large intestine, and anus (Figure 3.3). The inside of the tube that these organs form is called the **lumen**. Food within the lumen of the gastrointestinal tract has not been absorbed and is therefore technically still outside the body. Only after food is transferred into the cells of the intestine by the process of absorption is it actually "inside" the body.

The amount of time it takes for food to pass from mouth to anus is referred to as **transit time**. In a healthy adult, transit time is about 24 to 72 hours. It is affected by the composition of the diet, physical activity, emotions, medications, and illnesses. To measure transit time, researchers add a nonabsorbable dye to a meal and measure the time between consumption of the dye and its appearance in the feces. The shorter the transit time, the more rapid the passage through the digestive tract.

The digestive process is aided by substances that are secreted into the digestive tract both by cells lining the digestive tract and by a number of accessory organs. One of these substances is **mucus**, a viscous material produced by mucosal cells that line the gut. Mucus moistens, lubricates, and protects the digestive tract. **Enzymes**, protein molecules that speed up chemical reactions without themselves being consumed or changed by the reactions, are another component of digestive system secretions (Figure 3.4). In digestion, enzymes accelerate the breakdown of food. Different enzymes are needed for the breakdown of different food components. For example, an enzyme that digests carbohydrate would have no effect on fat, and one that digests fat would have no effect on carbohydrate.

In addition to secreting substances into the lumen of the digestive tract, the digestive system secretes hormones into the bloodstream. **Hormones** are chemical messengers that are released into the blood by one organ to regulate body functions

Digestion The process of breaking food into components small enough to be absorbed into the body.

Absorption The process of taking substances into the interior of the body.

Feces Body waste, including unabsorbed food residue, bacteria, mucus, and dead cells, which is excreted from the gastrointestinal tract by passing through the anus.

Gastrointestinal tract A hollow tube consisting of the mouth, pharynx, esophagus, stomach, small intestine, large intestine, and anus, in which digestion and absorption of nutrients occur.

Lumen The inside cavity of a tube, such as the gastrointestinal tract.

Transit time The time between the ingestion of food and the elimination of the solid waste from that food.

Mucus A viscous fluid secreted by glands in the gastrointestinal tract and other parts of the body. It acts to lubricate, moisten, and protect cells from harsh environments.

Enzymes Protein molecules that accelerate the rate of specific chemical reactions without being changed themselves.

Hormones Chemical messengers that are produced in one location, released into the blood, and elicit responses at other locations in the body.

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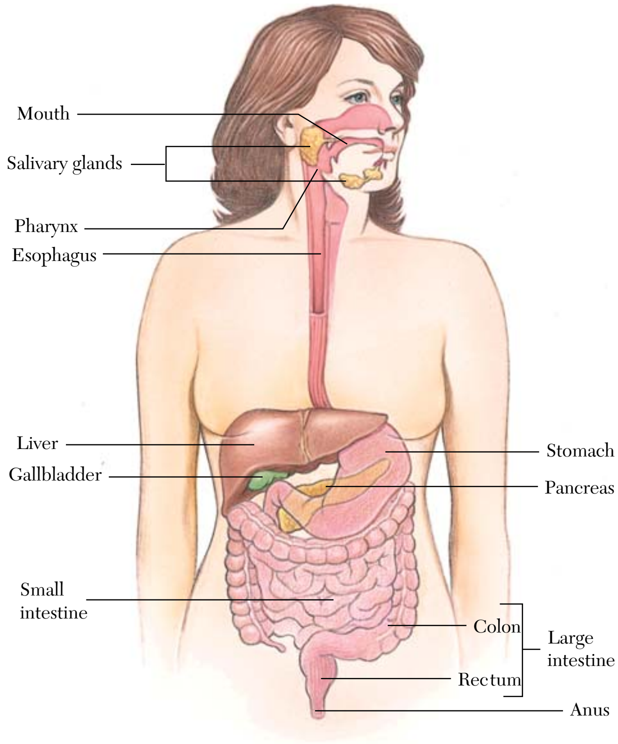

Figure 3.3
The digestive system consists of the organs of the gastrointestinal tract: the mouth, pharynx, esophagus, stomach, small intestine, large intestine, and anus, as well as a number of accessory organs: the salivary glands, liver, gallbladder, and pancreas.

elsewhere. In the gastrointestinal tract, hormones send signals that help prepare different parts of the gut for the arrival of food and thus regulate the rate that food moves through the system.

The wall of the gastrointestinal tract contains four layers of tissue (Figure 3.5). Lining the lumen is the **mucosa**, a layer of mucosal cells that secrete mucus into the lumen. The cells of the mucosa are in direct contact with churning food and harsh digestive secretions. Therefore, these cells have a short life span—only about two to five days. When these cells die, they are sloughed off into the lumen, where some components are digested and absorbed and the remainder are excreted in the

Mucosa The layer of tissue lining the gastrointestinal tract and other body cavities.

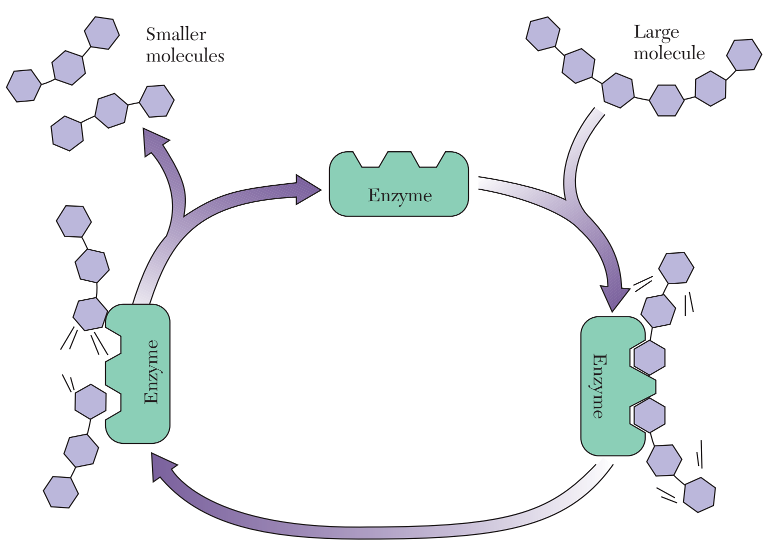

Figure 3.4
Enzymes speed up chemical reactions without themselves being altered by the reaction. In this example, an enzyme breaks a large molecule into two smaller ones.

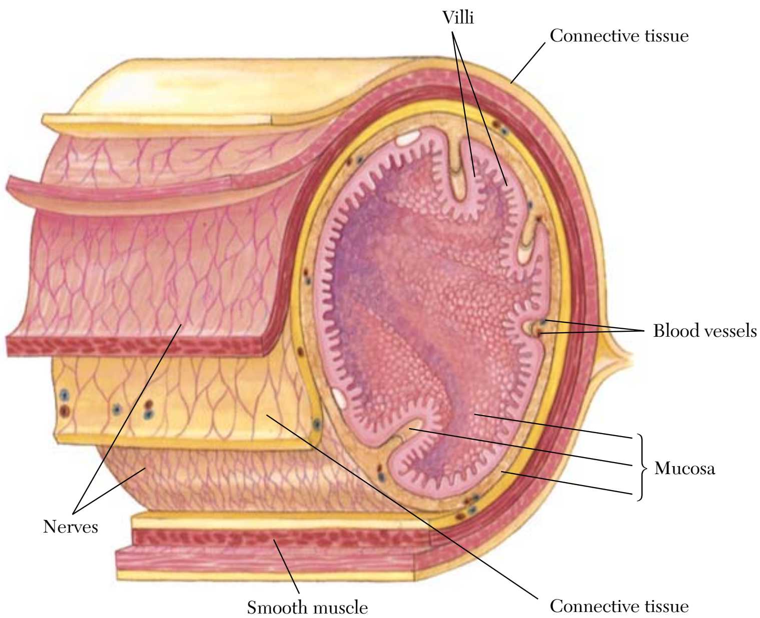

Figure 3.5
This cross section through the wall of the small intestine shows the four tissue layers: mucosa, connective tissue, smooth muscle layers, and outer connective tissue layer. (Adapted from E. P. Solomon, R. R. Schmidt, and P. J. Adragna, *Human Anatomy and Physiology*, 2nd ed. Philadelphia: Saunders College Publishing, 1990.)

feces. Because mucosal cells reproduce rapidly, the mucosa has high nutrient requirements and is therefore one of the first parts of the body to be affected by nutrient deficiencies. Surrounding the mucosa is a layer of connective tissue containing nerves and blood vessels. This layer provides support, delivers nutrients to the mucosa, and provides the nerve signals that control secretions and muscle contractions. Layers of smooth muscle—the type over which we do not have voluntary control—surround the connective tissue. The contraction of smooth muscles mixes food, breaks it into smaller particles, and propels it through the digestive tract. The final, external layer is also made up of connective tissue and provides support and protection.

• Digestion and Absorption

To be used by the body, food must be eaten and digested, and the nutrients must be absorbed and transported to the cells of the body. Because most foods we consume are mixtures of carbohydrate, fat, and protein, the physiology of the digestive tract is designed to allow the digestion of all of these components without competition among them. The following sections of this chapter will trace a meal through all these processes, from the body's anticipation of the meal to its elimination of the waste products.

Imagine slices of oven-roasted turkey served on fresh baked bread accompanied by an apple and a glass of lowfat milk (Figure 3.6).

Figure 3.6
The sight, smell, and sounds of food preparation can initiate activity in the digestive tract. (Charles D. Winters)

Sights, Sounds, and Smells

Activity in the digestive tract begins before food even enters the mouth. As the meal is being prepared, sensory input such as the sight of a turkey being lifted out of the oven, the clatter of the table being set, and the smell of freshly baked bread may make your mouth become moist and your stomach begin to secrete digestive substances. This response occurs when the nervous system signals the digestive system to ready itself for a meal. This cephalic (pertaining to the head) response occurs as a result of external cues, such as sight and smell, even when the body is not in need of food.

Mouth

Saliva A watery fluid produced and secreted into the mouth by the salivary glands. It contains lubricants, enzymes, and other substances.

Salivary amylase An enzyme secreted by the salivary glands that breaks down starch.

The mouth is the entry point for food into the digestive tract. In the mouth, the taste of food continues the processes begun by the smells, sights, and sounds of food preparation. The presence of food in the mouth stimulates the flow of **saliva** from the salivary glands located internally at the sides of the face and immediately below and in front of the ears (see Figure 3.3). Saliva contains the enzyme **salivary amylase**, which begins the digestion of carbohydrate. Salivary amylase can break the long sugar chains of starch in the bread of the turkey sandwich into shorter chains of sugars. Saliva also lubricates the upper gastrointestinal tract and moistens the food so that it can easily be tasted and swallowed.

Digestive enzymes can act only on the surface of food particles; therefore, chewing is important because it breaks food into small pieces, increasing the surface area in contact with digestive enzymes. Chewing also breaks apart fiber that traps nutrients in some foods. If the fiber is not broken, some nutrients cannot be absorbed. For example, the peel of the apple in the sample meal is a source of vitamins and minerals; however, these nutrients cannot be absorbed without first being released from the fiber in the peel. Adult humans have 32 teeth, specialized for biting, tearing, grinding, and crushing foods; thus, missing or decayed teeth can interfere with the proper digestion of food. Tooth decay, or caries, commonly called cavities, is caused by acid produced when bacteria break down carbohydrates (see Chapter 4).

Pharynx

Pharynx A funnel-shaped opening that connects the nasal passages and mouth to the respiratory passages and esophagus. It is a common passageway for food and air and is responsible for swallowing.

The meal that entered the mouth as a turkey sandwich, apple, and milk has now been formed into a bolus, a ball of chewed food mixed with saliva. From the mouth, the bolus moves into the **pharynx**, the part of the gastrointestinal tract responsible for swallowing. The pharynx is shared by the digestive tract and the respiratory tract: Food passes through the pharynx on its way to the stomach, and air passes here on its way to and from the lungs. During swallowing, the air passages are blocked by a valvelike flap of tissue called the epiglottis, so food passes to the stomach, not the lungs. Sometimes food can pass into an upper air passageway. It is usually dislodged with a cough, but if it becomes stuck it can block the flow of air and cause choking. A quick response is required to save the life of a person whose airway is completely blocked. The Heimlich maneuver, which forces air out of the lungs by using a sudden application of pressure to the upper abdomen, can blow an object out of the blocked air passage (Figure 3.7).

Esophagus

Esophagus A portion of the gastrointestinal tract that extends from the pharynx to the stomach.

Peristalsis Coordinated muscular contractions that move food through the gastrointestinal tract.

The **esophagus** passes through the diaphragm, a muscular wall separating the abdomen from the cavity where the lungs are located, to connect the pharynx and stomach. The bolus of food is moved along by rhythmic contractions of the smooth muscles, a process called **peristalsis**. This contractile movement, which is controlled automatically by the nervous system, occurs throughout the gastrointestinal tract, pushing the food bolus along from the pharynx through the large intestine (Figure 3.8).

Sphincter A muscular valve that helps control the flow of materials in the gastrointestinal tract.

To move from the esophagus into the stomach, food must pass through a **sphincter**, a muscle that encircles the tube of the digestive tract and acts as a valve. When the muscle contracts, the valve is closed. The gastroesophageal sphincter, located between the esophagus and the stomach, normally prevents foods from moving back out of the stomach. Occasionally, materials do pass out of the stomach through this valve. Heartburn occurs when some of the acidic stomach contents leak up and out of the stomach into the esophagus, causing a burning sensation. Vomiting is the result of a reverse peristaltic wave that causes the sphincter to relax and allow the food to pass upward out of the stomach toward the mouth.

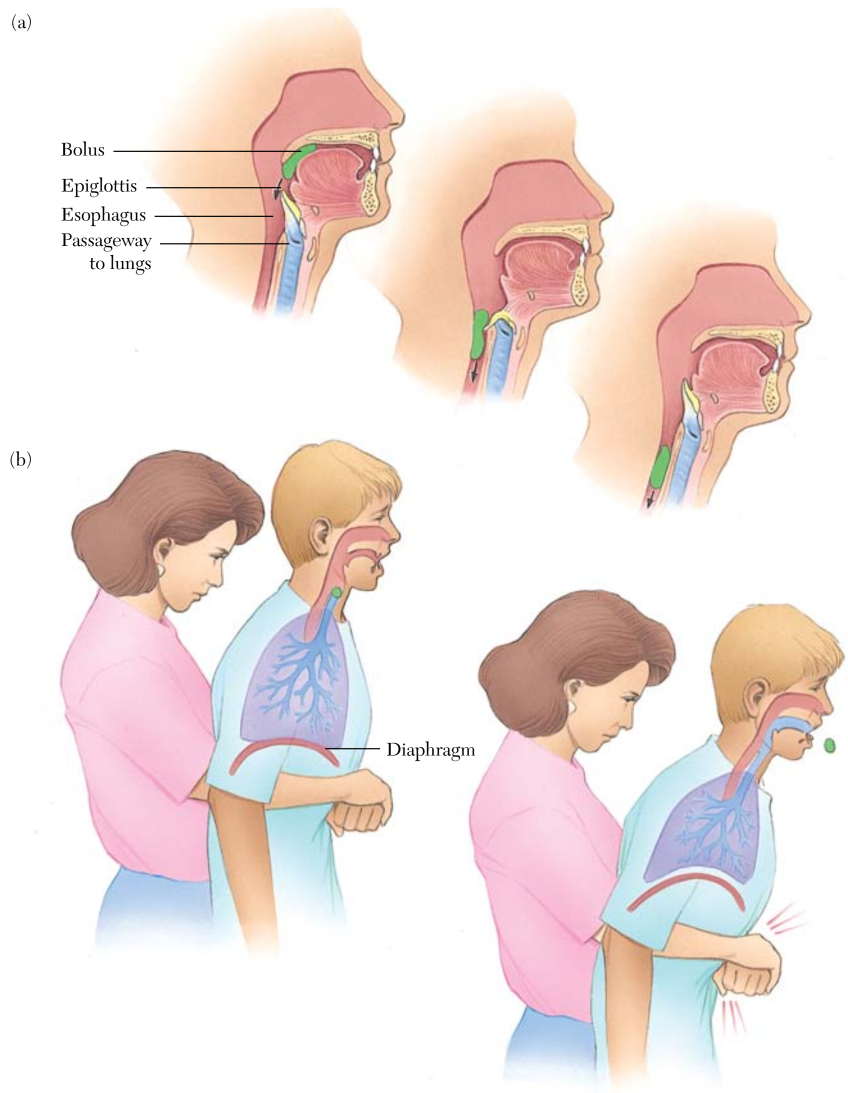

Figure 3.7
(*a*) When a bolus of food is swallowed, it pushes the epiglottis down over the opening to the air passageways. (*b*) If food does become lodged in the air passageways, it can be dislodged by the Heimlich maneuver, illustrated here.

Chyme A mixture of partially digested food and stomach secretions.

Stomach

The stomach is an expanded portion of the gastrointestinal tract that serves as a temporary storage place for food. While held in the stomach, the bolus is mixed with highly acidic stomach secretions to form a semiliquid food mass called **chyme**. The mixing of food in the stomach is aided by an extra layer of smooth muscle in the stomach wall. While most of the gastrointestinal tract is surrounded by two layers of muscle, the stomach contains a third layer, allowing for powerful contractions that thoroughly churn and mix the stomach contents. Some digestion takes place in the stomach, but, with the exception of some water, alcohol, and a few drugs such as aspirin and acetaminophen (Tylenol), very little absorption occurs here.

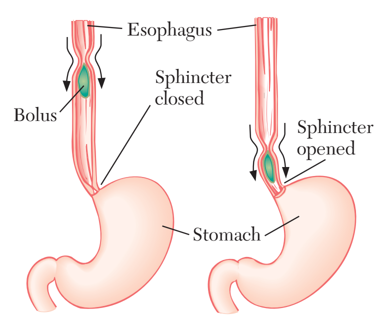

Figure 3.8
The rhythmic contractions of peristalsis propel food down the esophagus, through the open sphincter, and into the stomach.

Regulation of Gastric Secretion Gastric or stomach secretions are regulated by both nervous and hormonal mechanisms. Signals from three different sites—the brain, stomach, and small intestine—stimulate or inhibit gastric secretion. The three phases of gastric secretion are therefore called cephalic, gastric, and

Cephalic phase The phase of gastric secretion that is stimulated by the sight, smell, and taste of food.

Gastric phase The phase of gastric secretion triggered by the entry of food into the stomach.

Gastrin A hormone secreted by the stomach mucosa that stimulates the secretion of gastric juices.

Pepsin A protein-digesting enzyme produced by the stomach. It is secreted in the gastric juice in an inactive form and activated by acid in the stomach.

Peptic ulcer An open sore in the lining of the stomach, esophagus, or small intestine.

Intestinal phase The phase of gastric secretion that is begun by the entry of food into the small intestine.

intestinal. The **cephalic phase** occurs before food enters the stomach. During this phase, the thought, smell, sight, or taste of food causes the brain to send nerve signals that increase gastric secretion. This prepares the stomach to receive food (Figure 3.9).

The second phase, referred to as the **gastric phase**, begins when food enters the stomach. The presence of food in the stomach causes gastric secretion by stretching local nerves, by signaling the brain, and by stimulating the secretion of the hormone **gastrin** from the upper portion of the stomach. Gastrin triggers the release of gastric juice, which is produced by digestive glands, called gastric glands, in the lining of the stomach. One of the components of gastric juice is hydrochloric acid. Hydrochloric acid stops the carbohydrate-digesting activity of salivary amylase and helps to begin the digestion of protein. It also serves to kill most bacteria present in food. Another component of gastric juice is pepsinogen. When pepsinogen is exposed to the acidity of the stomach, it is converted into the protein-digesting enzyme **pepsin**, which breaks proteins into shorter chains of amino acids called polypeptides. Pepsin is produced in an inactive form and activated in the stomach; otherwise, its active form would digest the glands that produce it. Although salivary amylase function is stopped by the acidity of the stomach, pepsin functions best in acid. Therefore, digestion of starch from our sample meal stops in the stomach, and digestion of the protein from the turkey, milk, and bread begins. The protein of the stomach wall is protected from the acid and pepsin by a thick layer of mucus. If the mucus layer is penetrated, pepsin and acid can damage the underlying tissues and cause **peptic ulcers**, erosions of the stomach wall or some other region of the gastrointestinal tract. One of the leading causes of ulcers is acid-resistant bacteria that infect the lining of the stomach, causing damage to the gastrointestinal tract wall and destroying the protective mucosal layer.[1]

The third phase of gastric secretion, the **intestinal phase**, is begun by the passage of chyme into the small intestine. This triggers events that decrease stomach motility and secretions, and slow the release of food into the intestine. This ensures that the amount of chyme entering the small intestine does not exceed the ability of the intestine to process it.

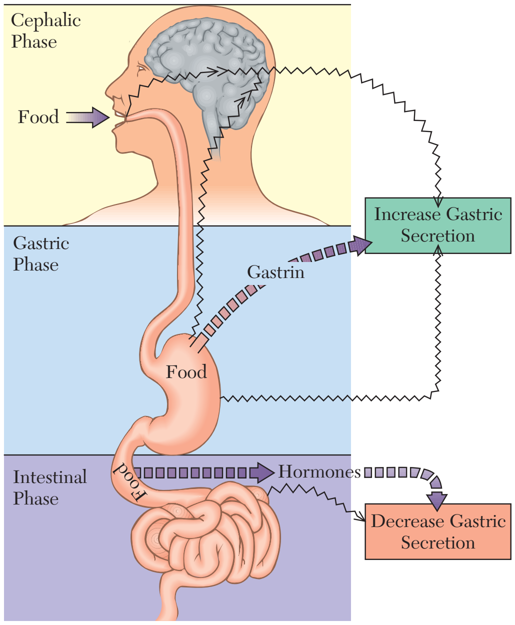

Figure 3.9
The regulation of gastric secretion is divided into three phases. In the cephalic phase, the sight, smell, and taste of food cause the brain to signal an increase in gastric secretions. In the gastric phase, food entering the stomach stimulates gastric secretions by stretching local nerves, signaling the brain, and causing gastrin release. In the intestinal phase, food entering the small intestine inhibits gastric secretions by triggering nervous and hormonal signals. In this diagram the zigzag arrows represent nerve signals, and the dashed arrows represent hormonal signals.

Control of Stomach Emptying Chyme normally leaves the stomach in 2 to 6 hours. The rate of stomach emptying is determined by the size and composition of the meal and controlled by signals from the small intestine. Chyme moving out of the stomach must pass through the pyloric sphincter. This sphincter helps regulate the rate at which food enters the intestine. The small intestine stretches as it fills with food. This distension inhibits stomach emptying. A large meal will take longer to leave the stomach than a small meal, and a solid meal will leave the stomach more slowly than a liquid meal. The nutritional composition of a meal also affects how long it stays in the stomach. The meal we have been following is of mixed composition. Together, the sandwich, apple, and milk contain about 25% of energy as protein, 45% as carbohydrate, and 30% as fat. The meal is partly solid and partly liquid, and so will be in the stomach for an average amount of time (about 4 hours). A high-fat meal will stay in the stomach the longest because fat entering the small intestine slows stomach emptying. A meal that is primarily protein will leave more quickly, and a meal of mostly carbohydrate will leave the fastest. The reason you are often ready to eat again soon after a meal of vegetables and rice is that this high-carbohydrate, lowfat meal leaves the stomach rapidly. Thus, what you choose for breakfast can affect when you become hungry for lunch. Toast and coffee will leave your stomach far more quickly than a larger meal with more protein and some fat, such as a bowl of cereal with lowfat milk, toast with peanut butter, and a glass of juice. Factors besides food composition also can affect gastric emptying. For example, sadness and fear tend to slow emptying, while aggression tends to increase gastric motility and speed emptying.

Small Intestine

The small intestine is a narrow tube about 20 feet in length. It is divided into three segments. The first 12 inches are the duodenum, the next 8 feet are the jejunum, and the last 11 feet are the ileum. The small intestine is the main site of digestion of food and absorption of nutrients.

Digestion in the Small Intestine In the small intestine, secretions from the **pancreas** and **gallbladder** as well as from the intestine itself aid digestion. The pancreas secretes pancreatic juice, which contains bicarbonate ions and digestive enzymes. The bicarbonate ions neutralize the acid in chyme, making the environment in the small intestine neutral rather than acidic as it is in the stomach. This neutrality allows enzymes from the pancreas and small intestine to function. Pancreatic amylase continues the job of breaking starch into sugars that was started in the mouth by salivary amylase. Pancreatic protein-digesting enzymes, including trypsin and chymotrypsin, continue to break protein into shorter and shorter chains of amino acids. Intestinal digestive enzymes, found attached to or inside the cells lining the small intestine, are involved in the digestion of sugars into single sugar units and the digestion of small polypeptides into amino acids.

The gallbladder secretes **bile**, a substance produced in the liver that is necessary for fat digestion and absorption. Bile secreted into the small intestine mixes with fat and emulsifies it, or breaks it into small droplets. These small droplets allow pancreatic enzymes, called **lipases**, to more efficiently access the fat and digest it and also facilitate fat absorption.

Hormonal Control of Secretions The release of bile and pancreatic enzymes into the small intestine is controlled by two hormones secreted by the mucosal lining of the duodenum. **Secretin** signals the pancreas to secrete bicarbonate ions and stimulates the liver to secrete bile into the gallbladder. **Cholecystokinin (CCK)** signals the pancreas to secrete digestive enzymes and causes the gallbladder to contract and release bile into the duodenum (Figure 3.10).

Pancreas An organ that secretes digestive enzymes and bicarbonate ions into the small intestine during digestion.

Gallbladder An organ of the digestive system that stores bile, which is produced by the liver.

Bile A substance made in the liver and stored in the gallbladder. It is released into the small intestine to aid in fat digestion and absorption.

Lipases Fat-digesting enzymes.

Secretin A hormone released by the duodenum that signals the pancreas to secrete bicarbonate ions and stimulates the liver to secrete bile into the gallbladder.

Cholecystokinin (CCK) A hormone released by the duodenum that signals the pancreas to secrete digestive enzymes and causes the gallbladder to contract and release bile into the duodenum.

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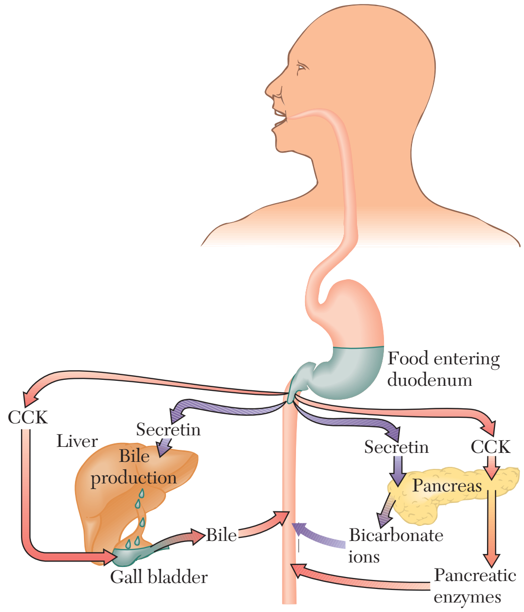

Figure 3.10
Food entering the duodenum triggers the release of the hormones secretin and cholecystokinin (CCK). Secretin increases the output of bile by the liver and the secretion of bicarbonate ions from the pancreas. CCK signals the release of bile by the gallbladder and the secretion of digestive enzymes from the pancreas.

Absorption in the Small Intestine The small intestine is the primary site of absorption for water, vitamins, minerals, and the products of carbohydrate, fat, and protein digestion. Several different mechanisms are involved (Figure 3.11). Some molecules are absorbed by diffusion—the process by which a substance moves from an area of higher concentration to an area of lower concentration. Substances that move from higher to lower concentrations are said to move down their concentration gradient. When a concentration gradient exists and the nutrient can pass freely from the lumen of the GI tract across the cell membrane into the mucosal cell, the process is called **simple diffusion**. This process requires no energy. The water, small lipid molecules, and fat-soluble vitamins from the milk in our meal are absorbed by simple diffusion. Many nutrients, however, cannot pass freely across cell membranes; they must be carried by other molecules in a process called **facilitated diffusion**. Even though these nutrients are carried across the cell membrane by other molecules, they still move down a concentration gradient from an area of higher concentration to one of lower concentration without requiring energy; the sugar fructose found in the apple is absorbed by facilitated diffusion. Substances un-

Simple diffusion The movement of substances from an area of higher concentration to an area of lower concentration. No energy is required.

Facilitated diffusion The movement of substances across a cell membrane from an area of higher concentration to an area of lower concentration with the aid of a carrier molecule. No energy is required.

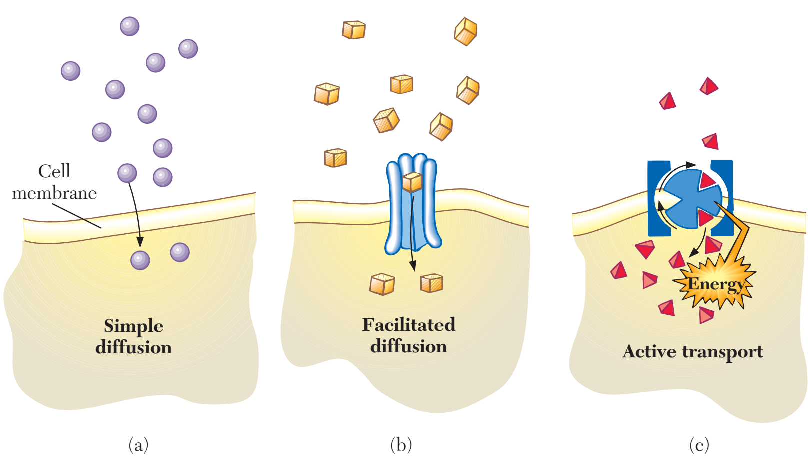

Figure 3.11
Nutrients are absorbed from the lumen across the cell membrane into the cell by several mechanisms. (*a*) Simple diffusion, which requires no energy, is shown here by the purple balls that move from an area of higher concentration to an area of lower concentration. (*b*) Facilitated diffusion, which requires no energy, is shown here by the yellow cubes that move from an area of higher concentration to an area of lower concentration with the help of a carrier. (*c*) Active transport, which requires energy and a carrier, is shown here by the red pyramids that move from an area of lower concentration to an area of higher concentration.

able to be absorbed by diffusion must enter the body by **active transport**, a process that requires both a carrier molecule and energy. This use of energy allows substances to be transported against their concentration gradient from an area of lower concentration to an area of higher concentration. The sugar glucose from the starch of the bread and amino acids from the protein in the milk, turkey, and bread are absorbed by active transport. This allows these nutrients to be absorbed even when they are present in higher concentrations inside the mucosal cells. More specific information about the absorption of the products of carbohydrate, fat, and protein digestion will be discussed in Chapters 4, 5, and 6, respectively.

Structure to Maximize Absorption The structure of the small intestine is specialized to allow maximal absorption of the nutrients. In addition to its length, the small intestine has three other features that increase the area of its absorptive surface (Figure 3.12). First, the intestinal walls are arranged in circular or spiral folds which increase the surface area in contact with nutrients. Second, its entire inner surface is covered with fingerlike projections called **villi** (singular, villus). And finally, each of these villi is covered with tiny **microvilli**, often referred to as the brush border. Together these features provide a surface area that is about the size of a tennis court (300 m^2 or 3229 ft^2). Each villus contains a blood vessel and a **lymph vessel** or **lacteal**, which are located only one cell layer away from the nutrients in the intestinal lumen. Nutrients must cross the mucosal cell layer to reach the bloodstream or lymphatic system for delivery to the tissues of the body.

Large Intestine

Components of chyme that are not absorbed in the small intestine pass through the ileocecal valve to the large intestine, which includes the **colon** and **rectum**. Although most absorption occurs in the small intestine, water and some vitamins

Active transport The transport of substances across a cell membrane with the aid of a carrier molecule and the expenditure of energy. This may occur against a concentration gradient.

Villi (villus) Fingerlike protrusions of the lining of the small intestine that participate in the digestion and absorption of foodstuffs.

Microvilli Minute brushlike projections on the mucosal cell membrane that increase the absorptive surface area in the small intestine.

Lymph vessel or **lacteal** A tubular component of the lymphatic system that carries fluid away from body tissues. Lymph vessels in the intestine are known as lacteals and can transport large particles such as the products of fat digestion.

Colon The largest portion of the large intestine.

Rectum The portion of the large intestine that connects the colon and anus.

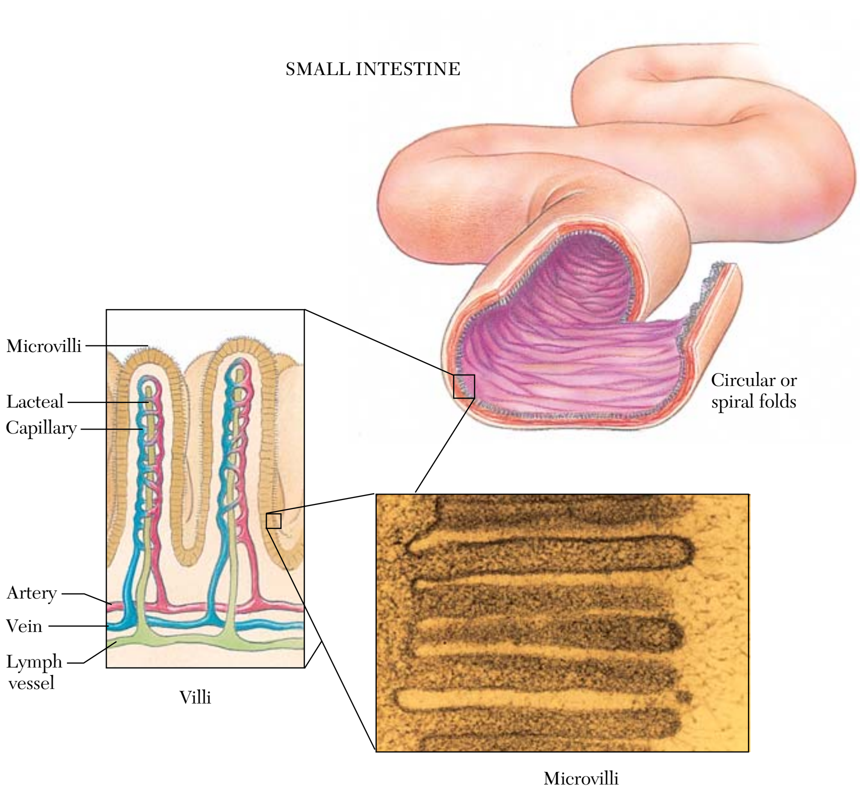

Figure 3.12
The small intestine contains folds, villi, and microvilli, which increase the absorptive surface area. (Photo, © S. Ito, D. W. Fawcett/Visuals Unlimited)

Off the Shelf

Should You Feed Your Flora?

Bacteria growing in your gut? Sounds bad, but the large intestine of a healthy adult is home to several hundred species of bacteria. The type and number of bacteria in your gastrointestinal tract are affected by both your diet and your health. In turn, the type and amount of bacteria in your GI tract can affect your health.

Most of the time the microflora in our gastrointestinal tracts have beneficial effects. They improve the digestion and absorption of essential nutrients; synthesize vitamins, some of which can be absorbed; and metabolize harmful substances, such as ammonia, thus reducing their concentration in the blood. They are important for intestinal immune function, proper growth of cells in the colon, and optimal intestinal motility and transit time.[1] A strong population of healthful bacteria can also inhibit the growth of harmful bacteria. If the wrong bacteria take over, the result could be diarrhea, infections, and perhaps an increased risk of cancer. Should we be supplementing our diet with beneficial bacteria or eating certain foods to promote their growth?

The recognition that intestinal bacteria are important to human health is not new. In the early 1900s, Nobel Prize-winning Russian scientist Eli Metchnikoff observed that Bulgarian peasants who consumed large quantities of yogurt and other fermented milk products lived long healthy lives. He proposed that the bacteria in these foods positively affected the microflora in the colon and "prevented intestinal putrification" and helped "maintain the forces of the body."[2] Modern research continues to support Metchnikoff's hypothesis that the bacteria in fermented dairy products, which include *Bifidobacterium* and *Lactobacillus*, provide health benefits.

Today, the consumption of products, such as yogurt, that naturally contain these bacteria and supplements containing live bacteria are referred to as probiotic therapy. When eaten alive, some of these organisms survive passage through the upper GI tract and live temporarily in the colon before they are excreted in the feces. Probiotics have been hypothesized to reduce the risk of heart disease, stimulate immune function, prevent cancer, and improve the integrity of the gastrointestinal mucosa. Research has provided some support for these claims. Evidence from both human and animal studies suggests that the consumption of fermented dairy products has a moderate cholesterol-lowering effect.[3] Probiotic bacteria have also been found to have beneficial effects on immune function in the intestine,[4] and studies in animals have shown that they can prevent the formation and growth of cancerous cells in the colon.[5] Probiotics have been found to shorten the duration of diarrhea due to viral infections, and these bacteria may also be useful in treating other disorders in which the gut barrier is compromised, such as colitis.[6,7] A healthy bacterial population in the intestine may also help prevent constipation, flatulence, and excess gastric acidity.

One problem with probiotics is that when they are no longer consumed, the added bacteria are rapidly washed out of the colon. A newer approach being used to maintain a healthy microflora is to consume foods or other substances that encourage the growth of particular types of bacteria. Substances that pass undigested into the colon and serve as food for bacteria are called prebiotics. Prebiotics can selectively stimulate the growth of certain types of bacteria. They are currently sold as dietary supplements and are added to commercially prepared tube feeding formulas to promote gastrointestinal health.

Our understanding of probiotics and prebiotics is expanding. We know that the risks of using these products are negligible, but their specific health benefits are still being investigated. Soon we may be able to take probiotics, instead of antibiotics, to eliminate hazardous bacteria in the gut. And, we may be paying attention to what we are feeding our flora—as well as ourselves.

[1] Madsen, K. L. The use of probiotics in gastrointestinal disease. *Can. J. Gastroenterol.* 15: 817–822, 2001.

[2] Metchnikoff, E. *The Prolongation of Life*. New York: G. P. Putnam's Sons, 1908.

[3] St-Onge, M-P, Farnworth, E. R., and Jones, P. J. H. Consumption of fermented and nonfermented dairy products: Effects on cholesterol concentrations and metabolism. *Am. J. Clin. Nutr.* 71: 674–681, 2000.

[4] Erickson, K. L., and Hubbard, N. E. Probiotic immunomodulation in health and disease. *J. Nutr.* 130:403S–409S, 2000.

[5] Brady, L. J., Gallaher, D. D., and Busta, F. F. The role of probiotic cultures in the prevention of colon cancer. *J. Nutr.* 130:410S–414S, 2000.

[6] De Roos, N. M., and Katan, M. B. Effects of probiotic bacteria on diarrhea, lipid metabolism, and carcinogenesis: A review of papers published between 1988 and 1998. *Am. J. Clin. Nutr.* 71:405–411, 2000.

[7] Rolfe, R. D. The role of probiotic cultures in the control of gastrointestinal health. *J. Nutr.* 130:396S–402S, 2000.

Intestinal microflora Microorganisms that inhabit the large intestine.

and minerals are also absorbed in the colon. Peristalsis here is slower than in the small intestine. Water, nutrients, and fecal matter may spend 24 hours in the large intestine, in contrast to the 3 to 5 hours it takes for chyme to move through the small intestine. This slow movement favors the growth of bacteria, referred to as **intestinal microflora**. These bacteria are permanent beneficial residents of this part of the gastrointestinal tract (see *Off the Shelf*: Should You Feed Your Flora?). The microflora act on unabsorbed portions of food, such as the fiber contained in the apple and whole grain bread, producing nutrients that they can use or, in some cases, that can be absorbed into the body. For example, the microflora synthesize small amounts of some B vitamins and vitamin K, some of which can be absorbed. One additional by-product of bacterial metabolism is gas, which causes flatulence.

Materials not absorbed are excreted as waste products in the feces. The amount of water in the feces is affected by fiber and fluid intake. Fiber retains water, so when adequate fiber and fluid are consumed, feces have a high water content and are easily passed. When inadequate fiber or fluid is consumed, feces are hard and dry, and constipation can result.

The end of the colon is connected to the rectum, where feces are stored prior to defecation. The rectum is connected to the **anus**, the external opening of the digestive tract. The rectum and anus work with the colon to prepare the feces for elimination. Defecation is regulated by a sphincter that is under voluntary control. It allows the feces to be eliminated at convenient and appropriate times. The digestion and absorption of carbohydrate, fat, and protein are summarized in Figure 3.13.

Anus The outlet of the rectum through which feces are expelled.

Digestive Problems and Solutions

Each of the organs and processes of the digestive system is necessary for the proper digestion and absorption of food. Problems at any step along the way can inhibit the ability to obtain nutrients from food and influence nutritional status. For example, dental problems can make it difficult to chew, limiting the types of food that can be consumed and reducing contact between digestive enzymes and the nutrients in

ON THE WEB
For more information on diet and digestive disease, go to the National Institute of Diabetes and Digestive and Kidney Disease at
www.niddk.nih.gov/health/digest/digest.htm/

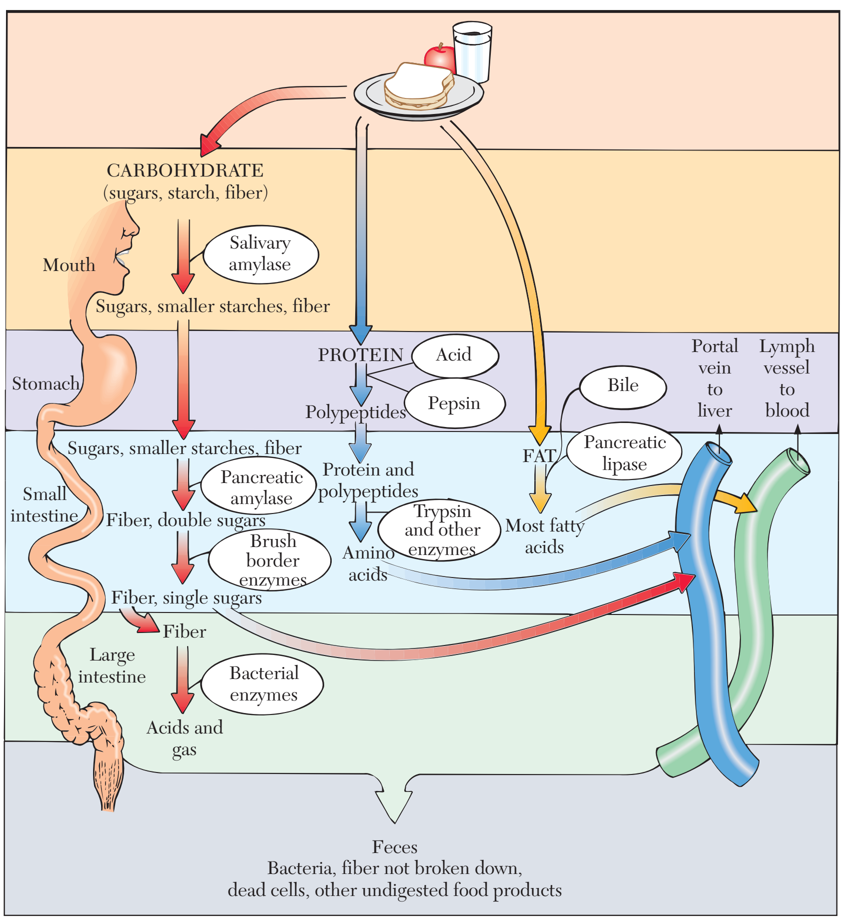

Figure 3.13
An overview of the digestion and absorption of a meal.

Off the Label

Antacids: Getting the Drug Facts

Medication is an often overlooked source of nutrients. In some cases, these nutrients are a welcome addition to the diet, but in others they may have a negative impact on nutritional status. Heartburn remedies, which are among the most popular over-the-counter drugs, are often a source of nutritive minerals.

Heartburn is a common minor digestive complaint that is caused by stomach acid leaking into the esophagus. The acid in stomach secretions is necessary for digestion; it enhances the absorption of certain nutrients and minimizes bacterial growth. But excess stomach acid or stomach acid that comes in contact with other parts of the gastrointestinal tract can cause pain and discomfort.

When choosing a product to help your heartburn (or any other ailment), be sure to check the label. Drug Facts labels on nonprescription drugs are designed to help consumers take medications correctly as well as understand the benefits and risks and any nutritional impact the drugs might have. The label must present information in a standardized, easy-to-follow format that is as readable and consistent as the Nutrition Facts label found on food products. Under the title "Drug Facts," the product's active ingredients must be listed first, along with the purpose for each, followed by uses, warnings, and directions, and then inactive ingredients.

The label shown here indicates that Reducid contains famotidine, a drug that works by reducing the amount of acid secreted by the stomach. It also contains calcium carbonate and magnesium hydroxide, compounds that decrease the acidity of the stomach contents as well as contribute nutrients to the diet. The label tells you that a single tablet contains 800 mg of calcium, which is 80% of the Daily Value, and 165 mg of magnesium, which is 40% of the Daily Value. Both of these nutrients are typically consumed in less than the recommended amounts in the American diet. Calcium carbonate is a good source of well-absorbed calcium. However, excess magnesium can cause diarrhea. In fact, when taken in high doses, magnesium antacids such as Milk of Magnesia can be used as laxatives.

Other antacids contain minerals that are not beneficial additions to the diet. For example, Alka-Seltzer contains sodium bicarbonate. Each tablet of Alka-Seltzer contains 567 mg of sodium, about 24% of the Daily Value. Sodium-containing antacids contribute a significant amount of sodium to any diet and would not be recommended for someone on a sodium-restricted diet. Aluminum is also found in a number of antacids. Aluminum binds to phosphate in the gut and limits phosphorus absorption. It may also cause constipation. In addition to minerals, a look at the inactive ingredients shows that many products marketed to treat heartburn contain sugar (added to make them more palatable) and starch (added as filler). The amount is small, but individuals who have diabetes or are consuming low-kcalorie diets should consider these in diet planning.

If you are looking for an over-the-counter medication to treat occasional heartburn, understanding how to read the label helps you to use it correctly and to know if the product will affect your nutritional health as well as reduce your heartburn.

[1]Nordenberg, T., New drug label spells it out simply, *FDA Consumer*, July/August 1999.

[2]Mortensen, L., and Charles, P. Bioavailability of calcium supplements and the effect of vitamin D: Comparisons between milk, calcium carbonate, and calcium carbonate plus vitamin D. *Am J. Clin. Nutr.* 63:354–357, 1996.

[3]Feldma, M. Comparison of the effects of over-the-counter famotidine and calcium carbonate antacid on postprandial gastric acid. *J.A.M.A.* 275: 1438–1441, 1996.

food. Pancreatic problems can limit the availability of enzymes needed to digest fat and protein, and gallbladder problems can interfere with fat absorption. Some digestive problems and their causes, consequences, and solutions are given in Table 3.2. Some of these problems can be treated with medications, whereas others require adaptations in the way nutrients are provided (see *Off the Label*: Antacids: Getting the Drug Facts)

For individuals who are unable to consume food or digest and absorb the nutrients needed to meet their requirements, several alternative feeding methods have been developed. People who are unable to swallow can be fed a liquid diet through a tube inserted into the stomach or intestine. Enteral or tube feeding with commercially prepared formula can provide a balanced diet containing all the essential nutrients. Tube feeding can be used in patients who are unconscious or have suffered an injury to the upper gastrointestinal tract. For individuals whose gastrointestinal tract is not functional, nutrients can be provided directly into the bloodstream. This is referred to as total parenteral nutrition (TPN). Carefully planned TPN can provide all the nutrients essential to life. When all nutrients are

not provided in a TPN solution, nutrient deficiencies develop quickly. Inadvertently feeding patients incomplete TPN solutions has helped demonstrate the essentiality of several trace minerals.

Differences in the Digestive System Throughout Life

There are some differences in the way the digestive system functions during pregnancy and infancy and with advancing age. These changes affect the ability to ingest and digest food and absorb nutrients. However, if the diet is properly managed, nutritional status can be maintained at all stages of life.

Pregnancy Physiological changes that occur during pregnancy may cause gastrointestinal problems. During the first three months, many women experience nausea, referred to as morning sickness. This term is a misnomer, because it can occur at any time of the day. Morning sickness is believed to be due to pregnancy-related hormonal changes. In most cases, it can be dealt with by eating frequent small meals

www.wiley.com/college/smolin

ON THE WEB
For more information on providing appropriate nutrition at all stages of life, go to the Fact sheets in the Knowledge Center of the American Dietetic Association Website at www.eatright.org/

Table 3.2 *Digestive Problems and Nutritional Consequences*

Problem	Cause	Nutritional Consequences	Solution
Dry mouth	Disease medications	Decreased food intake due to changes in taste, difficulty chewing and swallowing, increased tooth decay, and gum disease	Change medications, use artificial saliva
Dental pain and loss of teeth	Tooth decay, gum disease	Reduced food intake due to impaired ability to chew, reduced nutrient absorption due to incomplete digestion	Change consistency of foods consumed
Heartburn	Stomach acid leaking into esophagus, caused by overeating, anxiety, stress, pregnancy, and disease processes	Pain and discomfort after eating	Reduce meal size, avoid high fat foods, consume liquids between rather than with meals, remain upright after eating
Ulcers	Infection of stomach by acid-resistant bacteria that penetrate the mucous layer and damage the epithelial lining, chronic use of drugs such as aspirin and ibuprofen that erode the mucosa	Pain, bleeding, and possible abdominal infection	Antiobiotics to treat infection, antacids, change medications
Vomiting	Bacterial and viral infections, medications, other illnesses, eating disorders	Dehydration and electrolyte imbalance; if chronic, can damage the mouth, gums esophagus, and teeth	Medications to treat infection, fluid and electrolyte replacement
Pancreatic disease	Cystic fibrosis or other chronic pancreatic diseases	Malabsorption of fat, fat soluble vitamins, and vitamin B_{12} due to reduced availability of pancreatic enzymes and bicarbonate	Oral supplements of digestive enzymes
Gallstones	Deposits of cholesterol, bile pigments, and calcium	Pain and poor fat digestion	Lowfat diet, surgery

and avoiding foods and smells that cause nausea. Eating dry crackers or cereal may also help. In severe cases where uncontrollable vomiting occurs, TPN may be needed to obtain adequate nutrition.

Later in pregnancy, the enlarged uterus puts pressure on the stomach and intestines, which can make it difficult to consume large meals. In addition, the placenta produces the hormone progesterone, which causes the smooth muscles of the digestive tract to relax. The muscle-relaxing effects of progesterone may relax the gastroesophageal sphincter enough to allow stomach contents to move back into the esophagus, causing heartburn. Symptoms of heartburn can be reduced by avoiding spicy foods; avoiding fatty foods, which slow the rate of stomach emptying; and remaining upright after eating. In the large intestine, relaxed muscles and the pressure of the uterus cause less efficient peristaltic movements and may result in constipation. Increasing water intake, eating a diet high in fiber, and exercising regularly can help relieve constipation.

Infancy The digestive system is one of the last to fully mature in developing humans. At birth, the digestive tract is functional, but a newborn is not ready to consume an adult diet. The most obvious difference between the infant and adult digestive tracts is that newborns are not able to chew and swallow solid food. They are born with a suckling reflex that allows them to consume liquids from a nipple placed toward the back of the mouth. A protrusion reflex causes anything placed in the front of the mouth to be pushed out by the tongue. As head control increases, this reflex disappears, making spoon feeding possible.

Digestion and absorption also differ between infants and adults. In infants, the digestion of milk protein is aided by rennin, an enzyme produced in the infant stomach that is not found in adults.[2] The stomachs of newborns also produce the enzyme gastric lipase, which is present in adults but plays a more important role in infants where it begins the digestion of the fats in human milk. Low levels of pancreatic enzymes in infants limit starch digestion; however, enzymes at the brush border of the small intestine allow the milk sugar lactose to be digested and absorbed. The absorption of fat from the infant's small intestine is inefficient. However, the ability to absorb intact proteins is greater than that in adults. The absorption of whole proteins can cause food allergies (see Chapter 15), but it also allows infants to absorb immune factors from their mothers' milk. These proteins provide temporary immunity to certain diseases. The bacteria in the large intestine of infants are also different from those in adults because of the all-milk diet infants consume. This is the reason that the feces of breast-fed babies are almost odorless. Another feature of the infant digestive tract is the lack of voluntary control of elimination. Between the ages of two and three, this ability develops, and toilet training is possible.

Advanced Age Although there are few dramatic changes in the nutrient requirements of humans as they age, changes in the digestive tract and other systems may affect the palatability of food and the ability to obtain proper nutrition. The senses of smell and taste are often diminished or even lost with age, reducing the appeal of food. A reduction in the amount of saliva may make swallowing difficult, decrease the taste of food, and also promote tooth decay. Loss of teeth and improperly fitting dentures may limit food choices to soft and liquid foods or cause solid foods to be poorly chewed. Intestinal secretions may also be reduced, but this rarely impairs absorption because the levels secreted in healthy elderly are still sufficient to break down food into forms that can be absorbed. A condition called atrophic gastritis that causes a reduction in the secretion of stomach acid is also common in the elderly. This may decrease the absorption of several vitamins and minerals and may allow bacterial growth to increase (see Chapter 16). Constipation is a common complaint among the elderly that may be caused by decreased motility and elasticity in the colon, weakened abdominal and pelvic muscles, and a decrease in sensory perception. (see *Critical Thinking*: Gastrointestinal Problems Can Affect Nutrition).

CRITICAL THINKING

Gastrointestinal Problems Can Affect Nutrition

This chapter has followed the path of a turkey sandwich, an apple, and a glass of milk through the processes of digestion and absorption. During the journey from mouth to anus, many factors affect how well these processes work. For each situation described below, think about how digestion, absorption, and the GI tract itself might be altered.

An individual is taking medication that reduces the amount of saliva produced.

What effect would this have on nutrition?

When there is not enough saliva, the food is not tasted as well and it is difficult to swallow. Both of these factors are likely to decrease the appeal and therefore consumption of food. Since saliva helps protect teeth from decay, insufficient saliva also increases the likelihood of tooth decay and gum disease.

What nutrients might not be absorbed from the apple if an individual has just had some dental work done?

If the food is not well chewed, digestive enzymes cannot come in contact with all components of the food. If the fiber in the apple skin is not chewed, the vitamins and minerals it contains may not be available for absorption.

After consuming the turkey sandwich, apple, and glass of milk, a large slice of high-fat cheesecake is added for dessert.

How would this affect transit time?

Transit time would increase because the cheesecake is high in fat, which slows stomach emptying. The meal would take more time to pass from mouth to anus.

An individual has a disease of the pancreas that causes a deficiency of pancreatic enzymes.

What effect would this have on the digestion and absorption of the sample meal?

Pancreatic enzymes are needed to digest carbohydrate, fat, and protein. If these enzymes are lacking, digestion will be incomplete, and nutrient absorption will be compromised. Carbohydrate-digesting enzymes in the mouth and intestinal brush border, as well as protein-digesting enzymes in the stomach and mucosal cells, can partially compensate for a reduction in pancreatic enzymes.

An individual has been malnourished. The malnutrition causes the intestinal villi to become flattened.

If the sample meal was consumed, how would nutrient absorption be affected?

The absorption of all nutrients depends on the health of the small intestine. If the villi are flattened, the absorptive area will be decreased, so fewer nutrients will be absorbed.

An individual eats the turkey sandwich and apple but chooses not to drink the milk or consume any other fluid.

How might this affect the feces?

A diet low in fluid and high in fiber could result in hard feces and constipation.

An individual has gallstones, which cause pain when the gallbladder contracts.

What type of foods should be avoided?

Answer:

• Paths of Absorbed Nutrients

Absorbed materials are delivered to body cells by the cardiovascular system, which consists of the heart and blood vessels. The path by which nutrients enter the bloodstream varies with the nutrient. Amino acids from protein, simple sugars from carbohydrate, and the water-soluble products of fat digestion are absorbed directly into the bloodstream. The products of fat digestion that are not water soluble are taken into the lymphatic system before entering the blood.

Cardiovascular System

The cardiovascular system is a closed network of tubules through which blood is pumped. Blood carries nutrients and oxygen to the cells of all the organs and tissues of the body and removes waste products from these same cells. Blood also carries other substances, such as hormones, from one part of the body to another (Figure 3.14).

The heart is the workhorse of the cardiovascular system. It is a muscular pump with two circulatory loops—one that delivers blood to the lungs and one that delivers blood to the rest of the body. The blood vessels that transport blood and dissolved substances toward the heart are called **veins**, and those that transport blood and dissolved substances away from the heart are called **arteries**. As arteries carry blood away from the heart, they branch many times to form smaller and smaller blood vessels. The smallest arteries are called arterioles. Arterioles then branch to form **capillaries**. Capillaries are thin-walled vessels that are just large enough to allow one red blood cell to pass at a time. From the capillaries, oxygen and nutrients carried by the blood pass into the cells, and waste products pass from the cells into the capillaries. In the capillaries of the lungs, blood releases carbon dioxide to be exhaled and picks up oxygen to be delivered to the cells. In the capillaries of the GI tract, blood picks up water-soluble nutrients absorbed from the diet. Blood from capillaries then flows into the smallest veins, the venules, which converge to form larger and larger veins for return to the heart. Therefore, blood starting in the heart is pumped through the arteries to the capillaries of the lungs where it picks up oxygen. It then returns to the

Veins Vessels that carry blood toward the heart.

Arteries Vessels that carry blood away from the heart.

Capillaries Small, thin-walled blood vessels where the exchange of gases and nutrients between blood and cells occurs.

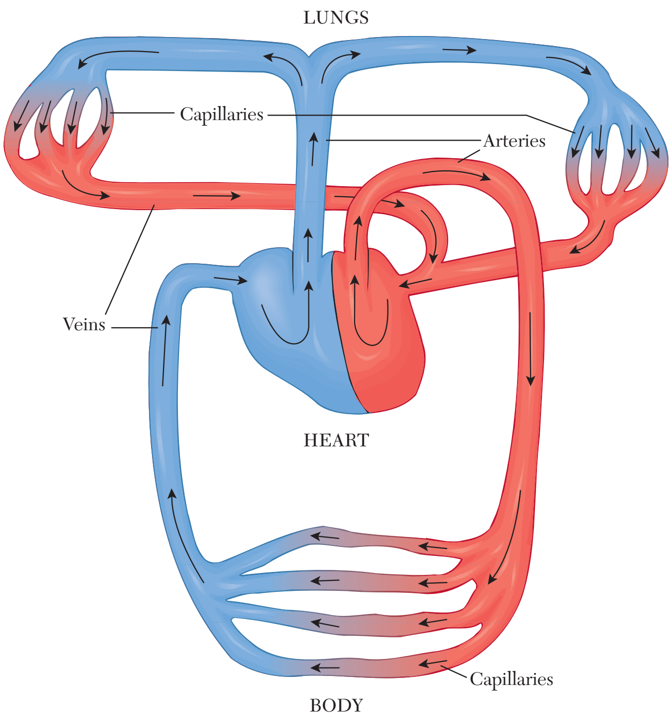

Figure 3.14
Blood is pumped from the heart through the arteries to the capillaries of the lungs, where it picks up oxygen. It then returns to the heart via the veins and is pumped out again into the arteries that lead to the rest of the body. In the capillaries of the body, blood delivers oxygen and nutrients and picks up wastes before returning to the heart via the veins. In this figure, red indicates blood that is rich in oxygen, and blue represents blood that is oxygen-poor and carrying more carbon dioxide.

heart via the veins and is pumped out again into the arteries that lead to the rest of the body. In the capillaries of the body, blood delivers oxygen and nutrients and removes wastes before returning to the heart via the veins.

The volume of blood flow, and hence the amounts of nutrients and oxygen that are delivered to an organ or tissue, depends on the need. When a person is resting, about 24% of the blood goes to the digestive system, 21% to the skeletal muscles, and the rest to the heart, kidneys, brain, skin, and other organs.[3] After a large meal, a greater proportion will go to the intestines to support digestion and absorption and to transport nutrients. When a person engages in strenuous exercise, about 85% of blood flow will be directed to the skeletal muscles to deliver nutrients and oxygen and remove carbon dioxide and waste products. Attempting to exercise after a large meal creates a conflict. The body cannot direct blood to the intestines and the muscles at the same time. The muscles win, and food remains in the intestines, often resulting in cramps.

Hepatic Portal and Lymphatic Circulation

Hepatic portal circulation The system of blood vessels that collects nutrient-laden blood from the digestive organs and delivers it to the liver.

Lymphatic system The system of vessels, organs, and tissues that drains excess fluid from the spaces between cells, transports fat-soluble substances from the digestive tract, and contributes to immune function.

Hepatic portal vein The vein that transports blood from the gastrointestinal tract to the liver.

Nutrients enter the blood circulation by either the **hepatic portal circulation** or the **lymphatic system**. The villi of the intestine contain both capillaries, which are part of the portal circulation, and lacteals, which are small vessels of the lymphatic system.

The Hepatic Portal Circulation In the small intestine, water-soluble molecules, including amino acids, sugars, water-soluble vitamins, and water-soluble products of fat digestion, cross the mucosal cells of the villi and enter capillaries. These capillaries merge to form venules at the base of the villi. The venules then merge to form larger and larger veins, which eventually form the **hepatic portal vein**. The hepatic portal vein transports blood directly to the liver, where absorbed nutrients are processed before they enter the general circulation (Figure 3.15).

The liver acts as a gatekeeper between substances absorbed from the intestine and the rest of the body. Some nutrients are stored in the liver, some are changed into different forms, and others are allowed to pass through unchanged. Based on the immediate needs of the body, the liver decides whether individual nutrients will be stored or delivered directly to the cells. For example, the liver, with the help of

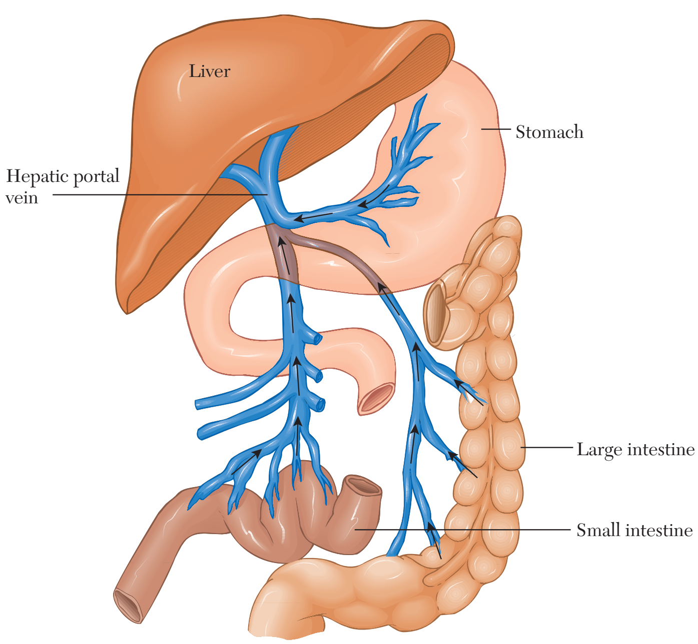

Figure 3.15
The hepatic portal circulation carries blood from the stomach and intestines to the hepatic portal vein and then to the liver.

hormones from the pancreas, keeps the concentration of sugar in the blood constant. The liver modulates blood glucose by removing absorbed glucose from the blood and storing it, by sending absorbed glucose on to the tissues of the body, or by releasing liver glucose (from stores or synthesis) into the blood. The liver is also important for the synthesis and breakdown of amino acids, proteins, and fats. It modifies the products of protein breakdown to form molecules that can be safely transported to the kidney for excretion. The liver also contains enzyme systems that protect the body from toxins that are absorbed by the gastrointestinal tract.

The Lymphatic System The lymphatic system consists of a network of tubules (lymph vessels), structures, and organs that contain infection-fighting cells. Fluid that has accumulated in tissues drains into the lymphatic system where it is filtered past a collection of infection-fighting cells. The cleansed fluid is then returned to the bloodstream. By draining the excess fluid, and any disease-causing agents it contains, away from the spaces between cells, the lymphatic system provides protection and prevents the accumulation of tissue fluid from causing swelling.

In the intestine, materials too large to enter the intestinal capillaries, such as triglycerides and fat-soluble vitamins, are transported by the lymphatic system. These pass from the intestinal mucosa into the lacteals, the smallest of the lymph vessels, which drain into larger lymph vessels. Lymph vessels from the intestine and most other organs of the body drain into the thoracic duct, which empties into the bloodstream near the neck. Therefore, substances that are absorbed via the lymphatic system do not pass through the liver before entering the blood circulation.

Destination: The Cell

For nutrients to enter a cell, they must first cross the **cell membrane**. The cell membrane maintains homeostasis in the cell by controlling what enters and what exits. It is **selectively permeable** because some substances, such as water, can pass freely back and forth, whereas the passage of others is regulated. Nutrients and other substances from the bloodstream are transported into cells by simple and facilitated diffusion and active transport. Once the nutrients have crossed the cell membrane and entered the cell, they can be broken down and used for energy, or they can be used to build the types of structural and regulatory molecules that are needed by the human body. Inside the cell membrane is the **cytoplasm**, or cell fluid that contains the cell **organelles** that perform functions necessary for cell survival. Organelles are also surrounded by membranes. The largest organelle is the nucleus, which contains the cell's genetic material (Figure 3.16).

Cell membrane The membrane that surrounds the cell contents.

Selectively permeable Describes a membrane or barrier that will allow some substances to pass freely but will restrict the passage of others.

Cytoplasm The cellular material outside the nucleus that is contained by the cell membrane.

Organelles Cellular organs that carry out specific metabolic functions.

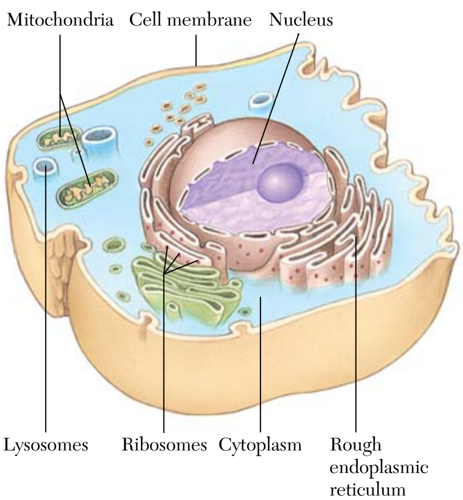

Figure 3.16
Structure of a general animal cell. Almost all human cells contain the organelles illustrated here.

• METABOLISM: MAKING AND BREAKING MOLECULES

To stay healthy our bodies use nutrients to produce energy and to manufacture structural and regulatory molecules. The sum of the chemical reactions that occur inside body cells is collectively referred to as metabolism. If the proper amounts and types of nutrients are not delivered to cells, the reactions of metabolism cannot proceed optimally, resulting in poor health. Each nutrient plays a unique role in metabolism. The following discussion provides only a brief overview. Details about the metabolism of each nutrient will be discussed in later chapters.

Many of the reactions of metabolism occur in series known as metabolic pathways. Molecules that enter these pathways are modified at each step of the pathway with the help of enzymes. Some of the pathways are **anabolic**, using energy to build body structures, whereas others are **catabolic**, breaking large molecules into smaller ones and releasing energy. If a nutrient needed for these pathways to proceed is missing, the production of important body structures, chemical compounds, or energy may be impaired. The consequences may be as severe as a life-threatening deficiency disease or as mild as impaired athletic performance.

Anabolic Energy-requiring processes in which simpler molecules are combined to form more complex substances.

Catabolic The processes by which substances are broken down into simpler molecules releasing energy.

Anabolic and catabolic processes occur in different cellular organelles. An example of an anabolic organelle is the endoplasmic reticulum, which is a maze of internal membranes. One type of endoplasmic reticulum specializes in the synthesis of lipid-based compounds such as the sex hormones estrogen and testosterone. Another type of endoplasmic reticulum is covered with organelles called ribosomes, which are the site of protein synthesis. Proteins such as digestive enzymes are made here. Lysosomes are catabolic organelles that act as a kind of digestive system for the cell. Lysosomes contain enzymes capable of breaking down carbohydrates, fats, proteins, and other types of molecules that originate both inside and outside the cell.

The **mitochondrion** is a catabolic organelle that obtains energy from carbohydrates (Chapter 4), fats (Chapter 5), and proteins (Chapter 6) by **cellular respiration**. This process completely metabolizes these macronutrients in the presence of oxygen to produce carbon dioxide, water, and a form of energy that can be used by cells called **ATP (adenosine triphosphate)**. The chemical bonds of ATP are very high in energy, and when they break, the energy is released. The energy contained in ATP can be used to do work such as pump blood or contract muscles—or it can be used to synthesize new molecules needed to maintain and repair body tissue.

Mitochondrion The cellular organelle responsible for generating energy in the form of ATP for cellular activities.

Cellular respiration The reactions that break down carbohydrates, fats, and proteins in the presence of oxygen to produce carbon dioxide, water, and energy in the form of ATP.

ATP (adenosine triphosphate) The high-energy molecule used by the body to perform energy-requiring activities.

The meal consumed at the beginning of this chapter has now been delivered to the cells. The carbohydrate in the bread has been broken down into glucose. The cells can use glucose to produce ATP or to synthesize other molecules for immediate use or storage. The protein in the turkey, milk, and bread has been broken down into amino acids that can be used by cells to synthesize needed protein, make glucose if it is in short supply, or produce ATP (Figure 3.17). The fat in the milk, turkey, and mayonnaise has been broken down into fatty acids. These can be used to make ATP or to produce lipids needed for body function, or they can be stored as body fat for later use.

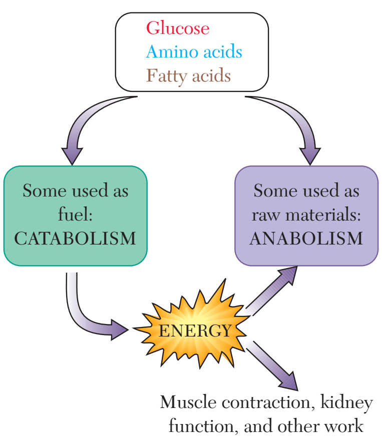

Figure 3.17
Nutrients delivered to cells can be used either to produce energy or as raw materials for the synthesis of carbohydrates, fats, and proteins in the body.

• ELIMINATION OF WASTES

The waste products left over from the digestion and metabolism of the meal must be removed from the body. Substances such as fiber that are not absorbed from the intestine are eliminated from the gastrointestinal tract in the feces. The waste products of cellular metabolism are eliminated by the lungs, the skin, and the kidneys. Carbon dioxide produced by cellular respiration leaves the cells and is transported to the lungs by red blood cells. At the lungs, red blood cells release their load of carbon dioxide, which is then exhaled into the environment. In addition to carbon dioxide, the lungs lose a significant amount of water by evaporation. Water, along with protein breakdown products and minerals, is also lost through the skin in perspiration or sweat.

The kidney is the primary site for the excretion of water, nitrogen, and other dissolved metabolic waste products. These are excreted in the urine. The amounts of water and other substances excreted in the urine are regulated so that homeostasis is maintained (see Chapters 10 and 13).

• APPLICATIONS •

1. Imagine you wake up on a Sunday morning and join some friends for a large breakfast consisting of: a cheese omelet and sausage (foods high in fat and protein); a croissant with butter (which contains carbohydrate but is also very high in fat); and a small glass of orange juice. After the meal, you remember that you have plans to play basketball with a friend in just an hour.

a. If you keep your plans and play basketball, what problems might you experience while exercising?

b. Had you remembered your plans for strenuous exercise before you had breakfast, what type of meal might you have selected to ensure that your stomach would empty more quickly?

2. There are hundreds of products available to aid digestion. Go to the drug store, health food store, or search the Internet and select a product claiming to aid digestion.

a. List the claims made for the product.

b. Using the information in Chapter 1 on judging nutritional claims, analyze the information given.

c. Does the product make any nutritional contributions to the diet?

d. Does it carry any risk?

e. Would you take it? Why or why not?

SUMMARY

1. The organization of all matter begins with the same basic structure—the atom. Atoms are linked by chemical bonds to form molecules. The cell is the smallest unit of life. Cells of similar structure and function are organized into tissues, and tissues into organs and organ systems.

2. The digestive system is the organ system primarily responsible for the movement of nutrients into the body. The digestive system provides two major functions: digestion and absorption. Digestion is the process by which food is broken down into units that are small enough to be absorbed. Absorption is the process by which nutrients are transported into the body.

3. The gastrointestinal tract consists of a hollow tube that begins at the mouth and continues through the pharynx, esophagus, stomach, small intestine, large intestine, and anus. The passage, digestion, and absorption of food in the lumen of this tube are aided by the secretion of mucus, enzymes, and hormones.

4. The processes involved in digestion begin in response to the smell or sight of food and continue as food enters the digestive tract at the mouth, where it is broken into smaller pieces by the teeth and mixed with saliva. Carbohydrate digestion is begun in the mouth by salivary amylase. From the mouth, food passes through the pharynx and into the esophagus. The rhythmic contractions of peristalsis propel it down the esophagus to the stomach.

5. The stomach acts as a temporary storage site for food. The muscles of the stomach mix the food into a semiliquid mass called chyme, and gastric juice containing hydrochloric acid and pepsin begins protein digestion. Stomach emptying is regulated by the amount and composition of food consumed and by nervous and hormonal signals from the small intestine.

6. The small intestine is the primary site of nutrient digestion and absorption. In the small intestine, bicarbonate from the pancreas neutralizes stomach acid, and pancreatic and intestinal enzymes digest carbohydrate, fat, and protein. The digestion of fat in the small intestine is aided by bile from the gallbladder. Bile helps make fat available to fat-digesting enzymes by breaking it into small droplets and also facilitates fat absorption. Secretions from the pancreas and liver are regulated by the hormones secretin and cholecystokinin, produced by the duodenum.

7. The absorption of food across the intestinal mucosa occurs by several different processes. Simple diffusion and facilitated diffusion do not require energy but depend on a concentration gradient. Active transport requires energy but can transport substances against a concentration gradient. The absorptive surface of the small intestine is increased by folds and fingerlike projections called villi, which are covered with tiny projections called microvilli.

8. Components of chyme that are not absorbed in the small intestine pass on to the large intestine, where some water and nutrients are absorbed. The large intestine is populated by bacteria that digest some of these unabsorbed materials, such as fiber, producing small amounts of nutrients and gas. The remaining unabsorbed materials are excreted in feces.

9. Absorbed nutrients are delivered to the cells of the body by the cardiovascular system. The heart pumps blood to the lungs to pick up oxygen and eliminate carbon dioxide. From the lungs, blood returns to the heart and is pumped to the rest of the body to deliver oxygen and nutrients and remove carbon dioxide and other wastes before returning to the heart. Blood is pumped away from the heart in arteries and returned to the heart in veins. Exchange of nutrients and gases occurs at the smallest blood vessels, the capillaries.

10. The products of carbohydrate and protein digestion and the water-soluble products of fat digestion enter capillaries in the intestinal villi and are transported to the liver via the hepatic portal circulation. The liver serves as a processing center, removing the absorbed substances for storage, converting them into other forms, or allowing them to pass unaltered. The liver also protects the body from toxic substances that may have been absorbed.

11. The fat-soluble products of digestion enter lacteals in the intestinal villi. The nutrients absorbed via the lymphatic system enter the blood circulation without first passing through the liver.

12. Cells are the final destination of absorbed nutrients. To enter the cells, nutrients must be transported across cell membranes. Within the cells, some organelles are catabolic, specializing in the breakdown of nutrients to produce energy. Others are anabolic, specializing in the synthesis of molecules needed by the body. The sum of all the chemical reactions of the body is called metabolism. The reactions that completely break down macronutrients in the presence of oxygen to produce water, carbon dioxide, and energy are referred to as cellular respiration.

13. Unabsorbed materials are excreted in the feces. The waste products of metabolism are excreted by the lungs, skin, and kidneys.

REVIEW QUESTIONS

1. What is an organic molecule?

2. What is the smallest unit of plant and animal life?

3. List three organ systems involved in the digestion and absorption of food.

4. How do teeth function in digestion?

5. What is peristalsis?

6. List two functions of the stomach.

7. List three mechanisms by which nutrients are absorbed.

8. Where does most digestion and absorption occur?

9. How does the structure of the small intestine aid absorption?

10. What products of digestion are transported by the lymphatic system?

11. What path does an amino acid follow from absorption to delivery to the cell? What path does a large fatty acid follow from absorption to delivery to the cell?

12. What is the form of energy used by cells?

13. List four ways that waste products are eliminated from the body.

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