Chapter 3

Digestion and Absorption

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THINK About It

1 Your friend warns you that eating some foods together is not healthful. Is this likely to change your eating behavior?
2 How good are you at identifying tastes?
3 Have you ever noticed that food sometimes tastes sweeter after chewing it for a while?
4 You feel particularly happy and you find that a meal prepared by your friend tastes especially good. Any connection?

LEARNING Objectives

- Sequence the steps for digestion of food and absorption of nutrients through the digestive system.
- Explain the role of enzymes in digestion.
- Explain how nutrients are circulated through and eliminated from the body.
- Identify factors that influence digestion, absorption, and nutrient transport in the body.
- Examine common nutritional and digestive system disorders for their root causes.

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The aroma of a roasting turkey floats past your nose. You haven't eaten for six or seven hours. Anticipating a delicious experience, your mouth waters, and your digestive juices are turned on. Is this virtual reality? Not at all! Before you eat a morsel of food, fleeting thoughts from your brain signal your body to prepare for the feast to come.

The body's machinery to process food and turn it into nutrients is not only efficient but elegant. The action unfolds in the digestive tract in two stages: **digestion**—the breaking apart of foods into smaller and smaller units—and **absorption**—the movement of those small units from the gut into the bloodstream or lymphatic system for circulation. Your digestive system is designed to digest carbohydrates, proteins, and fats simultaneously, while at the same time preparing other substances—vitamins, minerals, and cholesterol, for example—for absorption. Remarkably, your digestive system doesn't need any help! Despite promotions for enzyme supplements and diet books that recommend consuming food or nutrient groups separately, scientific research does not support these claims. Unless you have a specific medical condition, your digestive system is ready, willing, and able to digest and absorb the foods you eat, in whatever combination you eat them. But go back to the aroma of that roast turkey for a moment. Before we begin digesting and absorbing, our senses of taste and smell first attract us to foods we are likely to consume.

THINK About It 1

digestion The process of transforming the foods we eat into units for absorption.

absorption The movement of substances into or across tissues; in particular, the passage of nutrients and other substances into the walls of the gastrointestinal tract and then into the bloodstream.

chemosenses [key-mo-SEN-sez] The chemical sensing system in the body, including taste and smell. Sensory cells in the nose, mouth, or throat transmit messages through nerves to the brain, where smells and tastes are identified.

olfactory cells Nerve cells in a small patch of tissue high in the nose connected directly to the brain to transmit messages about specific smells. Also called *smell cells*.

gustatory cells Surface cells in the throat and on the taste buds in the mouth that transmit taste information. Also called *taste cells*.

common chemical sense A chemosensory mechanism that contributes to our senses of smell and taste. It comprises thousands of nerve endings, especially on the moist surfaces of the eyes, nose, mouth, and throat.

Taste and Smell: The Beginnings of Our Food Experience

You probably wouldn't eat a food if it didn't appeal in some way to your senses. Smell and taste belong to our chemical sensing system, or the **chemosenses**. The complicated processes of smelling and tasting begin when tiny molecules released by the substances around us bind to receptors on special cells in the nose, mouth, or throat. These special sensory cells transmit messages through nerves to the brain, where specific smells or tastes are identified.

THINK About It 2

The Chemosenses

Olfactory (smell) **cells** are stimulated by the odors around us, such as the fragrance of a gardenia or the smell of bread baking. These nerve cells are found in a small patch of tissue high inside the nose, and they connect directly to the brain.

Gustatory (taste) **cells** react to food and beverages. These surface cells in the mouth send taste information along their nerve fibers to the brain. The taste cells are clustered in the taste buds of the mouth and throat. Many of the visible small bumps on the tongue contain taste buds.

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A third chemosensory mechanism, the **common chemical sense**, contributes to our senses of smell and taste. In this system, thousands of nerve endings—especially on the moist surfaces of the eyes, nose, mouth, and throat—give rise to sensations such as the sting of ammonia, the coolness of menthol, and the irritation of chili peppers.

In the mouth, along with texture, temperature, and the sensations from the common chemical sense, tastes combine with odors to produce a perception of flavor. Flavor lets us know whether we are eating a pear or an apple. You recognize flavors mainly through the sense of smell. If you hold your nose while eating chocolate, for example, you will have trouble identifying it—even though you can distinguish the food's sweetness or bitterness. That's because the familiar flavor of chocolate is sensed largely by odor, as is the well-known flavor of coffee.

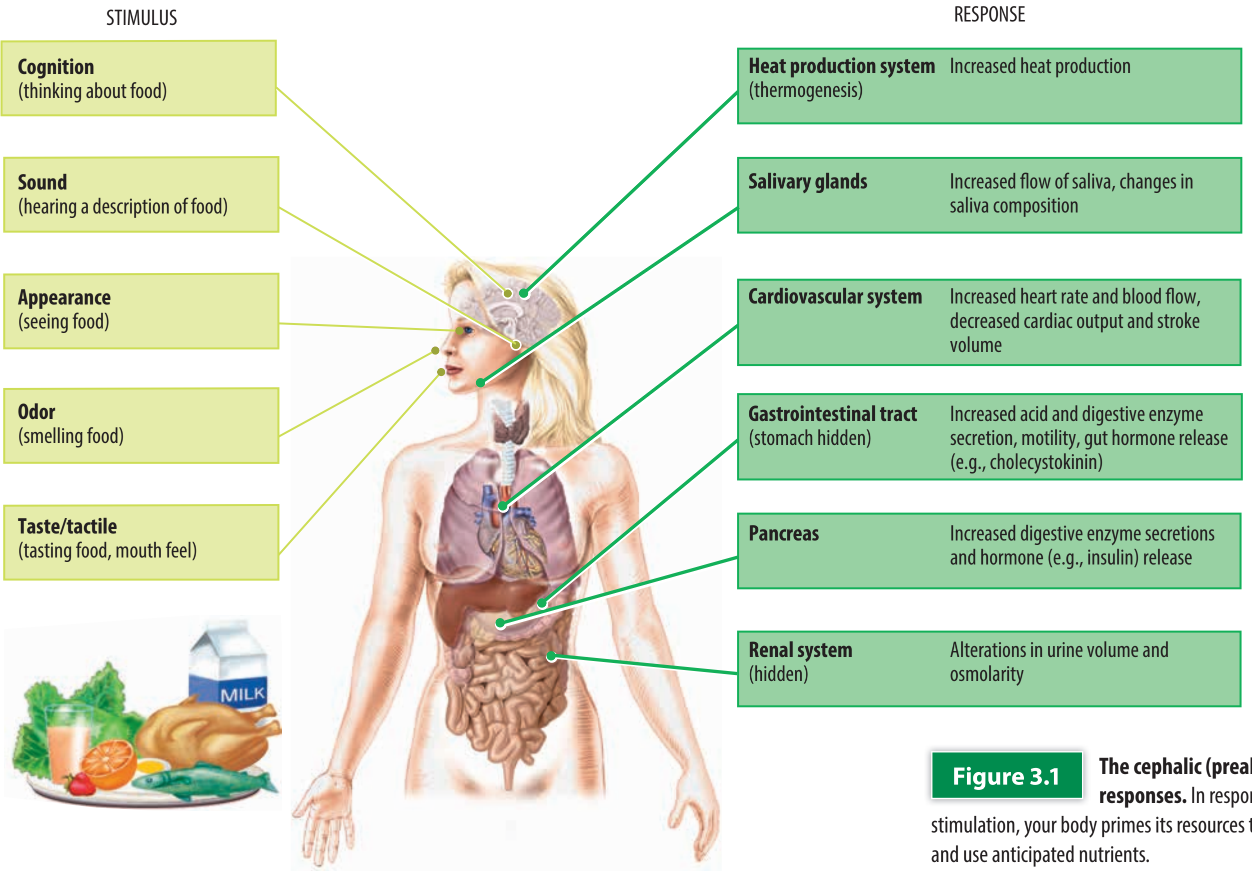

Figure 3.1 **The cephalic (preabsorptive) phase responses.** In response to sensory stimulation, your body primes its resources to better absorb and use anticipated nutrients.

Until recently, it has been suggested that dietary fat has no taste and that its appeal is solely because of its texture. However, this might not be the case. A number of studies have found a taste receptor for fat, and that essential fatty acids (fatty acids that must be obtained from the diet) elicit the strongest taste response.[1]

The sight, smell, thought, taste, and in some cases even the sound of food can trigger a set of physiologic responses known as the **cephalic phase responses**. These responses (see **Figure 3.1**) involve more than just the digestive tract, and they follow rapidly on the heels of sensory stimulation. In the digestive tract, salivary and gastric secretions flow, preparing for the consumption of food. If no food is consumed, the response diminishes; eating, however, continues the stimulation of the salivary and gastric cells.

Key Concepts Taste and smell are the first interactions we have with food. The flavor of a particular food is really a combination of olfactory, gustatory, and other stimuli. Smell (olfactory) receptors receive stimuli through odor compounds. Taste (gustatory) receptors in the mouth sense flavors. Other nerve cells (the common chemical senses) are stimulated by other chemical factors. If one of these stimuli is missing, our sense of flavor is incomplete.

The Gastrointestinal Tract

If, instead of teasing the body with mere sights and smells, we actually sit down to a meal and experience the full flavor and texture of foods, the real work of the digestive tract begins. For the food we eat to nourish our bodies, we need to digest it (break it down into smaller units); absorb it (move it from the gut into circulation); and finally transport it to the tissues and cells of the body. The digestive process starts in the mouth and continues as food journeys down the gastrointestinal, or GI, tract. At various

Quick Bite

How Many Taste Buds Do You Have?

We have almost 10,000 taste buds in our mouths, including those on the roofs of our mouths. In general, females have more taste buds than males.

cephalic phase responses The responses of the parasympathetic nervous system to the sight, smell, thought, and sound of food. Also called *preabsorptive phase responses*.

points along the GI tract, nutrients are absorbed, meaning they move from the GI tract into circulatory systems so they can be transported throughout the body. If there are problems along the way, with either incomplete digestion or inadequate absorption, the cells will not receive the nutrients they need to grow, perform daily activities, fight infection, and maintain health. A closer look at the gastrointestinal tract can help you see just how amazing this organ system is.

gastrointestinal (GI) tract [GAS-troh-in-TES-tin-al] The connected series of organs and structures used for digestion of food and absorption of nutrients; also called the *alimentary canal* or the *digestive tract*. The GI tract contains the mouth, esophagus, stomach, small intestine, large intestine (colon), rectum, and anus.

Organization of the GI Tract

The **gastrointestinal (GI) tract**, also known as the alimentary canal, is a long, hollow tube that begins at the mouth and ends at the anus. The specific parts include the mouth, esophagus, stomach, small intestine, large intestine, and rectum (see **Figure 3.2**). The GI tract works with the assisting organs—the salivary glands, liver, gallbladder, and pancreas—to turn food into small molecules that the body can absorb and use. The GI tract has an amazing variety of functions, including the following:

1. Ingestion—the receipt and softening of food
2. Transport of ingested food
3. Secretion of digestive enzymes, acid, mucus, and bile
4. Absorption of end products of digestion
5. Movement of undigested material
6. Elimination—the excretion of waste products

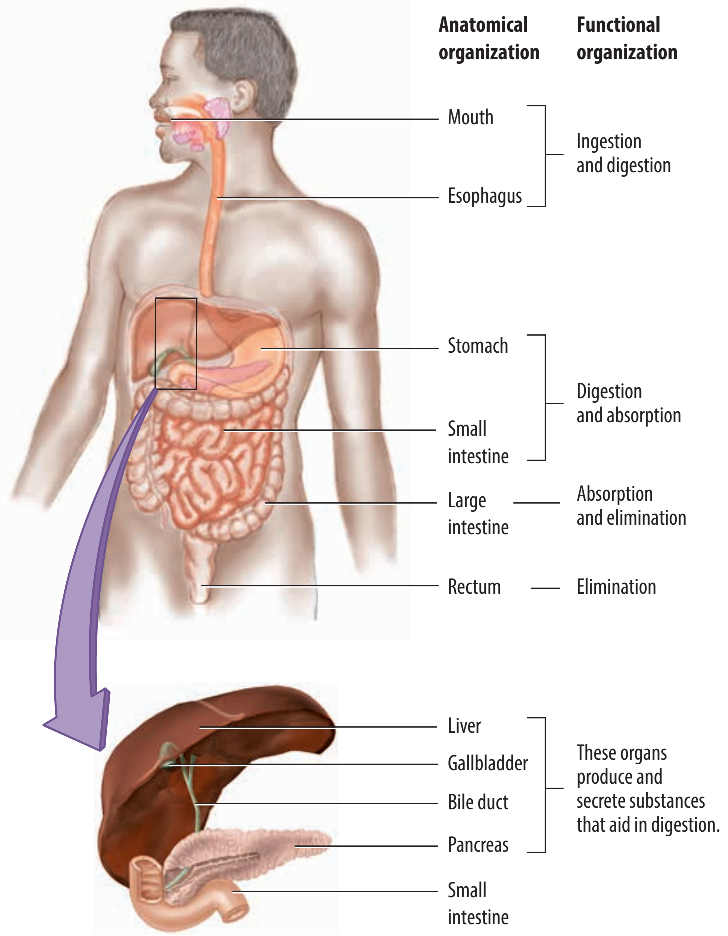

Figure 3.2 **Anatomic and functional organization of the GI tract.**
Although digestion begins in the mouth, most digestion occurs in the stomach and small intestine. Absorption primarily takes place in the small and large intestines.

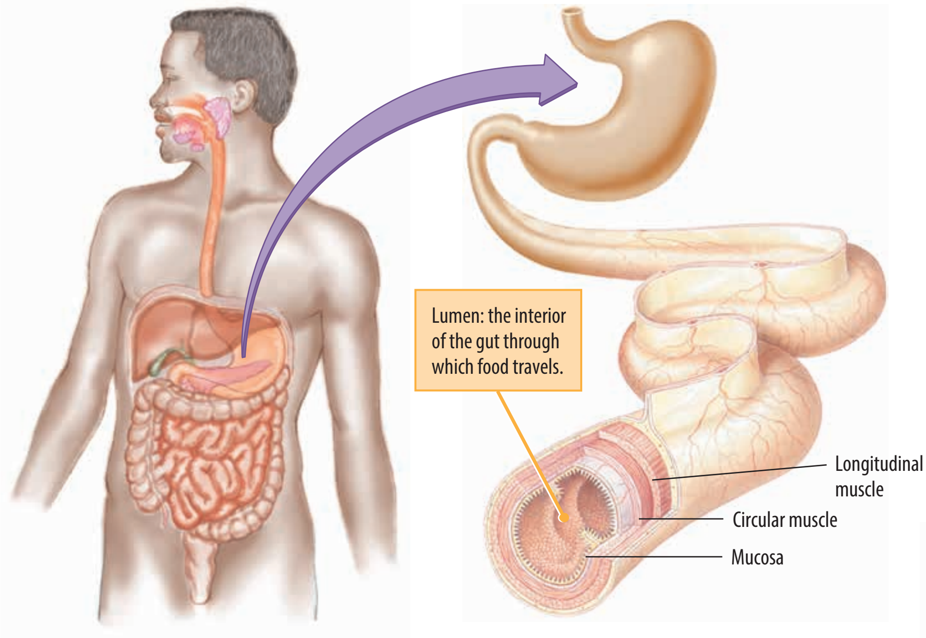

Figure 3.3 **Structural organization of the GI tract wall.** Your intestinal tract is a long, hollow tube lined with mucosal cells and surrounded by layers of muscle cells.

A Closer Look at Gastrointestinal Structure

Although it's convenient to describe the GI tract as a hollow tube, its structure is really much more complex. As you can see in **Figure 3.3**, there are several layers to this tube:

- The innermost layer, called the **mucosa**, is a layer of epithelial (lining) cells and glands.
- Next is the **submucosa**, a layer of loose, fibrous connective tissue.
- Continuing outward are two layers of muscle fibers:
  - First is a layer of **circular muscle**, where muscle fibers go around the tube.
  - Next is a layer of **longitudinal muscle**, where fibers lie lengthwise along the tube.
- Finally, the outer surface, or **serosa**, provides a covering for the entire GI tract.

At several points along the tract, where one part connects with another (e.g., where the esophagus meets the stomach), the muscles are thicker and form **sphincters**. As you can see in **Figure 3.4**, by alternately contracting and relaxing, a sphincter acts as a valve controlling the movement of food material so it goes in only one direction.

Key Concepts The gastrointestinal tract consists of the mouth, esophagus, stomach, small intestine, large intestine, and rectum. The function of the GI tract is to ingest, digest, and absorb nutrients and eliminate waste. The general structure of the GI tract consists of many layers, including an inner mucosal lining, a layer of connective tissue, layers of muscle fibers, and an outer covering layer. Sphincters are muscular valves along the GI tract that control movement from one part to the next.

Overview of Digestion: Physical and Chemical Processes

To absorb nutrients from the foods we eat, the bonds that link the nutrients together must first be broken down in the digestive tract. The breakdown of food into smaller units and finally into absorbable nutrients

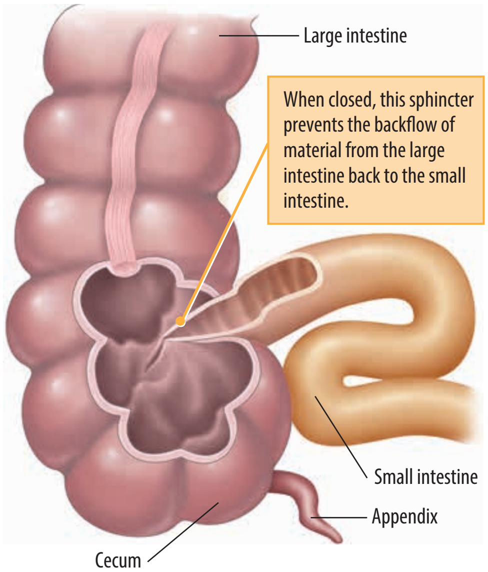

Figure 3.4 **Sphincters in action.** Movement from one section of the GI tract to the next is controlled by muscular valves called sphincters.

mucosa [myu-KO-sa] The innermost layer of a cavity. The inner layer of the gastrointestinal tract, also called the *intestinal wall*. It is composed of epithelial cells and glands.

submucosa The layer of loose, fibrous connective tissue under the mucous membrane.

circular muscle Layers of smooth muscle that surround organs, including the stomach and the small intestine.

longitudinal muscle Muscle fibers aligned lengthwise.

serosa A smooth membrane composed of a mesothelial layer and connective tissue. The intestines are covered in serosa.

sphincters [SFINGK-ters] Circular bands of muscle fibers that surround the entrance or exit of a hollow body structure (e.g., the stomach) and act as valves to control the flow of material.

involves both chemical and physical processes. First, there is the physical breaking of food into smaller pieces, such as what happens when we chew. In addition, the muscular contractions of the GI tract continue to break food up and mix it with various secretions, while at the same time moving the mixture (called **chyme**) along the GI tract. Enzymes, along with other chemicals, help complete the breakdown process and promote absorption of nutrients.

chyme [KIME] A mass of partially digested food and digestive juices moving from the stomach into the duodenum.

peristalsis [per-ih-STAHL-sis] The wavelike, rhythmic muscular contractions of the GI tract that propel its contents down the tract.

segmentation Periodic muscle contractions at intervals along the GI tract that alternate forward and backward movement of the contents, thereby breaking apart chunks of the food mass and mixing in digestive juices.

enzymes [EN-zimes] Large proteins in the body that accelerate the rate of chemical reactions but are not altered in the process.

catalyze To speed up a chemical reaction.

hydrolysis A reaction that breaks apart a compound through the addition of water.

The Physical Movement and Breaking Up of Food

Distinct muscular actions of the GI tract take the food on its journey. From mouth to anus, wavelike muscular contractions called **peristalsis** transport food and nutrients along the length of the GI tract. Peristaltic waves from the stomach muscles occur about three times per minute. In the small intestine, circular and longitudinal bands of muscle contract approximately every four to five seconds. The large intestine uses slow peristalsis to move the end products of digestion (feces) towards the anus.

Segmentation, a muscular movement that occurs in the small intestine, divides and mixes the chyme by alternating forward and backward movement of the GI tract contents. Segmentation also enhances absorption by bringing chyme into contact with the intestinal wall. In contrast, peristaltic contractions proceed in one direction for variable distances along the length of the intestine. Some even travel the entire distance from the beginning of the small intestine to the end. Peristaltic contractions of the small intestine often are continuations of contractions that began in the stomach. **Figure 3.5** shows peristalsis and segmentation.

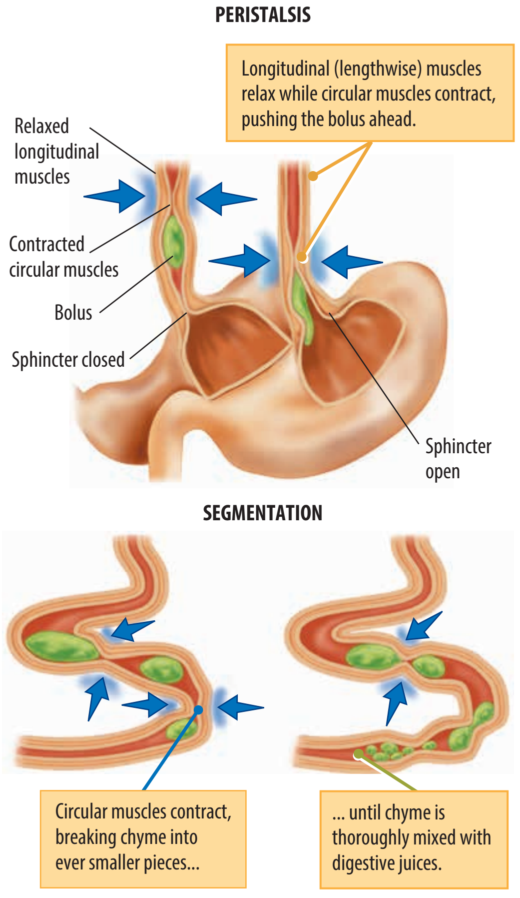

Figure 3.5 **Peristalsis and segmentation.** Peristalsis and segmentation help break up, mix, and move food through the GI tract.

The Chemical Breakdown of Food

Chemically, it is the action of enzymes that divide nutrients into compounds small enough for absorption. **Enzymes** are proteins that **catalyze**, or speed up, chemical reactions but are not altered in the process. Most enzymes can catalyze only one or a few related reactions, a property called enzyme specificity. Enzymes act in part by bringing the reacting molecules close together. In digestion, these chemical reactions divide substances into smaller compounds by a process called **hydrolysis** (breaking apart by water), as **Figure 3.6** shows. Most of the digestive enzymes can be identified by name; they commonly end in *–ase* (amylase, lipase, and so on). For example, the enzyme needed to digest sucr*ose* is sucr*ase*.

In addition to enzymes, other chemicals support the digestive process. These include acid in the stomach, a neutralizing base in the small intestine, bile that prepares fat for digestion, and mucus secreted along the GI tract. This mucus does not break down food but lubricates it and protects the cells that line the GI tract from the strong digestive chemicals. Along the GI tract, fluids containing various enzymes and other substances are added to the consumed food. In fact, the volume of fluid secreted into the GI tract is about 7,000 milliliters (about 7½ quarts) per day.[2] **Table 3.1** shows the average daily fluids in the GI tract.

Key Concepts Digestion involves both physical and chemical activity. Physical activity includes chewing and the movement of muscles along the GI tract that divide food into smaller pieces and mix it with digestive secretions. Chemical digestion is the breaking of bonds in nutrients, such as carbohydrates or proteins, to produce smaller units. Enzymes—proteins that encourage chemical processes—catalyze these hydrolytic reactions.

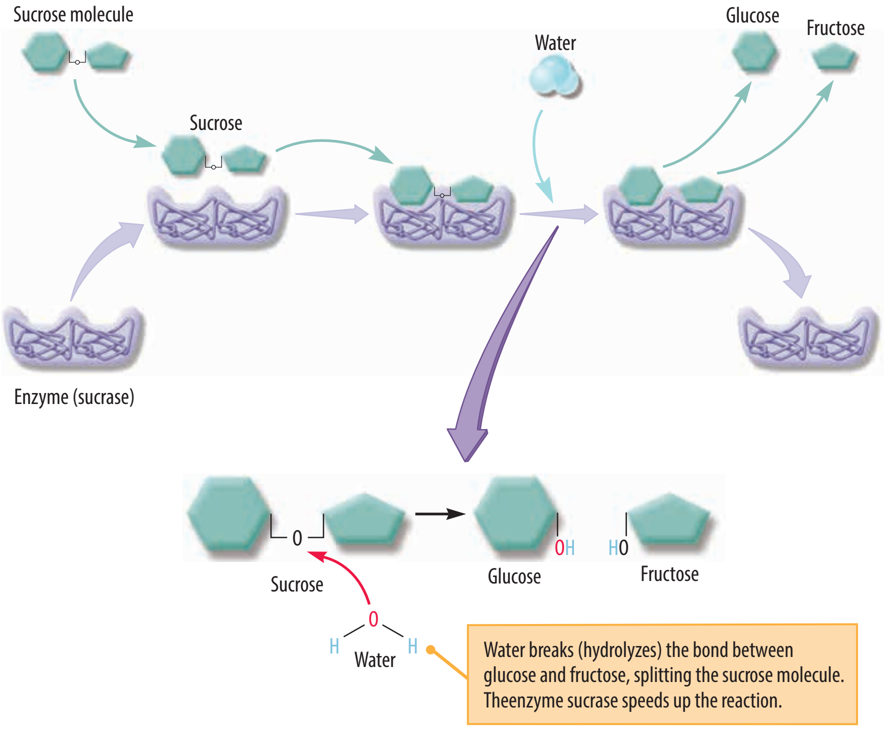

Figure 3.6 **Water and enzymes in chemical reactions.** Enzymes speed up (catalyze) chemical reactions. When water breaks a chemical bond, the action is called hydrolysis.

Table 3.1 **Average Daily Fluid Input and Output**

Source	Amount (mL)
Fluid Input	
Food and beverages	2,000
Saliva	1,500
Gastric secretions	2,500
Pancreatic secretions	1,500
Bile	500
Small intestine secretions	1,000
Total input	**9,000**
Fluid output	
Small intestine absorption	7,500
Large intestine absorption	1,400
Feces	100
Total output	**9,000**

Source: Data from Klein S, Cohn SM, Alpers DH. Alimentary tract in nutrition. In: Shils ME, Shike M, Ross AC, et al., eds. *Modern Nutrition in Health and Disease*. 10th ed. Philadelphia: Lippincott Williams & Wilkins; 2006:1115–1142.

Overview of Absorption

Food is broken apart during digestion, and it is then moved from the GI tract into circulation and on to the cells. Many of the nutrients—vitamins, minerals, and water—do not need to be digested before they are absorbed. But the energy-yielding nutrients—carbohydrate, fat, and protein—are too large to be absorbed intact and must be digested first. Let's look at how nutrients are moved from the interior, or **lumen**, of the gut through the lining cells (mucosa) and into circulation.

lumen Cavity or hollow channel in any organ or structure of the body.

passive diffusion The movement of substances into or out of cells without the expenditure of energy or the involvement of transport proteins in the cell membrane. Also called *simple diffusion*.

The Four Roads to Nutrient Absorption

There are four processes by which nutrients are absorbed: passive diffusion, facilitated diffusion, active transport, and endocytosis (see **Figure 3.7**).

Passive diffusion is the movement of molecules without the expenditure of energy through the cell membrane, through either special watery channels

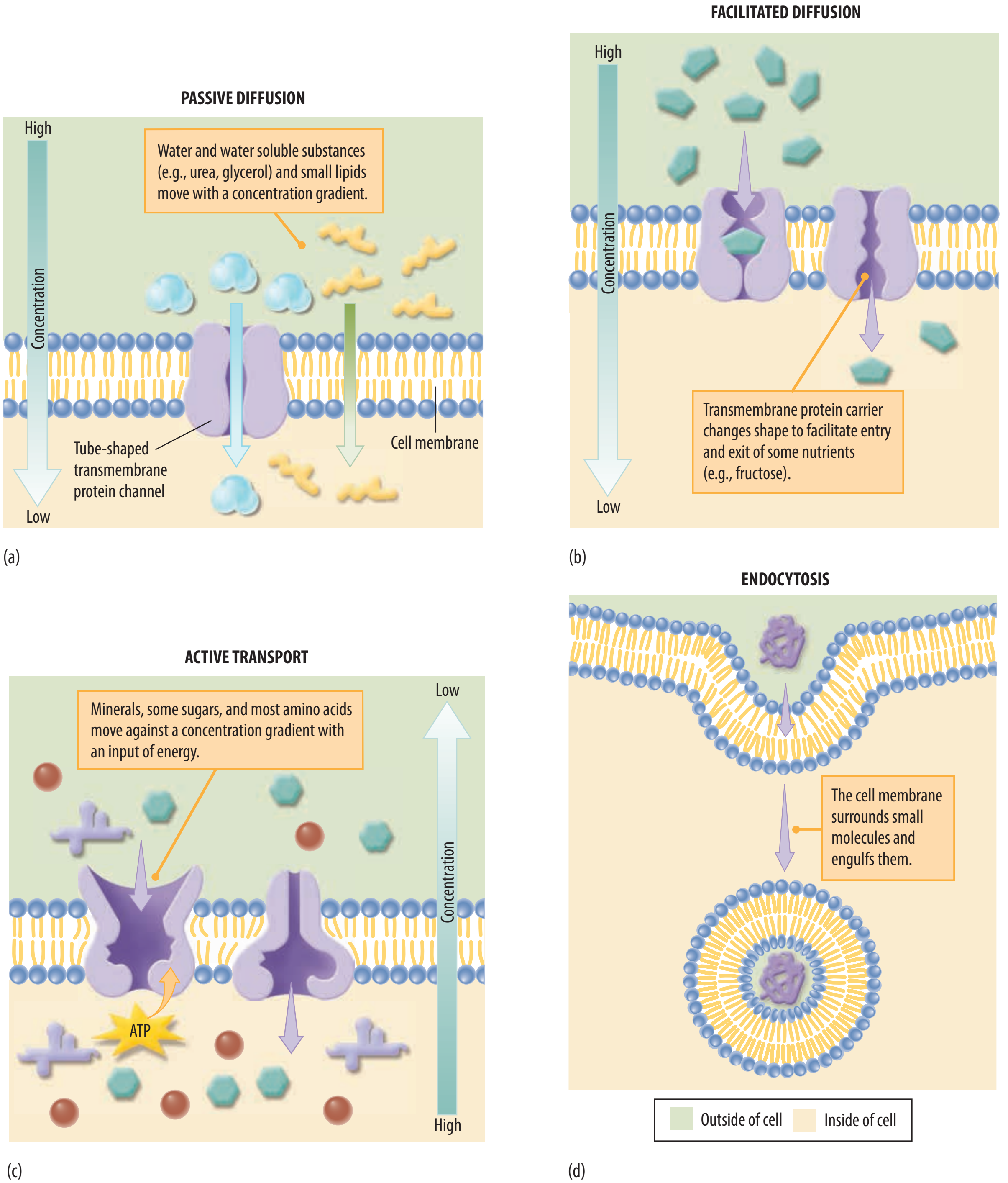

Figure 3.7 (a) **Passive diffusion.** Using passive diffusion, some substances easily move in and out of cells, either through protein channels or directly through the cell membrane. (b) **Facilitated diffusion.** Some substances need a little assistance to enter and exit cells. A transmembrane protein helps out by changing shape. (c) **Active transport.** Some substances need a lot of assistance to enter cells. Similar to swimming upstream, energy is needed for the substance to penetrate despite an unfavorable concentration gradient. (d) **Endocytosis.** Cells can use their cell membranes to engulf a particle and bring it inside the cell. The engulfing portion of the membrane separates from the cell wall and encases the particle in a vesicle.

or intermolecular gaps in the cell membrane. Molecules cross permeable cell membranes as a result of random movements that tend to equalize the concentration of substances on both sides of a membrane. **Concentration gradients** (e.g., a high outside concentration and a low inside concentration of molecules) drive passive diffusion. The larger the concentration of molecules on one side of the cell membrane, the faster those molecules move across the membrane to the area of lower concentration.

concentration gradients Differences between the solute concentrations of two substances.

Because the cell membrane mainly consists of fat-soluble substances, it welcomes fats and other fat-soluble molecules. Oxygen, nitrogen, carbon dioxide, and alcohols are highly soluble in fat and readily dissolve in the cell membrane and diffuse across it. Large amounts of oxygen are delivered this way, passing easily into a cell's interior almost as if it had no membrane barrier at all. Although water crosses cell membranes easily, most water-soluble nutrients (carbohydrates, amino acids, vitamins, and minerals) cannot be absorbed by passive diffusion. They need help to cross into the intestinal cells. This help comes in the form of a carrier and also requires energy.

Going Green

Air + Water + Brown Stuff + Green Stuff = Compost!

Composting is the way to recycle your yard and kitchen wastes: It is planned decomposition of plants and once-living materials to create enriched soil. It also is a critical step in disposing of garbage needlessly sent to landfills. Compost makes an earthy-smelling, dark, crumbly substance rich in nutrients for house plants or garden soil. Finished compost can be applied to lawns and gardens to help condition the soil and replenish nutrients.

What's in Compost?

The recipe for successful compost is fairly simple. Microorganisms (some too small to see, and others such as millipedes, sowbugs, and earthworms) turn yard and food waste into compost. Air, water, carbon, and nitrogen are the other ingredients needed to make useful compost material. Compost is made in the following way:

- "Brown stuff," such as dead dried plant parts (leaves, pine needles), newspaper, or sawdust, provides carbon.
- "Green stuff," such as fresh, recently living items like freshly cut grass, kitchen vegetable scraps, weeds, and other plants, provides nitrogen.
- Air is incorporated into the mixture by way of churning (by the microorganisms at work as well as by mixing with a shovel or using a rotating movement).
- Water is added to each layer of compost mixture as the pile is assembled. Water can also be added during the decomposition process to keep the microorganisms alive and to prevent the mixture from drying out.

The Benefits of Compost

Compost can do the following:

- Suppress plant diseases and pests
- Reduce or eliminate the need for chemical fertilizers
- Promote higher yields of agricultural crops
- Facilitate reforestation, wetlands restoration, and habitat revitalization efforts by amending contaminated, compacted, and marginal soils
- Cost-effectively remediate soils contaminated by hazardous waste
- Remove solids, oil, grease, and heavy metals from stormwater runoff
- Capture and destroy 99.6 percent of industrial volatile organic chemicals (VOCs) in contaminated air
- Provide cost savings of at least 50 percent over conventional soil, water, and air pollution remediation technologies, where applicable

(*continues*)

What to Compost

Not all items can be composted. Those items in the "In" list can be included in a compost pile, whereas those in the "Out" list should be excluded.

The In List

- Animal manure
- Clean paper, shredded newspaper, cardboard rolls
- Coffee grounds, filters, tea bags
- Cotton rags, wool rags
- Dryer and vacuum cleaner lint
- Eggshells, nut shells
- Fireplace ashes
- Fruits and vegetables
- Grass clippings, yard trimmings, leaves, houseplants, hay, and straw
- Hair and fur
- Sawdust, wood chips

The Out List

- Black walnut tree leaves or twigs (might release substances harmful to plants)
- Coal or charcoal ash (might contain substances harmful to plants)
- Dairy products (create odor problems and attract pests such as rodents and flies)
- Diseased or insect-ridden plants (infect other plants)
- Fats, grease, lard, or oils (create odor problems; attract pests such as rodents and flies)
- Meat or fish bones and scraps (create odor problems; attract pests such as rodents and flies)
- Pet wastes, such as dog or cat feces or soiled cat litter (might contain parasites, bacteria, germs, pathogens, and viruses harmful to humans)
- Yard trimmings treated with chemical pesticides (might kill beneficial composting organisms)

Source: Modified from US Environmental Protection Agency. Basic information: composting. www.epa.gov/wastes/conserve/composting/basic.htm.

facilitated diffusion A process by which carrier (transport) proteins in the cell membrane transport substances into or out of cells down a concentration gradient.

active transport The movement of substances into or out of cells against a concentration gradient. Active transport requires energy (ATP) and involves carrier (transport) proteins in the cell membrane.

endocytosis The uptake of material by a cell by the indentation and pinching off of its membrane to form a vesicle that carries material into the cell.

pinocytosis The process by which cells internalize fluids and macromolecules. To do so, the cell membrane invaginates and forms a pocket around the substance. From *pino*, "drinking," and *cyto*, "cell."

phagocytosis The process by which cells engulf large particles and small microorganisms. Receptors on the surface of cells bind these particles and organisms to bring them into large vesicles in the cytoplasm. From *phago*, "eating," and *cyto*, "cell."

In **facilitated diffusion**, special carriers help transport a substance (such as the simple sugar fructose) across the cell membrane. The facilitating carriers are proteins that reside in the cell membrane. The diffusing molecule becomes lightly bound to the carrier protein, which changes its shape to open a pathway for the diffusing molecules to move into the cell. Concentration gradients also help to drive facilitated diffusion, which is passive and can move substances only from a region of higher concentration to one of lower concentration.

Energy is required for **active transport** of substances in an unfavorable direction. Substances cannot diffuse "uphill" against an unfavorable gradient, whether the difference is one of concentration, electrical charge, or pressure. Substances that usually require active transport across some cell membranes include many minerals (sodium, potassium, calcium, iron, chloride, and iodide), several sugars (glucose and galactose), and most amino acids (simple components of protein). These substances can move from the intestine even though their concentration in the intestinal lumen is lower than their concentration in the absorptive cell.

Most substances either diffuse or are actively transported across cell membranes, but some are engulfed and ingested in a process known as **endocytosis**. In endocytosis, a portion of the cell membrane forms a sac around the substance to be absorbed, pulling it into the interior of the cell. When cells ingest small molecules and fluids, the process is known as **pinocytosis**. A similar ingestion process, **phagocytosis**, is used by specialized cells to absorb large particles.

Key Concepts Absorption through the GI cell membranes occurs by one of four basic processes. Passive diffusion occurs when nutrients (e.g., water) permeate the intestinal wall without a carrier or energy expenditure. Facilitated diffusion occurs when a carrier brings substances (e.g., fructose) into the absorptive intestinal cell without expending energy. Active transport requires energy (ATP) to transport a substance (e.g., glucose, galactose) across a cell membrane in an unfavorable direction. Endocytosis (phagocytosis or pinocytosis) occurs when the absorptive cell's membrane engulfs particles or fluids (e.g., absorption of antibodies from breast milk).

Assisting Organs

The salivary glands, liver, gallbladder, and pancreas all have critical roles in the digestive process. The GI tract works in coordination with these organs, which assist digestion by providing fluid, acid neutralizers, enzymes, and **emulsifiers**.

Salivary Glands

Three pairs of **salivary glands** (parotid, sublingual, and submandibular) located in or near the mouth secrete saliva into the oral cavity (see **Figure 3.8**). Saliva moistens food, lubricating it for easy swallowing. Saliva also contains enzymes that begin the process of chemical digestion. We secrete approximately 1,500 milliliters (about 1.5 quarts) of saliva each day. The mere sight, smell, or thought of food can start the flow of saliva.

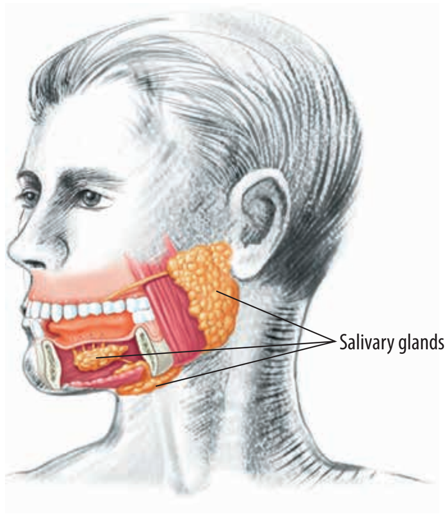

Figure 3.8 **The salivary glands.** The three pairs of salivary glands supply saliva, which moistens and lubricates food. Saliva also contains salivary enzymes that begin the digestion of starch.

Liver

The **liver** produces and secretes 600 to 1,000 milliliters of **bile** daily. Bile is a yellow-green, pasty material that contains water, bile salts and acids, pigments, cholesterol, phospholipids (a type of fat molecule), and electrolytes (electrically charged minerals). Bile tastes bitter, which is why the word *bile* has come to denote bitterness. Bile acts as an emulsifier, allowing more contact between fat molecules and enzymes in the small intestine.

Bile is concentrated in your gallbladder and released to the small intestine on demand. After it has done its work, most bile salts are reabsorbed and returned to the liver for recycling. This recirculation is known as the **enterohepatic** (*entero* meaning "intestines," and *hepatic* referring to the liver) **circulation** of bile salts (see **Figure 3.9**).

The liver also is a detoxification center that filters toxic substances from the blood and alters their chemical forms. These altered substances might be sent to the kidney for excretion or carried by bile to the small intestine and removed from the body in feces. The liver is a chemical factory—performing more than 500 chemical functions that include the production of blood proteins, cholesterol, and sugars. The liver is also a dynamic warehouse that stores vitamins, hormones, cholesterol, minerals, and sugars, releasing them to the bloodstream as needed.

Gallbladder

The primary function of the **gallbladder** is to store and concentrate bile from the liver. The gallbladder is a small, muscular, pear-shaped sac nestled in a depression on the right underside of the liver. This organ holds about a quarter of a cup of bile and is the storage stop for bile between the liver and the small intestine. The gallbladder fills with bile and thickens it until a hormone released after eating signals the gallbladder to squirt out its colorful contents.

The gallbladder is normally relaxed and full between meals. When dietary fats enter the small intestine, they stimulate the production of **cholecystokinin (CCK)**, a hormone, in the intestinal wall. Cholecystokinin causes the gallbladder to contract and the sphincter of Oddi, which is at the end of the common bile duct, to relax. Like a squeeze bulb, the gallbladder squirts bile into the

emulsifiers Agents that blend fatty and watery liquids by promoting the breakup of fat into small particles and stabilizing their suspension in aqueous solution.

salivary glands Glands in the mouth that release saliva.

liver The largest glandular organ in the body, it produces and secretes bile, detoxifies harmful substances, and helps metabolize carbohydrates, lipids, proteins, and micronutrients.

bile An alkaline, yellow-green fluid that is produced in the liver and stored in the gallbladder. The primary constituents of bile are bile salts, bile acids, phospholipids, cholesterol, and bicarbonate. Bile emulsifies dietary fats, aiding fat digestion and absorption.

enterohepatic circulation [EN-ter-oh-heh-PAT-ik] Recycling of certain compounds between the small intestine and the liver. For example, bile acids move from the liver to the gallbladder, and then into the small intestine, where they are absorbed into the portal vein and transported back to the liver.

gallbladder A pear-shaped sac that stores and concentrates bile from the liver.

cholecystokinin (CCK) [ko-la-sis-toe-KY-nin] A hormone produced by cells in the small intestine that stimulates the release of digestive enzymes from the pancreas and bile from the gallbladder.

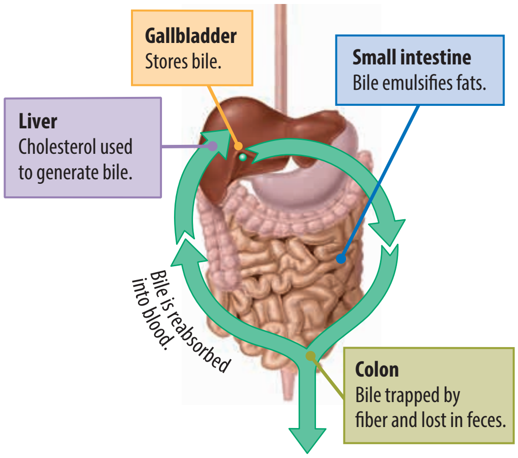

Figure 3.9 **Enterohepatic circulation.** During this recycling process, bile travels from the liver to the gallbladder and then to the small intestine, where it assists digestion. In the small intestine, most of the bile is reabsorbed and sent back to the liver for reuse.

duodenum (the upper part of the small intestine), about 500 milliliters each day. The common bile duct also carries digestive enzymes from the pancreas.

Pancreas

The **pancreas** secretes enzymes that affect the digestion and absorption of nutrients. During the course of a day, the pancreas secretes about 1,500 milliliters of fluid, which contains mostly water, bicarbonate, and digestive enzymes. The pancreas also releases hormones that are involved in other aspects of nutrient use by the body. For example, the pancreatic hormones insulin and glucagon regulate blood glucose levels. The combination of these two functions makes the pancreas one of the most important organs in the digestion and use of food.

Key Concepts The salivary glands, liver, gallbladder, and pancreas all make important contributions to the digestive process. The salivary glands release saliva, which contains mucus and enzymes, into the mouth. The liver produces bile, which is stored in the gallbladder and released into the small intestine, where bile helps to prepare fats for digestion. The pancreas also secretes liquid that contains bicarbonate and several types of enzymes into the small intestine.

Putting It All Together: Digestion and Absorption

Up to this point, our discussion has centered on structures, mechanisms, and processes to give you a general idea of the workings of the GI tract. Now you're ready for a complete tour, a journey along the GI tract to see what happens and how digestion and absorption are accomplished. Detailed descriptions of specific enzymes and actions on individual nutrients are covered in later chapters.

Mouth

As soon as you put food in your mouth the digestive process begins. As you chew, you break down the food into smaller pieces, increasing the surface area available to enzymes. Saliva contains the enzyme salivary **amylase** (ptyalin), which breaks down starch into small sugar molecules. Food remains in the mouth only for a short time, so only about 5 percent of the starch is completely broken down. The next time you eat a cracker or piece of bread, chew slowly and notice the change in the way it tastes. It gets sweeter. That's the salivary amylase breaking down the starch into sugar. Salivary amylase continues to work until the strong acid content of the stomach deactivates it. To start the process of fat digestion, the cells at the base of the tongue secrete another enzyme, **lingual lipase**. The overall impact of lingual lipase on fat digestion, though, is small.

THINK About It 3

Saliva and other fluids, including mucus, blend with the food to form a **bolus**, a chewed, moistened lump of food that is soft and easy to swallow. When you swallow, the bolus slides past the epiglottis, a valve-like flap of tissue that closes off your air passages so that you don't choke. The bolus then moves rapidly through the **esophagus** to the stomach, where it is digested further. Figure 3.10 shows the process of swallowing.

Stomach

The bolus enters the **stomach** through the **esophageal sphincter**, also called the cardiac sphincter, which immediately closes to keep the bolus from sliding back into the esophagus. Quick and complete closure by the esophageal sphincter is essential to prevent the acidic stomach contents from backing up into the esophagus, causing the pain and tissue damage called heartburn.

pancreas An organ that secretes enzymes that affect the digestion and absorption of nutrients and that releases hormones, such as insulin, that regulate metabolism as well as the disposition of the end products of food in the body.

amylase [AM-ih-lace] A salivary enzyme that catalyzes the hydrolysis of amylose, a starch. Also called *ptyalin*.

lingual lipase A fat-splitting enzyme secreted by cells at the base of the tongue.

bolus [BOH-lus] A chewed, moistened lump of food that is ready to be swallowed.

esophagus [ee-SOFF-uh-gus] The food pipe that extends from the pharynx to the stomach, about 25 centimeters long.

stomach The enlarged, muscular, saclike portion of the digestive tract between the esophagus and the small intestine, with a capacity of about 1 quart.

esophageal sphincter The opening between the esophagus and the stomach that relaxes and opens to allow the bolus to travel into the stomach, and then closes behind it. Also acts as a barrier to prevent the reflux of gastric contents. Commonly called the cardiac sphincter.

Nutrient Digestion in the Stomach

The stomach cells produce secretions that are collectively called gastric juice. Included in this mixture are water, hydrochloric acid, mucus, pepsinogen (the inactive form of the enzyme pepsin), the enzyme gastric lipase, the hormone gastrin, and intrinsic factor.

- **Hydrochloric acid** makes the stomach contents extremely acidic, dropping the **pH** to 2, compared with a neutral pH of 7. (See **Figure 3.11**.) This acidic environment kills many pathogenic (disease-causing) bacteria that might have been ingested and also aids in the digestion of protein. **Mucus** secreted by the stomach cells coats the stomach lining, protecting these cells from damage by the strong gastric juice. Hydrochloric acid works in protein digestion in two ways. First, it demolishes the functional, three-dimensional shape of proteins, unfolding them into linear chains; this increases their vulnerability to attacking enzymes. Second, it promotes the breakdown of proteins by converting the enzyme precursor **pepsinogen** to its active form, **pepsin**.
- Pepsin then begins breaking the links in protein chains, cutting dietary proteins into smaller and smaller pieces.
- Stomach cells also produce an enzyme called **gastric lipase**. It has a minor role in the digestion of lipids, specifically triglycerides with an abundance of short-chain fatty acids.

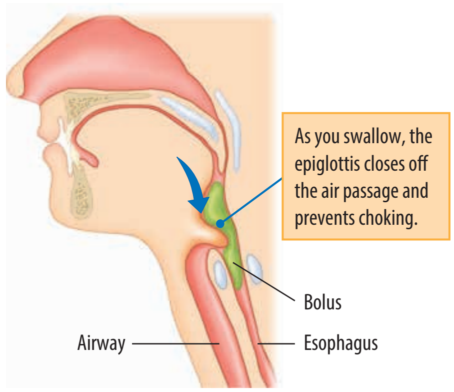

Figure 3.10 **Swallowing.** Your epiglottis didn't completely do its job if you have ever had a drink go "down the wrong pipe" and choked.

hydrochloric acid An acid of chloride and hydrogen atoms made by the gastric glands and secreted into the stomach. Also called *gastric acid*.

pH A measurement of the hydrogen ion concentration, or acidity, of a solution. It is equal to the negative logarithm of the hydrogen ion (H^+) concentration expressed in moles per liter.

mucus A slippery substance secreted in the GI tract (and other body linings) that protects cells from irritants such as digestive juices.

pepsinogen The inactive form of the enzyme pepsin.

pepsin A protein-digesting enzyme produced by the stomach.

gastric lipase An enzyme in the stomach that hydrolyzes certain triglycerides into fatty acids and glycerol.

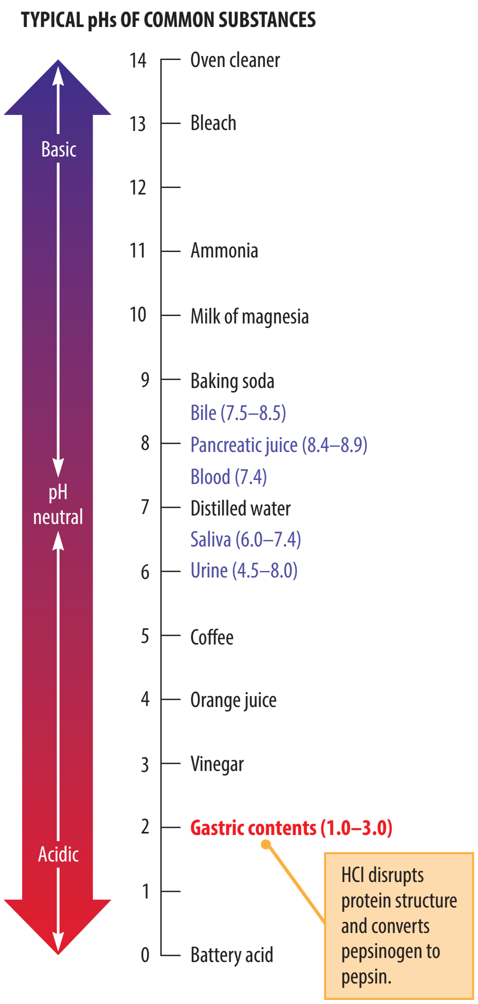

Figure 3.11 **The pH scale.** Because pancreatic juice has a pH around 8, it can neutralize the acidic chyme, which leaves the stomach with a pH around 2.

gastrin [GAS-trin] A polypeptide hormone released from the walls of the stomach mucosa and duodenum that stimulates gastric secretions and motility.

intrinsic factor A glycoprotein released from parietal cells in the stomach wall that binds to and aids in absorption of vitamin B_{12}.

pyloric sphincter [pie-LORE-ic] A circular muscle that forms the opening between the stomach and the duodenum. It regulates the passage of food into the small intestine.

- **Gastrin**, another component of gastric juice, is a hormone that stimulates gastric secretion and motility.
- **Intrinsic factor** is a substance necessary for the absorption of vitamin B_{12} that occurs farther down the GI tract, near the end of the small intestine. In the absence of intrinsic factor, only about one-fiftieth of ingested vitamin B_{12} is absorbed.

After swallowing, salivary amylase continues to digest carbohydrates. After about an hour, acidic stomach secretions become well mixed with the food. This increases the acidity of the food and effectively blocks further salivary amylase activity.

Do you sometimes feel your stomach churning? An important action of the stomach is to continue mixing food with GI secretions to produce the semiliquid chyme. To accomplish this, the stomach has an extra layer of diagonal muscles. These, along with the circular and longitudinal muscles, contract and relax to mix food completely. When the chyme is ready to leave the stomach, about 30 to 40 percent of carbohydrate, 10 to 20 percent of protein, and less than 10 percent of fat have been digested.[3] The stomach slowly releases the chyme through the **pyloric sphincter** into the small intestine. The pyloric sphincter then closes to prevent the chyme from returning to the stomach (see **Figure 3.12**).

The stomach normally empties in one to four hours, depending on the types and amounts of food eaten. Carbohydrates speed through the stomach in the shortest time, followed by protein and fat. Thus, the higher the fat content of a meal, the longer it will take to leave the stomach.

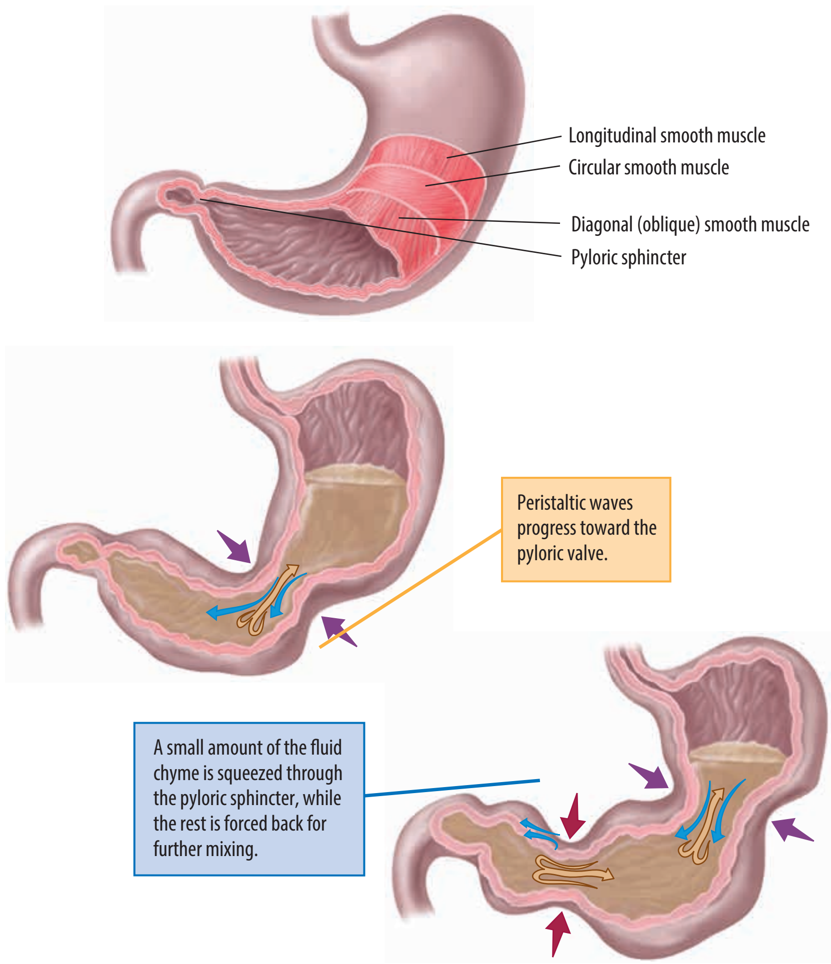

Figure 3.12 **The stomach.** The stomach churns and mixes food with stomach secretions. Hydrochloric acid unfolds proteins and stops salivary amylase action, while pepsin begins protein digestion. The pyloric sphincter controls movement of chyme from the stomach to the small intestine.

Nutrient Absorption in the Stomach

Although a substantial fraction of digestion has been accomplished by the time chyme leaves the stomach, very little absorption has occurred. Only some lipid-soluble compounds and weak acids, such as alcohol and aspirin, are absorbed through the stomach. Chyme moves on to the small intestine, the digestive and absorptive workhorse of the gut.

Small Intestine

The **small intestine** is where the digestion of protein, fat, and nearly all carbohydrate is completed and where most nutrients are absorbed. As you can see in **Figure 3.13**, the small intestine is a tube about 3 meters long (about 10 feet), divided into three parts:

small intestine The tube (approximately 10 feet long) where the digestion of protein, fat, and carbohydrate is completed, and where the majority of nutrients are absorbed. The small intestine is divided into three parts: the duodenum, the jejunum, and the ileum.

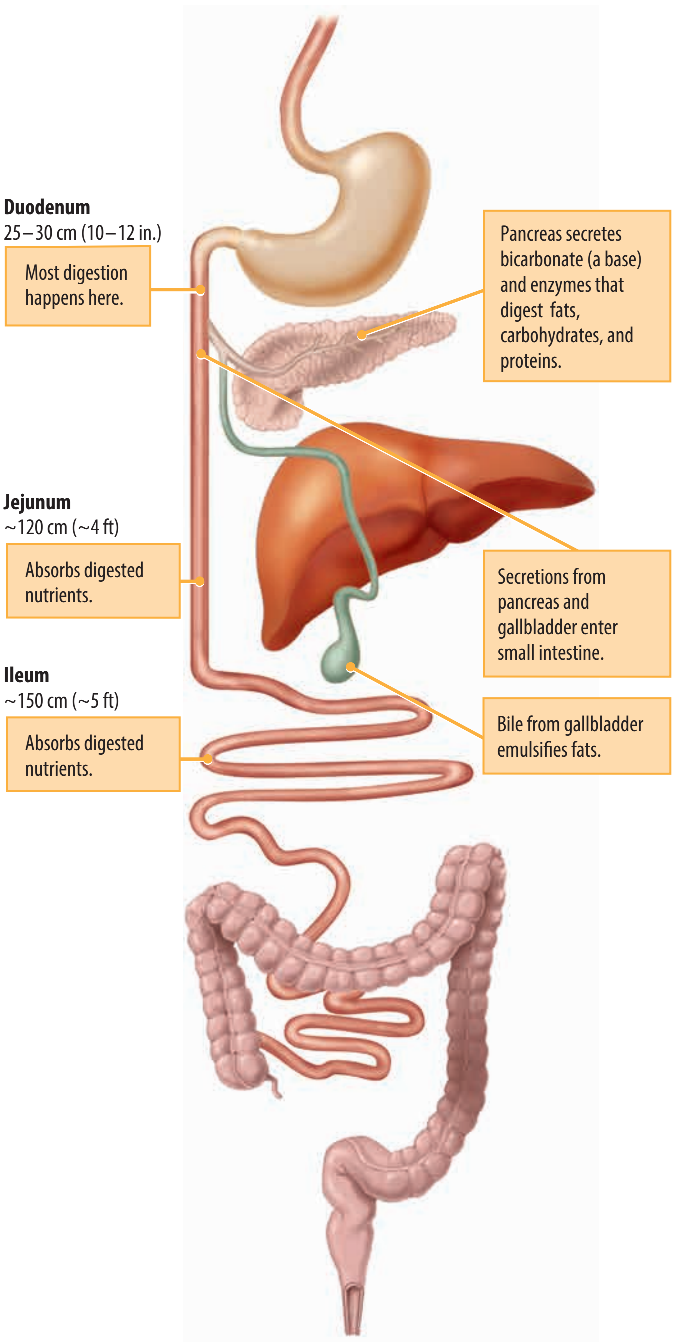

Figure 3.13 **The small intestine.** The duodenum is mainly responsible for digesting food; the jejunum and ileum primarily deal with the absorption of food. The duodenum secretes mucus, enzymes, and hormones along with other digestive juices from assisting organs to aid digestion. All along the intestinal walls, nutrients are absorbed into blood and lymph. Undigested materials are passed on to the large intestine.

duodenum [doo-oh-DEE-num or doo-AH-den-um] The portion of the small intestine closest to the stomach. The duodenum is 10 to 12 inches long and wider than the remainder of the small intestine.

jejunum [je-JOON-um] The middle section (about 4 feet) of the small intestine, lying between the duodenum and ileum.

ileum [ILL-ee-um] The terminal segment (about 5 feet) of the small intestine, which opens into the large intestine.

digestive secretions Substances released at different places in the GI tract to speed the breakdown of ingested carbohydrates, fats, and proteins into smaller compounds that can be absorbed by the body.

secretin [see-CREET-in] An intestinal hormone released during digestion that stimulates the pancreas to release water and bicarbonate.

villi Small, finger-like projections that blanket the folds in the lining of the small intestine. Singular is *villus*.

microvilli Minute, hairlike projections that extend from the surface of absorptive cells facing the intestinal lumen. Singular is *microvillus*.

- **Duodenum** (the first 25 to 30 centimeters—10 to 12 inches)
- **Jejunum** (about 120 centimeters—about 4 feet)
- **Ileum** (about 150 centimeters—about 5 feet)

Most digestion occurs in the duodenum, where the small intestine receives **digestive secretions** from the pancreas, gallbladder, and its own glands. The remainder of the small intestine primarily absorbs previously digested nutrients.

Nutrient Digestion in the Small Intestine

In the duodenum, the acidic chyme from the stomach is neutralized by a base, bicarbonate, from the pancreas. The slow delivery of chyme through the pyloric sphincter (about 2 milliliters per minute) allows chyme to be adequately neutralized. This is important because the enzymes of the small intestine need a more neutral environment to work effectively. The stimulus for release of bicarbonate from the pancreas is the hormone **secretin**. This hormone is released from intestinal cells in response to the appearance of chyme. Pancreatic juice contains a variety of digestive enzymes that help to digest fats, carbohydrates, and proteins. Secretions from the intestinal wall cells add enzymes to complete carbohydrate digestion.

The presence of fat in the duodenum stimulates the release of stored bile by the gallbladder. The specific signal comes from the intestinal hormone cholecystokinin. Lipids ordinarily do not mix with water, but bile acts as an emulsifier, keeping lipid molecules mixed with the watery chyme and digestive secretions. Without the action of bile, lipids might not come into contact with pancreatic lipase, and digestion would be incomplete.

With the pancreatic and intestinal enzymes working together, digestion progresses nicely, leaving smaller protein, carbohydrate, and lipid compounds ready for absorption. Other nutrients, such as vitamins, minerals, and cholesterol, are not digested and generally are absorbed unchanged.

Just as the small intestine accomplishes much of the nutrient digestion, it is also responsible for most nutrient absorption. Its structure makes the process of absorption efficient and complete. In most cases, more than 90 percent of ingested carbohydrate, fat, and protein is absorbed. To see how this is possible, we need to examine the structure of the small intestine.

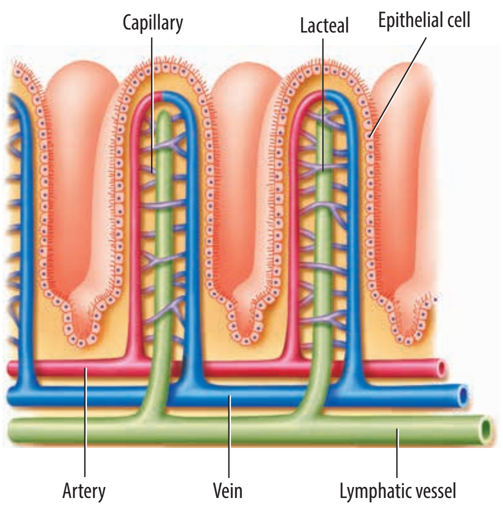

Figure 3.14 **The absorptive surface of the small intestine.** To maximize the absorptive surface area, the small intestine is folded and lined with finger-like villi. You have a surface area the size of a tennis court packed into your gut.

Absorptive Structures of the Small Intestine

The small intestine packs a gigantic surface area into a small space. As you can see in **Figure 3.14**, the interior surface of the small intestine is wrinkled into folds, tripling the absorptive surface area. These folds are carpeted with fingerlike projections called **villi** that expand the absorptive area another 10-fold. Each cell lining the surface of each villus is covered with a "brush border" containing as many as 1,000 hairlike projections called **microvilli**. The microvilli increase the surface area another 20 times. Taken together, the folds plus the villi and microvilli yield a 600-fold increase in surface area. In fact, your 10-foot (3-meter) long intestine has an absorptive surface area of more than 300 square yards (250 or more square meters)—equivalent to the surface of a tennis court!

Nutrient Absorption in the Small Intestine

As nutrients journey through the small intestine, they are trapped in the folds and projections of the intestinal wall and absorbed through the microvilli into the lining cells. Depending on your diet, each day your small intestine absorbs several hundred grams of carbohydrate, 60 or more grams of fat, 50 to 100 grams of amino acids, 3 to 5 grams of vitamins and minerals, and 7 to 8 liters of water. But the total absorptive capacity of the healthy small

FYI For Your Information

Lactose Intolerance

When drinking a milkshake is followed shortly by bloating, gas, abdominal pain, and diarrhea, it could be lactose intolerance—the incomplete digestion of the lactose in milk caused by low levels of the intestinal enzyme lactase. Lactose is the primary carbohydrate in milk and other dairy foods. Nondairy foods—such as instant breakfast mixes, cake mixes, mayonnaise, luncheon meats, medications, and vitamin supplements—also contain small amounts of lactose. Lactase is necessary to digest lactose in the small intestine. If lactase is deficient, undigested lactose enters the large intestine, where it is fermented by colonic bacteria, producing short-chain organic acids and gases (hydrogen, methane, carbon dioxide).

With the exception of a rare inherited disorder in which infants are born without lactase, infants have sufficiently high levels of lactase for normal digestion. However, lactase activity declines with weaning in many racial/ethnic groups. This normal, genetically controlled decrease in lactase activity, called lactose maldigestion, is prevalent among Asians, Native Americans, and African Americans. However, among U.S. Caucasians and northern and central Europeans, lactose maldigestion is far less common because lactase activity tends to persist. Lactose maldigestion occurs in about 25 percent of the U.S. population and in 75 percent of the worldwide population.

In addition to primary lactose intolerance, lactose intolerance can be secondary to diseases or conditions (e.g., inflammatory bowel disease such as Crohn's disease or celiac disease, gastrointestinal surgery, and certain medications) that injure the intestinal mucosa where lactase is expressed. Secondary lactose maldigestion is temporary, and lactose digestion improves once the underlying causative factor is corrected.

Lactose intolerance is less prevalent than commonly believed. Many factors unrelated to lactose, including strong beliefs, can contribute to this condition. Studies have demonstrated that among self-described lactose-intolerant individuals, one-third to one-half develop few or no gastrointestinal symptoms following intake of lactose under well-controlled, double-blind conditions.

Self-diagnosis of lactose intolerance is a bad idea because it could lead to unnecessary dietary restrictions, expense, nutritional shortcomings, and failure to detect or treat a more serious gastrointestinal disorder. If lactose maldigestion is suspected, tests are available to diagnose this condition.

People with real or perceived lactose intolerance might limit their consumption of dairy foods unnecessarily and jeopardize their intake of calcium and other essential nutrients. A low intake of calcium is associated with increased risk of osteoporosis (porous bones), hypertension, and colon cancer.

With the exception of the few individuals who are sensitive to even very small amounts of lactose, avoiding all lactose is neither necessary nor recommended because some lactase is still being produced. Lactose maldigestors need to determine the amount of lactose they can comfortably consume at any one time. Here are some strategies for including milk and other dairy foods in your diet without developing symptoms:

1. Initially, consume small servings of lactose-containing foods such as milk (e.g., ½ cup). Gradually increase the serving size until symptoms begin to appear, and then back off.
2. Consume lactose with a meal or other foods (e.g., milk with cereal) to improve tolerance.
3. Adjust the type of dairy food. Whole milk might be tolerated better than low-fat milk, and chocolate milk might be tolerated better than unflavored milk. Many cheeses (e.g., cheddar, Swiss, Parmesan) contain considerably less lactose than milk. Aged cheeses generally have negligible amounts of lactose. Yogurts with live, active cultures are another option; these bacteria digest lactose. Sweet acidophilus milk, yogurt milk, and other nonfermented dairy foods might be tolerated better than regular milk by lactose maldigestors. However, factors such as the strain of bacteria used can influence tolerance to these dairy foods.
4. Lactose-hydrolyzed dairy foods and/or commercial enzyme preparations (e.g., lactase capsules, chewable tablets, solutions) are another option. Lactose-reduced (70 percent less lactose) and lactose-free (99.9 percent less lactose) milks are available, although at a higher cost than regular milk.

Lactose maldigestion need not be an impediment to meeting the needs for calcium and other essential nutrients provided by milk and other dairy foods.

Source: Data from National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK), NIH. Washington, DC; and Enattah NS, Sahi T, Savilahti E, et al. Identification of a variant associated with adult-type hypolactasia. *Nat Genet.* 2002;30(2):233–237.

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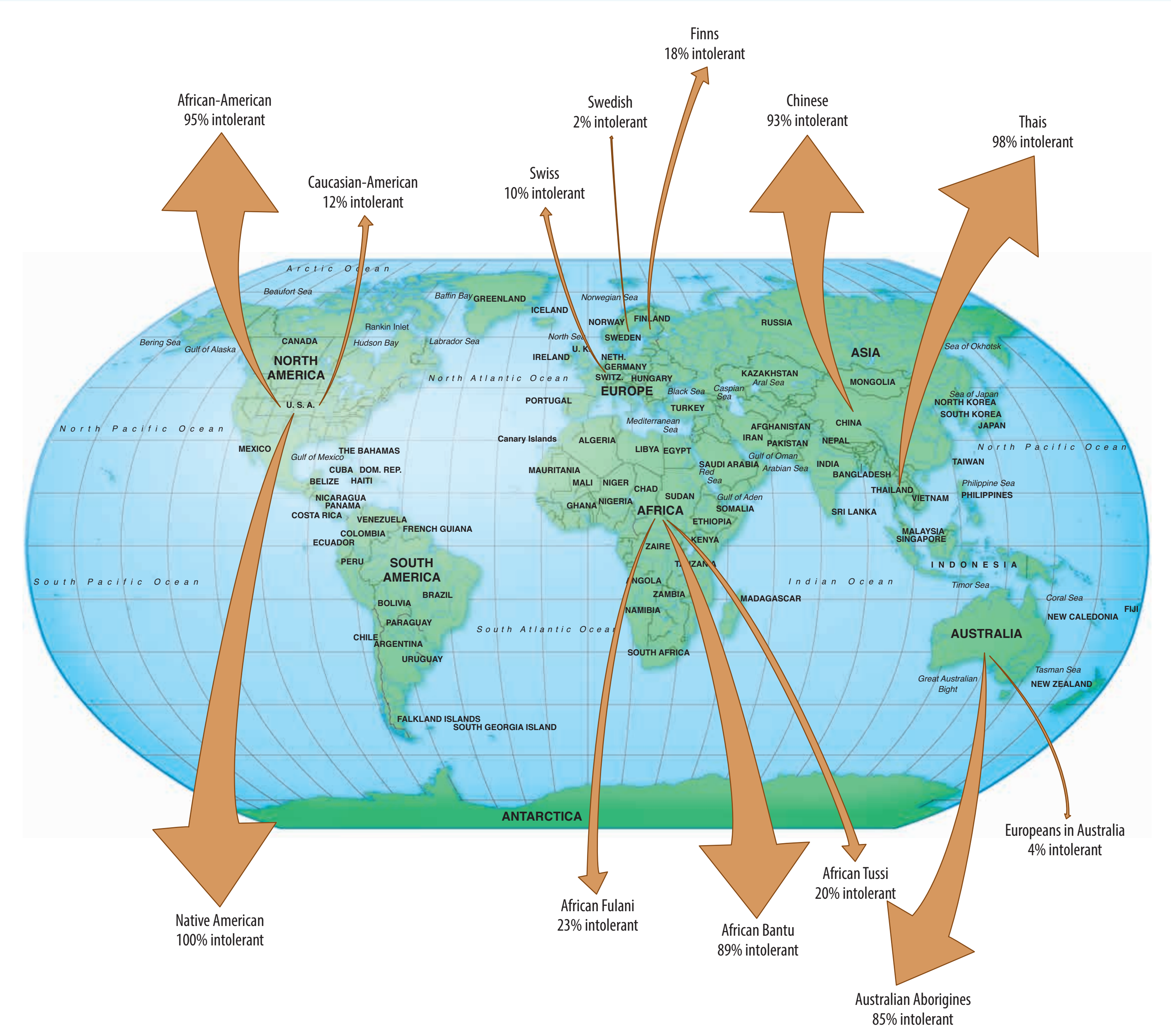

Distribution of lactose intolerance worldwide.
Source: Data from National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK), NIH. Washington, DC.

intestine is far greater. It actually has the capacity to absorb as much as several kilograms of carbohydrate, 500 grams of fat, 500 to 700 grams of amino acids, and 20 or more liters of water per day.[4] Approximately 85 percent of the water absorption by the gut occurs in the jejunum.[5]

Nutrients absorbed through the intestinal lining pass into the interior of the villi. Each villus contains blood vessels (veins, arteries, and capillaries) and a **lymph** vessel (known as a **lacteal**) that transport nutrients to other parts of your body. Water-soluble nutrients are absorbed directly into the bloodstream. Fat-soluble lipid compounds are absorbed into the lymph rather than directly into the blood.

Absorption takes place along the entire length of the small intestine. Most minerals, with the exception of the electrolytes sodium, chloride, and potassium, are absorbed in the duodenum and upper part of the jejunum. Carbohydrates, amino acids, and water-soluble vitamins are absorbed along the jejunum and upper ileum, whereas lipids and fat-soluble vitamins are absorbed primarily in the ileum. At the very end of the small intestine, the terminal ileum is the site of vitamin B_{12} absorption. If there is damage to the lower small intestine, or surgical removal of this section in the treatment of cancer and other diseases, malabsorption of fat-soluble vitamins and vitamin B_{12} is likely.

The small intestine suffers constant wear and tear as it propels and digests the chyme. The intestinal lining is renewed continually as the mucosal cells are replaced every two to five days. When the chyme has completed its 3- to 10-hour journey through the small intestine, it passes through the **ileocecal valve**, the connection to the large intestine.

lymph Fluid that travels through the lymphatic system, made up of fluid drained from between cells and large fat particles.

lacteal A small lymphatic vessel in the interior of each intestinal villus that picks up chylomicrons and fat-soluble vitamins from intestinal cells.

ileocecal valve The sphincter at the junction of the small and large intestines.

large intestine The tube (about 5 feet long) extending from the ileum of the small intestine to the anus. The large intestine includes the appendix, cecum, colon, rectum, and anal canal.

cecum The blind pouch at the beginning of the large intestine into which the ileum opens from one side and which is continuous with the colon.

colon The portion of the large intestine extending from the cecum to the rectum. It is made up of four parts—the ascending, transverse, descending, and sigmoid colons. Although often used interchangeably with the term *large intestine*, these terms are not synonymous.

rectum The muscular final segment of the intestine, extending from the sigmoid colon to the anus.

The Large Intestine

The chyme's next stop is the **large intestine**. As Figure 3.15 shows, this tube is about 5 feet (1.5 meters) long and includes the **cecum**, **colon**, rectum, and anal canal. As chyme fills the cecum, a local reflex signals the ileocecal valve to close, preventing material from reentering the ileum of the small intestine.

Digestion in the Large Intestine

The peristaltic movements of the large intestine are sluggish compared with those of the small intestine. Normally 18 to 24 hours are required for material to traverse its length. During that time, the colon's large population of bacteria digests small amounts of fiber, providing a negligible number of calories daily.[6] Of more significance are the other substances formed by this bacterial activity, including vitamin K, vitamin B_{12}, thiamin, riboflavin, biotin, and various gases that contribute to flatulence.[7] Other than bacterial action, no further digestion occurs in the large intestine.

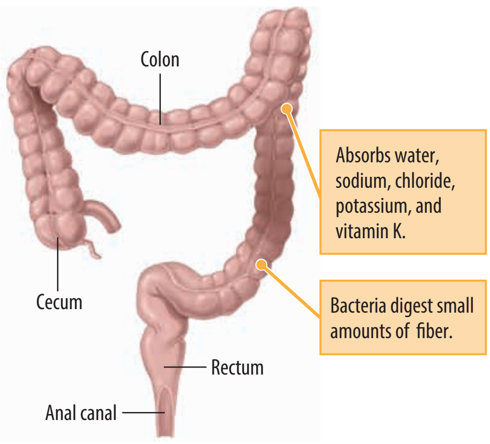

Figure 3.15 **The large intestine.** In the large intestine, bacteria break down dietary fiber and other undigested carbohydrates, releasing acids and gas. The large intestine absorbs water and minerals and forms feces for excretion.

Nutrient Absorption in the Large Intestine

Minimal nutrient absorption takes place in the large intestine, limited to water, sodium, chloride, potassium, and some of the vitamin K produced by bacteria. Although vitamin B_{12} is also produced by colonic bacteria, it is not absorbed. The colon dehydrates the watery chyme, removing and absorbing most of the remaining fluid. Of the approximately 1,000 milliliters of material that enter the large intestine, only about 150 milliliters remain for excretion as feces. The semisolid feces, consisting of roughly 60 percent solid matter (food residues, which include dietary fiber, bacteria, and digestive secretions) and 40 percent water, then passes into the rectum. In the **rectum**, strong muscles hold back the waste until it is time to defecate. The rectal muscles then relax, and the anal sphincter opens to allow passage of the stool out the anal canal.[8] Figure 3.16 summarizes nutrient absorption along the GI tract.

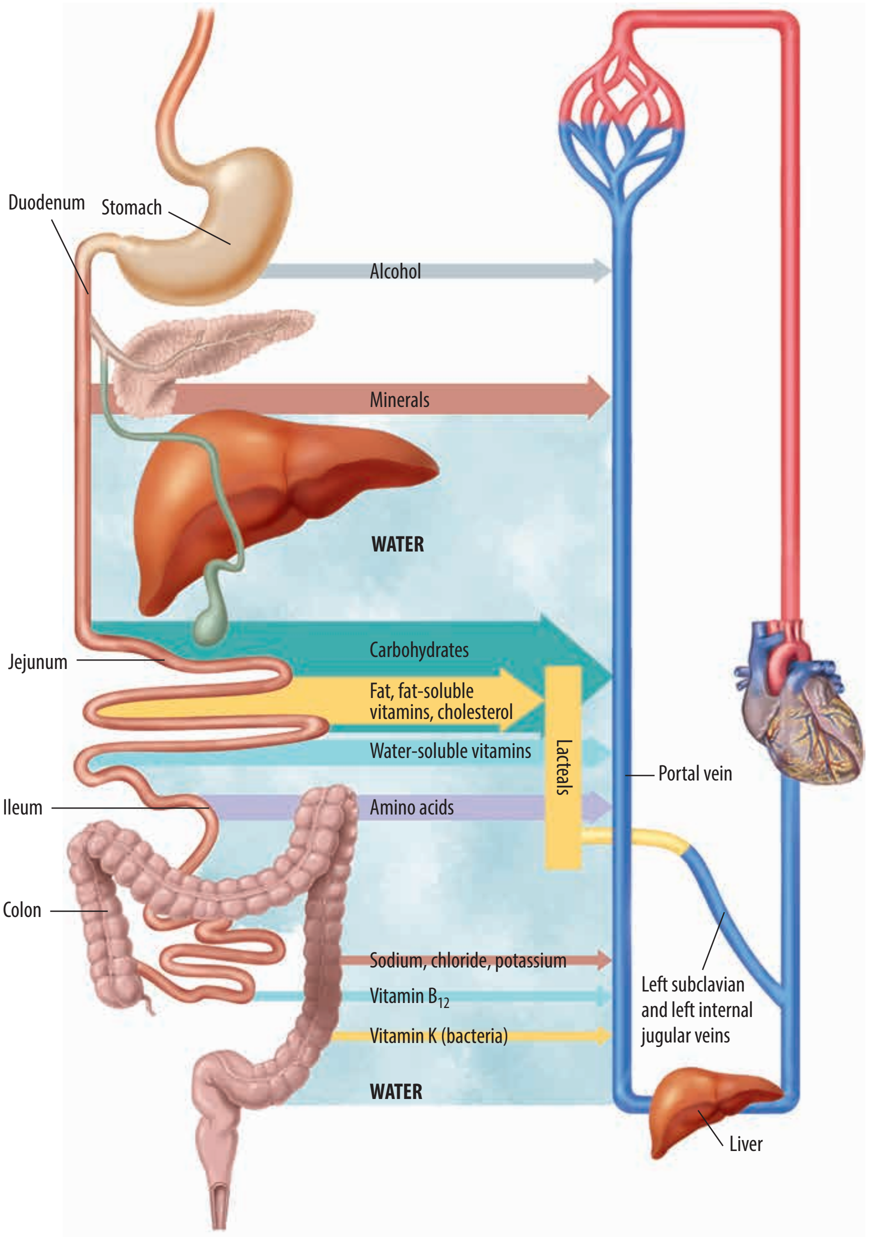

Figure 3.16 **Absorption of nutrients.**

Key Concepts Digestion begins in the mouth with the action of salivary amylase. Food material next moves down the esophagus to the stomach, where it mixes with gastric secretions. Protein digestion is begun through the action of pepsin, while salivary amylase action ceases because of the low pH level of the stomach. Some substances, such as alcohol, are absorbed directly from the stomach. The liquid material (chyme) next moves to the small intestine. Here, secretions from the gallbladder, pancreas, and intestinal lining cells complete the digestion of carbohydrates, proteins, and fats. The end products of digestion, along with vitamins, minerals, water, and other compounds, are absorbed through the intestinal wall and into circulation. Undigested material and some liquid move on to the large intestine, where water and electrolytes are absorbed, leaving waste material to be excreted as feces.

Quick Bite

The Clever Colon

Though it has been presumed that the colon has no digestive function, recent research shows that the human colon can be an important digestive site in patients who are missing significant sections of their intestines. These patients can actually absorb energy from starch and nonstarch polysaccharides in the colon.

Regulation of Gastrointestinal Activity

The processes of digestion and absorption are regulated by interaction of the nervous and hormonal systems. It would be wasteful to use energy for peristalsis or to secrete digestive enzymes when they were not needed. So, a system of signals is necessary to control GI movement and secretions. That's where nerve cells and hormones come in.

Nervous System

Nerves carry information back and forth between tissues and the brain. Chemicals called neurotransmitters send signals to either excite or suppress nerves, thereby stimulating or inhibiting activity in various parts of the body.

The **central nervous system (CNS)** regulates GI activity in two ways. The **enteric nervous system** is a local system of nerves in the gut wall that is stimulated both by the chemical composition of chyme and by the stretching of the GI lumen that results from food in the GI tract. This stimulation leads to nerve impulses that enhance the muscle and secretory activity along the tract. The enteric nervous system plays an essential role in the control of motility, blood flow, water and electrolyte transport, and acid secretion in the GI tract. A branch of the **autonomic nervous system** (the portion of the CNS that controls organ function) responds to the sight, smell, and thought of food. This branch of the CNS carries signals to and from the GI tract through the vagus nerve and enhances GI motility and secretion. In the past, treatments for some ulcers and other GI ailments included severing the vagus nerve, a measure that brought temporary, but not long-term, relief.

central nervous system (CNS) The brain and the spinal cord. The central nervous system transmits signals that control muscular actions and glandular secretions along the entire GI tract.

enteric nervous system A network of nerves located in the gastrointestinal wall.

autonomic nervous system The part of the central nervous system that regulates the automatic responses of the body; consists of the sympathetic and parasympathetic systems.

Hormonal System

Hormones also are involved in GI regulation (see **Figure 3.17**). Hormones are chemical messengers that are produced at one location and travel in the bloodstream to affect another location in the body. Some GI hormones, however, are secreted by and active in the same tissue.

Gastrointestinal hormonal signals increase or decrease GI motility and secretions and influence your appetite by sending signals to the central nervous system. Some GI hormones function as growth factors for the gastrointestinal mucosa and pancreas.

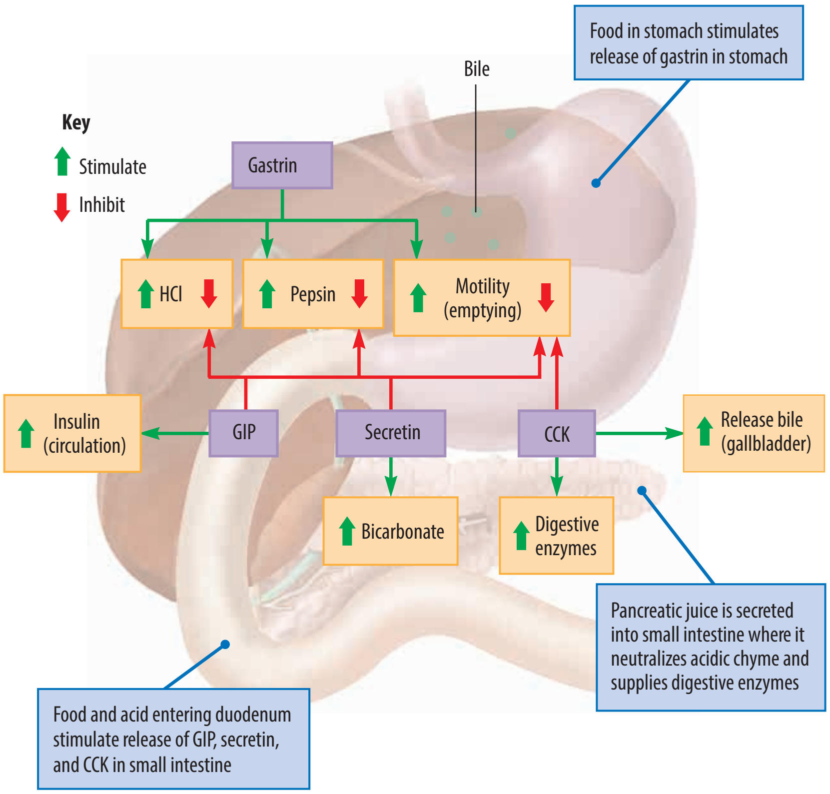

Figure 3.17 **Hormonal regulation of digestion.** In response to food moving through the digestive tract, hormones control the increase and decrease of digestive activities.

The four major hormones that regulate the GI function are gastrin, secretin, cholecystokinin, and gastric inhibitory peptide.

- Gastrin is released by cells in the stomach in response to distention of the stomach, nerve impulses from the vagus nerve, and the presence of chemicals such as alcohol and caffeine. Gastrin increases muscle movement in the stomach and enhances release of hydrochloric acid and pepsinogen to encourage digestion.
- Secretin is released by cells along the duodenal wall when acidic chyme begins to move into the duodenum. Secretin opposes the action of gastrin; it reduces gastric secretion and motility, and stimulates the pancreas to release bicarbonate to neutralize chyme.
- Cholecystokinin (CCK) is released by cells along the small intestine as the amino acids and fatty acids from digestion begin to enter the small intestine. CCK stimulates the pancreas to secrete enzymes, stimulates the gallbladder to contract and release bile, and slows gastric emptying.
- **Gastric inhibitory peptide (GIP)** is also released from the intestinal mucosal cells in response to fat and glucose in the small intestine. As its name implies, GIP inhibits gastric secretion, motility, and emptying. In addition, GIP stimulates the release of insulin, which is necessary for glucose utilization.

gastric inhibitory peptide (GIP) [GAS-trik in-HIB-ihtor-ee PEP-tide] A hormone released from the walls of the duodenum that slows the release of the stomach contents into the small intestine and stimulates release of insulin from the pancreas.

vascular system A network of veins and arteries through which the blood carries nutrients. Also called the *circulatory system*.

lymphatic system A system of small vessels, ducts, valves, and organized tissue (e.g., lymph nodes) through which lymph moves from its origin in the tissues toward the heart.

Taken together, nerve cells and hormones coordinate the movement and secretions of the GI tract so that enzymes are released when and where they are needed and chyme moves at a rate that optimizes digestion and absorption. Side effects from abdominal surgery can slow or halt movement through the GI tract for hours or days. Researchers are investigating strategies for stimulating the release of hormones to improve postoperative GI movement and speed recovery.

Key Concepts Both hormonal and nervous system signals regulate gastrointestinal activity. Nerve cells in both the enteric and autonomic nervous systems control muscle movement and secretory activity. Key hormones involved in regulation are gastrin, secretin, cholecystokinin, and gastric inhibitory peptide. The net effect of these regulators is to coordinate GI movement and secretion for optimal digestion and absorption of nutrients.

Circulation of Nutrients

After foods are digested and nutrients are absorbed, nutrients are transported by the vascular and lymphatic systems to specific destinations throughout the body. Let's take a closer look at how each of these circulatory systems delivers nutrients to the places they are needed.

Vascular System

The **vascular system** is a network of veins and arteries through which the blood carries nutrients (see Figure 3.18). The heart is the pump that keeps the blood circulating through the body. From intestinal cells, water-soluble nutrients are absorbed directly into tiny capillary tributaries of the bloodstream, where they travel to the liver before being dispersed throughout the body. Blood carries oxygen from the lungs and nutrients from the GI system to all body tissues. Once the destination cells have used the oxygen and nutrients, carbon dioxide and waste products are picked up by the blood and transported to the lungs and kidneys, respectively, for excretion.

Lymphatic System

The **lymphatic system** is a network of vessels that drain lymph, the clear fluid formed in the spaces between cells. Lymph moves through this system and eventually empties into the bloodstream near the neck. Lymph vessels

Television Watching and Diet Quality

Background

High levels of television viewing time is associated with many unhealthy dietary practices, including lower intake of fruits and vegetables and higher intake of fat and total energy. A greater level of television viewing also has been linked to higher mortality, obesity, and cardiometabolic disease in both adults and children. Most studies to date have focused on energy intake or the consumption of specific food groups and television-viewing time, but not overall dietary quality. Overall dietary quality is an important factor in health and weight status, and therefore deserves examination.

Study Purpose

To quantify associations between television -viewing time and overall dietary quality as measured by the Healthy Eating Index–2005 (HEI-2005) using a nationally representative sample of U.S. adults and children (NHANES 2003–2006).

Experimental Plan

Dietary quality was assessed using the HEI-2005 based on dietary information collected from two averaged interviewer-administered 24-hour dietary recalls. A questionnaire to assess television viewing time and activity levels of participants was administered. Anthropometric measures of participants to classify weight status were obtained. Participants with missing data for dietary recalls, gender, race/ethnicity, height, weight, television-viewing time, or physical activity were excluded from analysis.

Results

Lower television-viewing time was associated with higher HEI-2005 (i.e., healthier diet) for all gender and age groups (see **Table A**). Results remained significant in all groups after adjusting for physical activity.

Conclusion and Discussion

In U.S. adults and children, better dietary quality is associated with less television-viewing time. The results of this study not only support and expand on previous investigations' findings but also are unique in that the association between television-viewing time and dietary quality were examined using a nationally representative sample and a previously validated and reliable measure of dietary quality. This study also included participants from a wide range of age groups, increasing the applicability of study findings. Both dietary intake and television-viewing time are modifiable through lifestyle intervention. Additional research should focus on interventional studies to determine whether a reduction in television-viewing time can affect dietary quality. This could help to further develop and expand programs that address health promotion and disease prevention.

Source: Data from Sisson SB, Shay CM, Broyles ST, Leyva M. Television-viewing time and dietary quality among U.S. children and adults. *Am J Prev Med.* 2012;43(2):196–200.

Table A Healthy Eating Index—2005[a] by Television-Watching Category for Children and Adults in 2003–2006 NHANES

	Television-Viewing Time (hours/day)			
	≤ 1	2–3	≥ 4	*p*-value
Preschool Children (aged 2–5 years)				
Boys	52.5 (0.6)	50.2 (0.6)	48.6 (0.8)	0.006
Girls	52.2 (0.7)	50.8 (0.9)	48.1 (1.0)	0.04
School-aged Children (aged 6–11 years)				
Boys	50.8 (0.7)	48.6 (0.6)	47.1 (1.2)	0.03
Girls	51.0 (0.8)	48.0 (0.6)	47.4 (0.9)	0.003
Adolescents (aged 12–18 years)				
Boys	47.0 (0.5)	46.8 (0.4)	44.7 (0.7)	0.003
Girls	49.1 (0.7)	46.5 (0.6)	47.1 (0.6)	0.03
Adults (aged ≥ 19 years)				
Men	49.0 (0.3)	48.9 (0.4)	47.3 (0.4)	< 0.001
Women	51.8 (0.4)	50.2 (0.4)	48.9 (0.5)	0.005

Note: All values in parentheses represent SE.

[a] Values calculated as least-squared means with adjustment for age; BMI (percentile for all children); physical activity (daily minutes moderate-to-vigorous physical activity for children aged 12–18 years and adults and weekly times of "hard play" for children aged 2–11 years); and ethnicity. *p*-values were calculated on unadjusted means.

Source: Reproduced from Sisson SB, Shay CM, Broyles ST, Leyva M. Television-viewing time and dietary quality among U.S. children and adults [Table 2, p. 199]. *Am J Prev Med.* 2012;43(2):196–200.

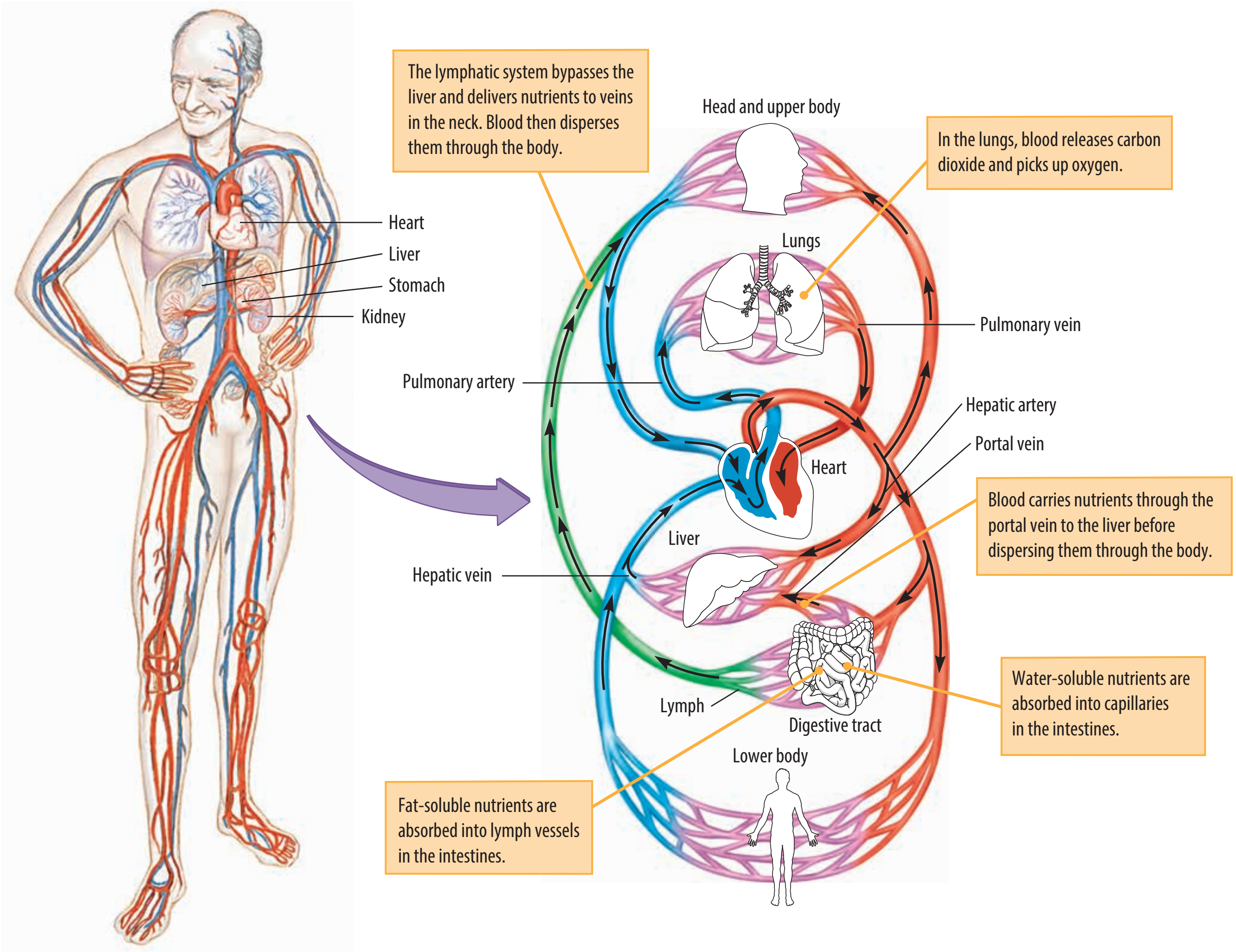

Figure 3.18 **Circulation.** Blood carries oxygen from the lungs and nutrients from the GI system to all body tissues. Intestinal cells absorb water-soluble nutrients and deliver them directly into tiny capillary tributaries of the bloodstream. From there, they travel to the liver before being dispersed throughout the body. Intestinal cells absorb fat-soluble nutrients and deliver them to the lymphatic system, a circulatory system that bypasses the liver before connecting to the bloodstream.

in the small intestine absorb fat-soluble nutrients and most end products of fat digestion. After a fatty meal, lymph can become as much as 1 to 2 percent fat. Nutrients absorbed into the lymphatic system, unlike those absorbed directly into the vascular system, bypass the liver before entering the bloodstream.

Unlike the vascular system, the lymphatic system has no pumping organ. The major lymph vessels contain one-way valves; when the vessels are filled with lymph, smooth muscles in the vessel walls contract and pump the lymph forward. The succession of valves allows each segment of the vessel to act as an independent pump. Lymph also is moved along by skeletal muscle contractions that squeeze the vessels.

The lymphatic system also performs an important cleanup function. Proteins and large particulate matter in tissue spaces cannot be absorbed directly into the blood capillaries, but they easily enter the lymphatic system, where they are carried away for removal. This removal process is essential—without it a person would die within 24 hours from buildup of fluid and materials around the cells.[9]

Key Concepts Absorbed nutrients are carried by either the vascular or lymphatic system. Water-soluble nutrients are absorbed directly into the bloodstream, carried to the liver, and then distributed around the body. Fat-soluble vitamins and large lipid molecules are absorbed into the lymphatic vessels and are carried by this system before entering the vascular system.

Quick Bite

Short Bowel Syndrome

Patients who suffer from short bowel syndrome commonly have difficulty absorbing fat-soluble vitamins. To enhance absorption, treatment includes taking a fat-soluble vitamin supplement that easily mingles with water. These patients also might need to take intramuscular shots of B_{12} because they are unable to absorb this water-soluble vitamin.

Influences on Digestion and Absorption

Psychological Influences

The taste, smell, and presentation of foods can have a positive effect on digestion. Just the thought of food can trigger saliva production and peristalsis. Stressful emotions such as depression and fear can have the reverse effect (see **Figure 3.19**): They stimulate the brain to activate the autonomic nervous system. This results in decreased gastric acid secretion, reduced blood flow to the stomach, inhibition of peristalsis, and reduced propulsion of food.[10] The next time you sit down to a holiday meal, notice how you feel at the sight of your family's traditional foods as well as smells from your childhood. Happiness and positive memories add to the enjoyment of food, whereas sadness can bring on a poor appetite or stomach upset.

THINK About It 4

Chemical Influences

The type of protein you eat and the way it is prepared affect digestion. Plant proteins tend to be less digestible than animal proteins. Cooking food usually denatures protein (uncoils its three-dimensional structure), which increases digestibility. Cooking meat softens its connective tissue, making chewing easier and increasing the meat's accessibility to digestive enzymes.

Food processing produces chemicals that can influence digestive secretions. For example, frying foods in fat at very high temperatures produces small amounts of **acrolein**,[11] which decreases the flow of digestive secretions; in contrast, meat extracts can stimulate digestion. The physical condition of a food sometimes causes problems with digestion. Cold foods can cause intestinal spasms in people who suffer from irritable bowel syndrome or Crohn's disease. Stomach contents can affect absorption. When food is consumed on an empty stomach, it has more contact with gastric secretions and is absorbed faster than if it were consumed on a full stomach. Certain medicines inhibit nutrient absorption, and in turn, certain foods interact with medicines, making the drugs less effective or toxic.

Bacterial Influences

In the healthy stomach, hydrochloric acid kills most bacteria. In conditions where there is a lower concentration of hydrochloric acid, more bacteria can survive and multiply. Harmful bacteria can cause gastritis (an inflammation of the stomach lining) and peptic ulcer (a wound in the mucous membranes lining the stomach or duodenum). Bacteria that cause foodborne illness resist the germicidal effects of hydrochloric acid, so they survive to wreak havoc on the digestive process.

The large intestine maintains a large population of bacteria. These bacteria can form several vitamins and digest small amounts of fiber, producing a small amount of energy. These bacteria also synthesize gases, such as hydrogen, ammonia, and methane, as well as acids and various substances that contribute to the odor of feces. If the digestion and absorption of food in the small intestine are incomplete, the undigested material enters the large intestine, where bacterial action produces excessive gas, and possibly bloating and pain.

Key Concepts Psychological, chemical, and bacterial factors can influence the processes of digestion and absorption. Emotions can influence GI motility and secretion. The temperature and form of food also can affect digestive secretions. Although stomach acid kills many types of bacteria, some are resistant to acid and cause foodborne illness. Helpful bacteria in the large intestine can cause bloating and gas if they receive and begin to digest food components that are normally digested in the small intestine.

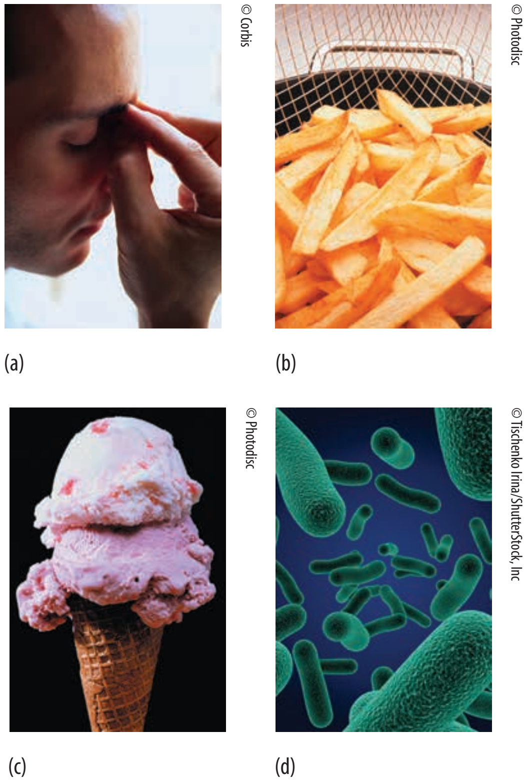

Figure 3.19 **Negative factors for digestion.** (a) Stress. (b) High-temperature fat frying. (c) Cold foods. (d) Bacteria.

Quick Bite

Gastrointestinal Flora Abound

Your entire body has about 100 trillion cells, but this is only one-tenth the number of protective microorganisms normally living in your body. More than 500 bacterial species live in your GI tract.

acrolein A pungent decomposition product of fats, generated from dehydrating the glycerol components of fats; responsible for the coughing attacks caused by the fumes released by burning fat. This toxic water-soluble liquid vaporizes easily and is highly flammable.

Nutrition and GI Disorders

"I have butterflies in my stomach." "It was a gut-wrenching experience." Our language contains many references to the connection between emotional distress and the GI tract. Most of us have experienced intestinal cramping right before a big date or job interview or a queasy stomach in response to something very disgusting. The brain, through numerous neurochemical connections with the gut, exerts a profound influence on GI function. Nearly all GI disorders are influenced to some degree by emotional state. On the other hand, a number of illnesses that were once attributed largely to emotional stress, such as peptic ulcer disease, have been shown to be caused primarily by infection and other physical causes. **Figure 3.20** shows some common ailments that affect the GI tract.

Although stress management can help and medical intervention might be required, we can prevent and manage most GI disorders with diet. For instance, adding fiber-rich foods (see **Table 3.2**) and water to the diet reduces intestinal pressure, decreases the time food by-products remain in the colon, and promotes bowel regularity. You can avoid most problems and keep your GI tract operating at peak efficiency if you regularly eat a healthful diet, exercise, and maintain a healthy weight.

Quick Bite

Halt! Who Goes There?

Be they friend or foe, antibiotics kill microorganisms in your GI tract, frequently causing diarrhea. About half of pharmaceutical drugs have gastrointestinal side effects.

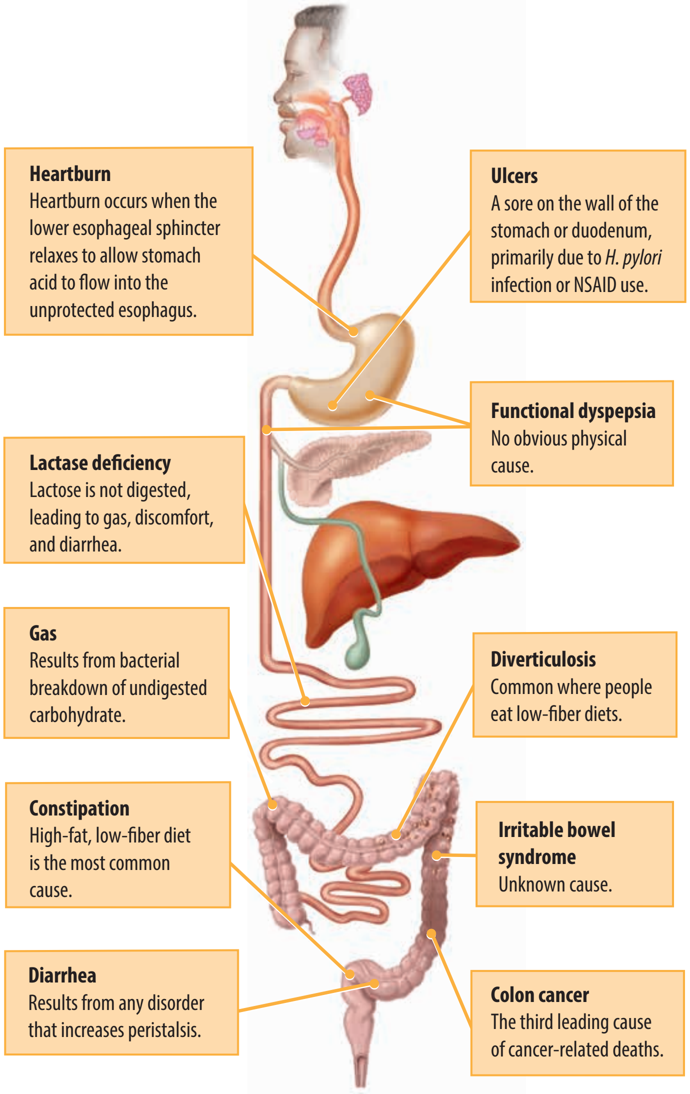

Figure 3.20 Gastrointestinal symptoms and disorders can occur all along the GI tract.

Table 3.2 Fiber Content of Foods

Food Group	Serving Size	Fiber (g)
Legumes		
Kidney beans	1 cup, cooked	13.1
Lentils	1 cup, cooked	15.6
Split peas	1 cup, cooked	16.3
Fruit		
Dried plums	½ cup	6.2
Apple with skin	1 small	3.6
Peach with skin	1 large	2.6
Vegetables		
Broccoli	1 cup, raw	2.4
Carrot	2 medium, raw	3.4
Tomato	1 large, raw	2.2
Grains		
Wheat bran-flake cereal	1 ounce	5.3
Bulgur wheat	½ cup, cooked	4.1
Whole-wheat bread	1 slice	1.9
Brown rice	½ cup, cooked	1.8
Spaghetti, enriched white	½ cup, cooked	1.3
White bread	1 slice	0.7
White rice	½ cup, cooked	0.3

Source: Data from US Department of Agriculture, Agricultural Research Service. USDA National Nutrient Database for Standard Reference, Release 25. 2012. www.ars.usda.gov/ba/bhnrc/ndl. Accessed 1/20/13.

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Constipation

Constipation is defined as having a bowel movement fewer than three times per week.[12] With constipation, stools are usually hard, dry, small in size, and difficult to eliminate. People who are constipated might find it painful to have a bowel movement and often experience straining, bloating, and the sensation of a full bowel.

Constipation is a symptom, not a disease. Almost everyone experiences constipation at some point, and a poor diet (low in fiber and water and high in fats) is a common cause. Some fibers, such as the pectins in fruits and gums in beans, dissolve easily in water and take on a soft, gel-like texture in the intestines. Other fibers, such as the cellulose in wheat bran, pass almost unchanged through the intestines. The bulk and soft texture of fiber help prevent hard, dry stools that are difficult to pass. People who eat plenty of high-fiber foods are not likely to become constipated.

Liquids such as water and juice add fluid to the colon and bulk to stools, making bowel movements softer and easier to pass. The caffeine in many liquids (e.g., coffee, tea, many soft drinks) is a mild diuretic (a substance that increases urine production). Although treatment depends on the cause, severity, and duration, in most cases dietary changes help relieve symptoms and prevent constipation.

constipation Infrequent and difficult bowel movements, followed by a sensation of incomplete evacuation.

diarrhea Loose, watery stools that occur more than three times in one day—is caused by digestive products moving through the large intestine too rapidly for sufficient water to be reabsorbed.

Diarrhea

Diarrhea is a symptom of many disorders that cause increased peristalsis. Culprits include stress, intestinal irritation or damage, and intolerance to gluten, fat, or lactose. Eating food contaminated with bacteria or viruses often causes diarrhea when the digestive tract speeds the offending food along the alimentary canal and out of the body.

Diarrhea can cause dehydration, which means the body lacks enough fluid to function properly. Dehydration is particularly dangerous in children and older adults, and it must be treated promptly to avoid serious health problems.

A diet of broth, tea, and toast and avoidance of lactose, caffeine, and sorbitol can reduce diarrhea until it subsides. As stools form, you can gradually introduce more foods. Pectin, a form of dietary fiber found in apples and citrus peel, can be helpful. Also, include foods high in potassium, if tolerated, to replace lost electrolytes. Fluid replacement is also important to avoid dehydration.

Diverticulosis

Like an inner tube that pokes through weak places in an old tire, the colon develops small pouches that bulge outward through weak spots as people age. Known as diverticulosis, this condition afflicts about half of all Americans aged 60 to 80 years, and almost everyone older than age 80 years. Although it

FYI For Your Information

Bugs in Your Gut? Health Effects of Intestinal Bacteria

Unseen and unnoticed, millions and millions of bacteria call your GI tract home. Although we often associate bacteria with illness, the right kinds of bacteria in the gut actually protect us from disease. The normal microflora of the gut, specifically strains of lactobacilli and bifidobacteria, have been linked to improved digestion, intestinal regularity, enhanced GI immune function, improved lactose tolerance, reduced risk of developing allergies, and even reduced risk of colorectal cancer. So, how can we be good hosts to our intestinal guests, keeping them well fed and happy? The answer might be in food products and dietary supplements known as probiotics and prebiotics.

Probiotics are foods (or supplements) that contain live microorganisms such as *Lactobacillus acidophilus*. Such lactic-acid-producing bacteria have been used for centuries to ferment milk into yogurt, cheeses, and other products. The bacteria convert lactose into lactic acid, which causes the milk to gel and imparts a tart flavor to the product. The resulting product has a much longer shelf life than fresh milk and is associated with good health and longevity in many societies. Other probiotics are *Bifidobacterium* organisms and yeast. When consumed in sufficient quantities, these microorganisms have the potential to improve health.

The term *prebiotic* describes a nondigestible food product that can be fermented by gastrointestinal bacteria and stimulates the growth or activity of "good" gut bacteria. For example, it is thought that the composition of breast milk strongly favors the growth of lactobacilli and bifidobacteria in the newborn gut. Some scientists have found bifidobacteria to be the dominant species in breastfed infants, whereas the microflora of bottle-fed infants is more diverse. The reduced incidence of GI infections in breastfed infants has been attributed to the dominance of bifidobacteria. Substances that can be effective prebiotics include fructooligosaccharides, polydextrose, arabinogalactan, polyols, and inulin.

So, how does feeding the bacteria in your gut improve your health? Successful colonization of helpful bacteria allows them to outnumber (and outeat) disease-causing bacteria, thus reducing the likelihood of foodborne illness and other infections. Studies in young children show that supplementation with *Lactobacillus* reduced the severity and duration of diarrhea caused by rotavirus, a common infectious agent in daycare centers. Some probiotics enhance the ability of the gut to act as a barrier to infectious agents and might also adjust the activity of the immune system.

"Good" bacteria can digest the lactose that enters the colon of a person with lactose intolerance, reducing symptoms and discomfort. Intestinal bacteria metabolize both indigestible and incompletely digested food material. Probiotics produce by-products that reduce disease risk. For example, acids produced by probiotic colon bacteria change the pH of the colon, which can interfere with carcinogenesis (development of cancer).

In addition to promoting the growth and function of beneficial bacteria, prebiotics might have other health effects. Some prebiotics have been shown to enhance absorption of calcium and magnesium. Others inhibit growth of lesions in the gut, which in turn reduces colorectal cancer risk. Although lipid-lowering effects have been attributed to prebiotics, the limited data available show inconsistent effects on cholesterol and triglycerides.

Fermented milk products such as yogurt and kefir are one way to keep your gut happy. Look for a seal adopted by the National Yogurt Association to identify products that contain a minimum of 100 million live lactic acid bacteria per gram of yogurt. Not all brands of yogurt contain live, active cultures. Supplemental probiotics must have sufficient numbers of live bacteria to be useful; currently, identification and standardization procedures are lacking. Prebiotics are found in whole grains, onions, bananas, garlic, artichokes, and a variety of fortified foods, beverages, and dietary supplements. Although results are preliminary, food and supplement sources of probiotics and prebiotics might be another useful way to improve gut microflora and overall health.

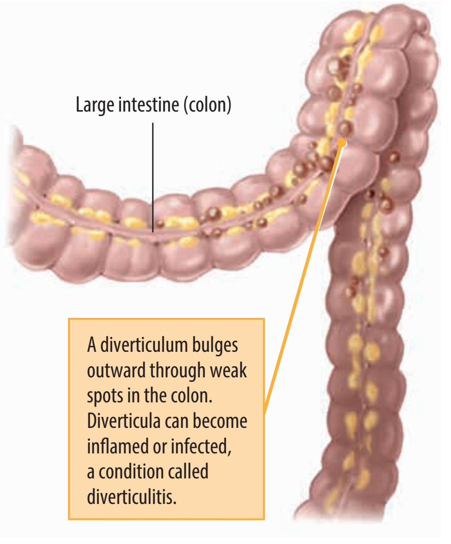
usually causes few problems, in 10 to 25 percent of these people the pouches become infected or inflamed—a condition called diverticulitis.

Diverticulosis and diverticulitis are common in developed or industrialized countries—particularly the United States, England, and Australia—where low-fiber diets are common. Diverticular disease is rare in Asian and African countries, where people eat high-fiber, vegetable-based diets.

A low-fiber diet can make stools hard and difficult to pass. If the stool is too hard, muscles must strain to move it. This is the main cause of increased pressure in the colon, which causes weak spots to bulge outward.

Increasing the amount of fiber in the diet can reduce symptoms of diverticulosis and prevent complications such as diverticulitis. Fiber keeps stools soft and lowers pressure inside the colon so that bowel contents can move through easily. Additional benefits of fiber are listed in **Table 3.3**.

If cramps, bloating, and constipation are problems, a doctor might prescribe a short course of pain medication. However, many medications used to treat such symptoms can cause either diarrhea or constipation, undesirable side effects for people with diverticulosis.



Diverticulosis. In industrialized nations, diverticulosis is common in older people. It is unusual in developing countries where people eat high-fiber diets.

Heartburn and Gastroesophageal Reflux

Heartburn occurs when the lower esophageal sphincter (LES) relaxes inappropriately, allowing the stomach's contents to flow back into the esophagus. Unlike the stomach, the esophagus has no protective mucous lining, so acid can damage it quickly and cause pain. Many people experience occasional heartburn, but for some, heartburn is a chronic, often daily, event and a symptom of a more serious disorder called **gastroesophageal reflux disease (GERD)**. GERD, along with obesity, is a key risk factor for esophageal cancer.[13] GERD has a variety of causes, and many treatment strategies involve lifestyle and nutrition.

gastroesophageal reflux disease (GERD) A condition in which gastric contents move backward (reflux) into the esophagus, causing pain and tissue damage.

Doctors recommend avoiding foods and beverages that can weaken the LES, including chocolate, peppermint, fatty foods, coffee, and alcoholic beverages. Foods and beverages that can irritate a damaged esophageal lining, such as citrus fruits and juices, tomato products, and pepper, also should be avoided. Individual response to food varies so many people with GERD use trial and error to determine what foods cause discomfort.

Decreasing both the portion size and the fat content of meals can help. High-fat meals remain in the stomach longer than low-fat meals. This creates

Table 3.3 Benefits of Fiber

- Helps control weight by delaying gastric emptying and providing a feeling of fullness.
- Improves glucose tolerance by delaying the movement of carbohydrate into the small intestine.
- Reduces risk for heart disease by binding with bile (which contains cholesterol) in the intestine and causing it to be excreted, which in turn helps to lower blood cholesterol levels.
- Promotes regularity and reduces constipation by increasing stool weight and decreasing transit time.
- Reduces the risk of diverticulosis by decreasing pressure within the colon, decreasing transit time, and increasing stool weight.

Source: Modified from Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids*. Washington, DC: National Academies Press; 2002. Copyright © 2002, National Academy of Sciences.

back pressure on the lower esophageal sphincter. Eating meals at least two to three hours before bedtime can lessen reflux by allowing partial emptying and a decrease in stomach acidity. Elevating the head of the bed or sleeping on a specially designed wedge reduces heartburn by allowing gravity to minimize reflux of stomach contents into the esophagus.

In addition, cigarette smoking weakens the LES, and being overweight often worsens symptoms. Stopping smoking is important, and many overweight people find relief when they lose weight.

Irritable Bowel Syndrome

irritable bowel syndrome (IBS) A disruptive state of intestinal motility with no known cause. Symptoms include constipation, abdominal pain, and episodic diarrhea.

Irritable bowel syndrome (IBS) is a common, functional gastrointestinal disorder with estimated worldwide prevalence of 10–20 percent[14] and significantly higher prevalence in women than in men.[15] This poorly understood condition causes abdominal pain, altered bowel habits (such as diarrhea or constipation), and cramps.[16] Often, IBS is just a mild annoyance, but for some people it can be disabling.

The cause of IBS remains a mystery, but emotional stress and specific foods clearly aggravate the symptoms in most sufferers.[17] Beans, chocolate, milk products, and large amounts of alcohol are frequent offenders. Fat in any form (animal or vegetable) is a strong stimulus of colonic contractions after a meal. Caffeine causes loose stools in many people, but it is more likely to affect those with IBS. Women with IBS might have more symptoms during their menstrual periods, suggesting that reproductive hormones can increase IBS symptoms.

The good news about IBS is that although its symptoms can be uncomfortable, it does not shorten life span or progress to more serious illness. IBS can usually be controlled with diet and lifestyle modifications and judicious use of medication. Stress management is an important part of treatment for IBS and includes stress reduction (relaxation) training and relaxation therapies, such as meditation; counseling and support; regular exercise; changes to stressful situations in your life; and adequate sleep.[18]

IBS sufferers may have abnormal patterns of intestinal motility, or might be hypersensitive to GI stimuli, but research results are inconclusive. We are a long way from understanding what causes IBS, but it is likely that a number of physical and psychosocial factors combine to trigger this disorder.

Colorectal Cancer

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After lung cancer, colorectal cancer—cancer of the colon or rectum—is the second leading cause of cancer-related deaths in the United States.[19] According to the World Health Organization, "Review of the relationships between diet and colorectal cancer suggests that risk is increased by high intakes of meat and fat, and decreased by high intakes of fruit, vegetables, folate, and calcium. The link between colorectal cancer and the consumption of cooked and processed red meat, is attributed to chemical carcinogens that arise during the cooking process."[20] Overweight and obesity also increase risk, while maintenance of regular physical activity and having an appropriate body mass reduce risk.[21]

Observational and case control studies support the idea that fiber-rich diets reduce colorectal cancer risk, and scientists have hypothesized a number of possible ways that fiber might be protective.[22] These include dilution of carcinogens in a bulkier stool, more rapid transit of carcinogens through the GI tract, and lower colon pH resulting from bacterial fermentation of fiber.

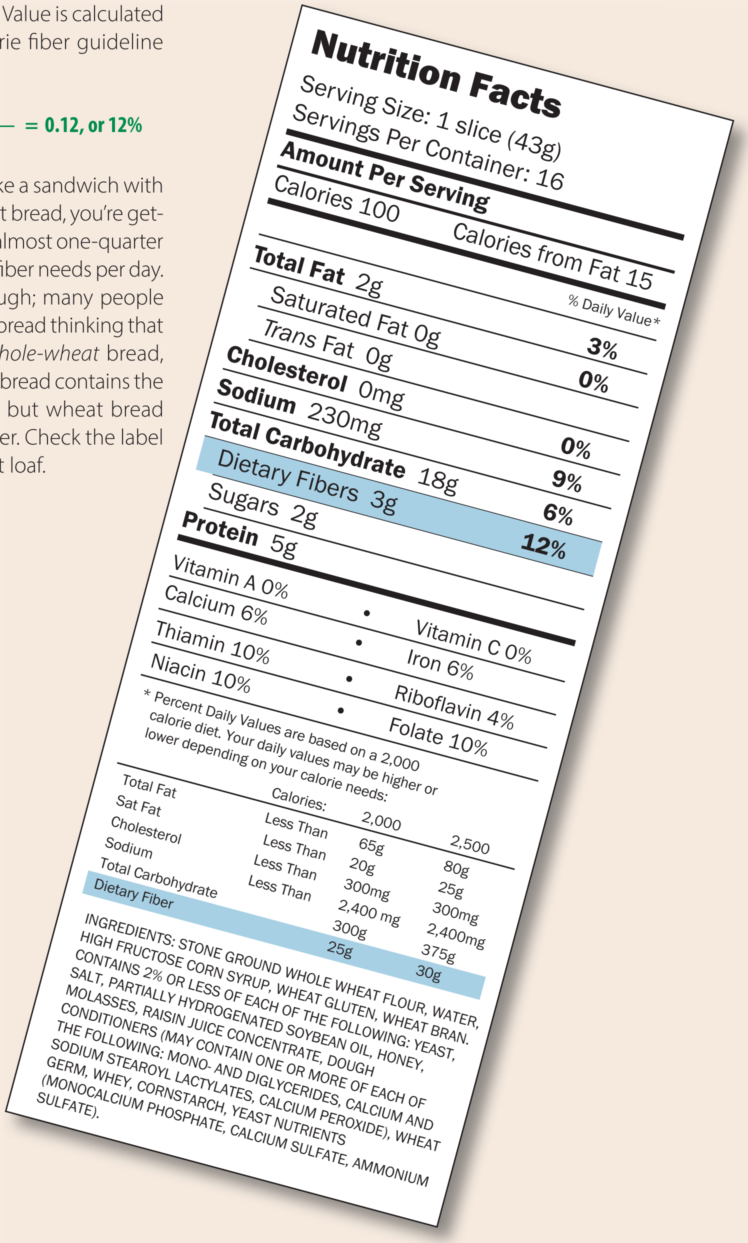
Label to Table

As you've learned in this chapter, fiber is one of the few things you do not digest fully. Instead, fiber moves through the GI tract and most of it leaves the body in feces. If it's not digested, then why all the fuss about eating more fiber? A healthy intake of fiber can lower your risk of cancer and heart disease and help with bowel regularity. So, how do you know which foods have fiber? You have to check out the food label!

This Nutrition Facts panel is from the label on a loaf of whole-wheat bread. The highlighted sections show you that every slice of bread contains 3 grams of fiber. The 12% listed to the right of that refers to the Daily Values below. Look at the Daily Values at the far right of the label, and note that there are two numbers listed for fiber. One (25 g) is for a person who consumes about 2,000 kilocalories per day, and the other (30 g) is for a 2,500-kilocalorie level. It should be no surprise that if you are consuming more calories, you should also be consuming more fiber. The 12% Daily Value is calculated using the 2,000-kilocalorie fiber guideline as follows:

$$\frac{\text{3 grams fiber per slice}}{\text{25 grams Daily Value}} = 0.12\text{, or }12\%$$

This means if you make a sandwich with two slices of whole-wheat bread, you're getting 6 grams of fiber and almost one-quarter (24% Daily Value) of your fiber needs per day. Not bad! Be careful, though; many people inadvertently buy wheat bread thinking that it's as high in fiber as *whole-wheat* bread, but it's not. Whole-wheat bread contains the whole (complete) grain, but wheat bread often is stripped of its fiber. Check the label before you buy your next loaf.



Nutrition Facts
Serving Size: 1 slice (43g)
Servings Per Container: 16

Amount Per Serving	
Calories 100	Calories from Fat 15
	% Daily Value*
Total Fat 2g	**3%**
Saturated Fat 0g	**0%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 230mg	**9%**
Total Carbohydrate 18g	**6%**
Dietary Fibers 3g	**12%**
Sugars 2g	
Protein 5g	

Vitamin A 0%	•	Vitamin C 0%
Calcium 6%	•	Iron 6%
Thiamin 10%	•	Riboflavin 4%
Niacin 10%	•	Folate 10%

* Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:

	Calories:	2,000	2,500
Total Fat	Less Than	65g	80g
Sat Fat	Less Than	20g	25g
Cholesterol	Less Than	300mg	300mg
Sodium	Less Than	2,400 mg	2,400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

INGREDIENTS: STONE GROUND WHOLE WHEAT FLOUR, WATER, HIGH FRUCTOSE CORN SYRUP, WHEAT GLUTEN, WHEAT BRAN. CONTAINS 2% OR LESS OF EACH OF THE FOLLOWING: YEAST, SALT, PARTIALLY HYDROGENATED SOYBEAN OIL, HONEY, MOLASSES, RAISIN JUICE CONCENTRATE, DOUGH CONDITIONERS (MAY CONTAIN ONE OR MORE OF EACH OF THE FOLLOWING: MONO- AND DIGLYCERIDES, CALCIUM AND SODIUM STEAROYL LACTYLATES, CALCIUM PEROXIDE), WHEAT GERM, WHEY, CORNSTARCH, YEAST NUTRIENTS (MONOCALCIUM PHOSPHATE, CALCIUM SULFATE, AMMONIUM SULFATE).

Gas

Everyone has gas and eliminates it by burping or passing it through the rectum. Gas is made primarily of odorless vapors. The unpleasant odor of flatulence comes from bacteria in the large intestine that release small amounts of gases that contain sulfur. Although having gas is common, it can be uncomfortable and embarrassing.

Gas in the stomach is commonly caused by swallowing air. Everyone swallows small amounts of air when they eat and drink. However, eating or drinking rapidly, chewing gum, smoking, or wearing loose dentures can cause some people to take in more air. Burping, or belching, is the way most swallowed air leaves the stomach. The remaining gas moves into the small intestine, where it is partially absorbed. A small amount travels into the large intestine for release through the rectum. (The stomach also releases carbon dioxide when stomach acid and bicarbonate mix, but most of this gas is absorbed into the bloodstream and does not enter the large intestine.)

Frequent passage of rectal gas can be annoying, but it's seldom a symptom of serious disease. **Flatus** (lower intestinal gas) composition depends largely on dietary carbohydrate intake and the activity of the colon's bacterial population.

Most foods that contain carbohydrates can cause gas. By contrast, fats and proteins cause little gas. In the large intestine, bacteria partially break down undigested carbohydrate, producing hydrogen, carbon dioxide, and, in about one-third of people, methane. Eventually these gases exit through the rectum.

Foods that produce gas in one person might not cause gas in another. Some common bacteria in the large intestine can destroy the hydrogen that other bacteria produce. The balance of the two types of bacteria explains why some people have more gas than others do.

Carbohydrates that commonly cause gas are raffinose and stachyose, found in large quantities in beans; lactose, the natural sugar in milk; fructose, a common sweetener in soft drinks and fruit drinks; and sorbitol, found naturally in fruits and used as an artificial sweetener.

Most starches, including potatoes, corn, noodles, and wheat, produce gas as they are broken down in the large intestine. Rice is the only starch that does not cause gas. The fiber in oat bran, beans, peas, and most fruits is not broken down until it reaches the large intestine, where digestion causes gas. In contrast, the fiber in wheat bran and some vegetables passes essentially unchanged through the intestines and produces little gas.

flatus Lower intestinal gas that is expelled through the rectum.

ulcer A craterlike lesion that occurs in the lining of the stomach or duodenum; also called a *peptic* ulcer to distinguish it from a skin ulcer.

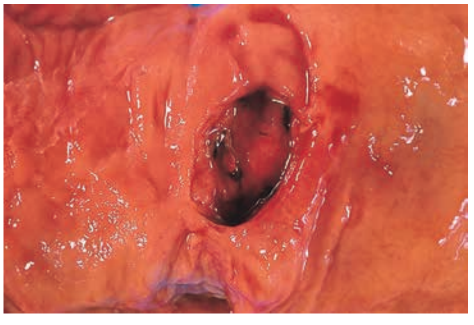


Figure 3.21 Stomach ulcer.

Figure 3.22 ***Helicobacter pylori.***

Ulcers

A gnawing, burning pain in the upper abdomen is the classic sign of a peptic ulcer, which also can cause nausea, vomiting, loss of appetite, and weight loss. A peptic **ulcer** is a sore that forms in the duodenum (duodenal ulcer) or the lining of the stomach (gastric ulcer) (see **Figure 3.21**).

It was once assumed that stress was a major factor in the development of peptic ulcer disease, particularly in people with "intense" personalities. Diet also was thought to be important, with spicy foods often cast as a major villain. But much to the amazement of most of the medical community, research over the last 10 years has confirmed that the vast majority of ulcers are actually caused by infection with a bacterium, *Helicobacter pylori* (see **Figure 3.22**). Excessive use of nonsteroidal anti-inflammatory drugs (NSAIDs), such as aspirin, ibuprofen, and naproxen sodium, also is a common cause of ulcers.

H. pylori causes 80 percent of gastric ulcers and more than 90 percent of duodenal ulcers. These bacteria weaken the protective mucous coating, allowing acid to penetrate to the sensitive lining beneath. Both the acid and the bacteria irritate the lining and cause a sore, or ulcer. *H. pylori* can survive in stomach acid because it secretes enzymes that neutralize the acid. This mechanism enables *H. pylori* to make its way to the "safe" area—the protective mucous lining. Once there, the bacterium's spiral shape helps it burrow through the mucous lining.[23] NSAIDs cause ulcers by interfering with the GI tract's ability to protect itself from acidic stomach juices. Normally, the stomach and duodenum employ three defenses against digestive juices: mucus that coats the lining and shields it from stomach acid; the chemical bicarbonate, which neutralizes acid; and blood circulation, which aids in cell renewal and repair. NSAIDs hinder all these protective mechanisms. With the defenses down, digestive juices can cause ulcers by damaging the sensitive lining of the stomach and duodenum. Fortunately, NSAID-induced ulcers usually heal once the person stops taking the medication.

If you had ulcers in the 1950s, you would have been told to quit your high-stress job and switch to a bland diet. Today, ulcer sufferers are usually treated with an antimicrobial regimen aimed at eradicating *H. pylori*.[24] Although personality and life stress are no longer considered significant factors in the development of most ulcers, relapse after treatment is more common in people who are emotionally stressed or suffering from depression.

Quick Bite

Flatulence Facts

Researchers studying pilots and astronauts during the 1960s made some interesting discoveries. The average person inadvertently swallows air with food and drink and subsequently expels approximately 1 pint of gas per day, composed of 50 percent nitrogen. Another 40 percent is composed of carbon dioxide and the products of aerobic bacteria in the intestine.

Dyspepsia

Dyspepsia, also known as upset stomach or indigestion, refers to a condition of impaired digestion. Dyspepsia can be divided into two categories: organic and functional dyspepsia (FD). Organic causes of dyspepsia include peptic ulcer, gastroesophageal reflux disease, gastric or esophageal cancer, pancreatic or biliary disorders, intolerance to food or drugs, and other infectious or systemic diseases.[25] Underlying causes of FD include delayed gastric emptying and impaired gastric accommodation to a meal, while genetic predisposition, infection from *H. pylori* or other organisms, inflammation, and psychosocial factors also play a role.[26]

dyspepsia A condition also known as upset stomach or indigestion; refers to difficulty with digestion.

The treatment of functional dyspepsia includes drugs that speed up the transit of food through the upper part of the intestinal tract, agents that decrease stomach acid production, and antibiotics. Just as with IBS, stress reduction techniques such as meditation and biofeedback can often improve the symptoms of functional dyspepsia.

Key Concepts GI disorders generally produce uncomfortable symptoms such as abdominal pain, gas, bloating, and change in elimination patterns. Some GI disorders, such as diarrhea, are generally symptoms of some other illness. Although medications are useful in reducing symptoms, many GI disorders are treatable with changes in diet, especially getting adequate fiber and fluids in the diet.

As shown, the gastrointestinal tract is the key to turning food and its nutrients into nourishment for our bodies. **Figure 3.23** shows the sites for digestion and absorption of the macronutrients using a piece of pizza as an example of a food that contains substantial amounts of carbohydrate, fat, and protein. A healthy GI tract is an important factor in our overall health and well-being.

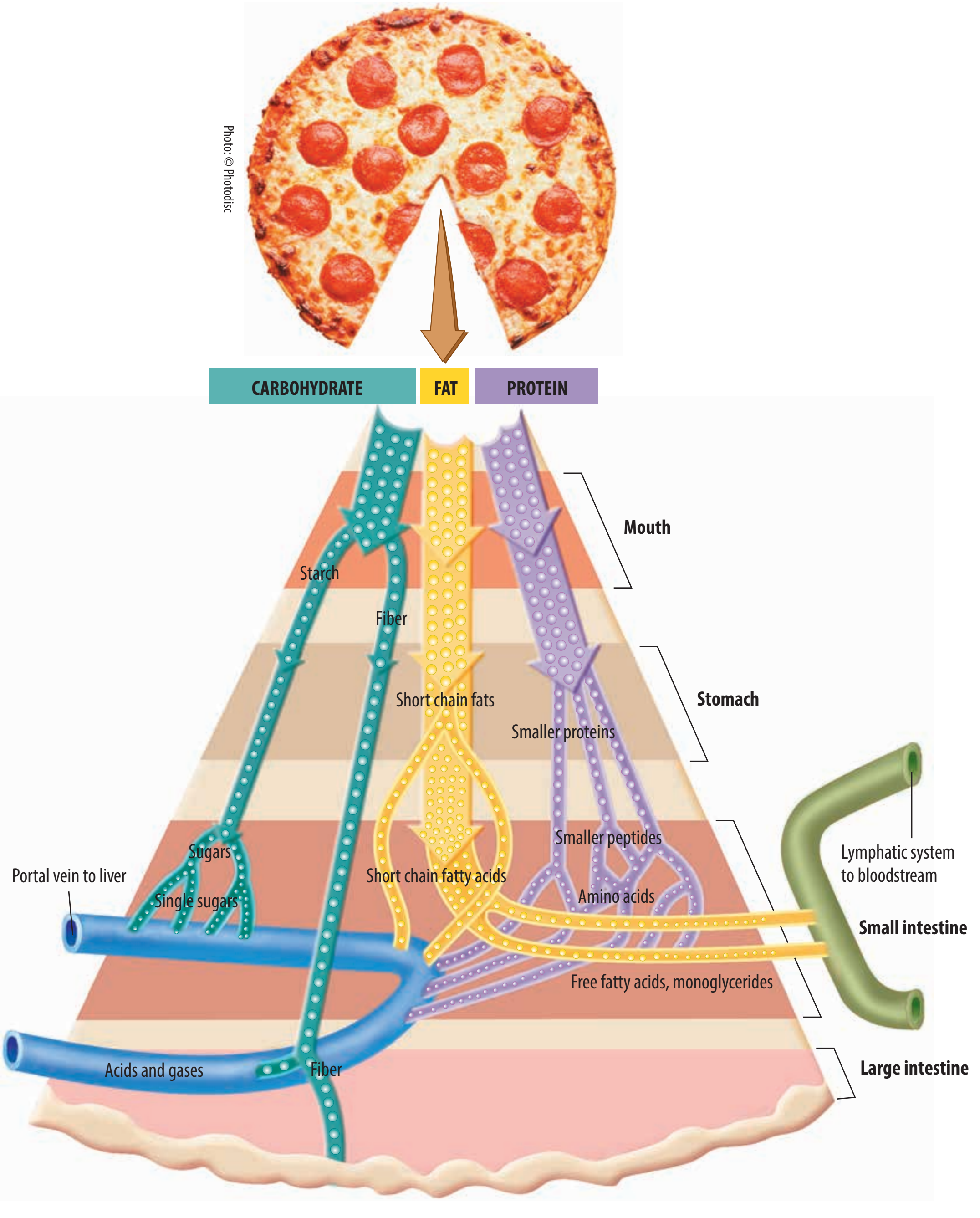


Figure 3.23 **Fate of a piece of pizza.** When you eat a piece of pizza, what happens to the carbohydrate, fat, and protein?

- *Carbohydrate.* Enzymes in the mouth begin the breakdown of starch. Stomach acid halts carbohydrate digestion. In the small intestine, enzymes break down carbohydrate, which is absorbed into the blood. In the large intestine, bacteria digest small amounts of fiber. The remainder is eliminated in feces.
- *Fat.* The stomach absorbs a few short-chain fatty acids into the blood. But most fat is broken down and absorbed in the small intestine, where it enters the lymphatic system.
- *Protein.* Stomach acid unfolds proteins, and enzymes begin protein breakdown. The small intestine completes the breakdown to amino acids, which enter the blood.

Learning Portfolio

Key Terms

Study Points

- The GI tract is a tube that can be divided into regions: the mouth, esophagus, stomach, small intestine, large intestine, and rectum.
- Digestion and absorption of the nutrients in foods occur at various sites along the GI tract.
- Digestion involves both physical processes (e.g., chewing, peristalsis, segmentation) and chemical processes (e.g., the hydrolytic action of enzymes).
- Absorption is the movement of molecules across the lining of the GI tract and into circulation.
- Four mechanisms are involved in nutrient absorption: passive diffusion, facilitated diffusion, active transport, and endocytosis.
- In the mouth, food is mixed with saliva for lubrication. Salivary amylase begins the digestion of starch.
- Secretions from the stomach lower the pH of stomach contents and begin the digestion of proteins.
- The pancreas and gallbladder secrete material into the small intestine to help with digestion.
- Most chemical digestion and nutrient absorption occur in the small intestine.
- Electrolytes and water are absorbed from the large intestine. Remaining material, waste, is excreted as feces.
- Both the nervous system and the hormonal system regulate GI tract processes.
- Numerous factors affect GI tract functioning, including psychological, chemical, and bacterial factors.
- Problems that occur along the GI tract can affect digestion and absorption of nutrients.
- Dietary changes are important in the treatment of GI disorders.

Study Questions

1. The contents of which organ has the lowest pH? Which organ produces an alkaline or basic solution to buffer this low pH?
2. Where in the GI tract does the majority of nutrient digestion and absorption take place?
3. Describe the path food follows as it travels through the digestive system. Summarize the muscular actions that take place along the way.
4. Name three "assisting" organs that are not part of the GI tract but that are needed for proper digestion. What are their roles in digestion?
5. List the four major hormones involved in regulating digestion and absorption. What are their roles?
6. What is gastroesophageal reflux disease?

Try This

The Saltine Cracker Experiment

This experiment will help you understand the effect of salivary amylase. Remember, salivary amylase is the starch-digesting enzyme produced by the salivary glands. Chew two saltine crackers until a watery texture forms in your mouth. You have to fight the urge to swallow so you can pay attention to the taste of the crackers. Do you notice a change in the taste?

The crackers first taste salty and "starchy," but as amylase is secreted it begins to break the chains of starch into sugar. As it does this, the saltines begin to taste sweet like animal crackers!

What About Bobbie?

Because both fluid and fiber are important for a healthy gastrointestinal tract, let's check out Bobbie's intake of these. Here is a typical day of eating for Bobbie:

Sample one-day menu from Bobbie's diet

7:45 A.M.
1 raisin bagel, toasted
  3 tablespoons light cream cheese
10 fluid ounces regular coffee
  2 packets of sugar
  2 tablespoons of 2% milk

10:15 A.M.
1 banana

12:15 P.M.
Turkey and cheese sandwich
  2 slices sourdough bread
  2 ounces sliced turkey lunch meat
  2 teaspoons regular mayonnaise
  2 teaspoons mustard
  2 slices tomato
  2 slices dill pickle
  shredded lettuce
Salad from cafeteria salad bar
  2 cups shredded iceberg lettuce
  2 tablespoons each:
    shredded carrot
    chopped egg
    croutons
    kidney beans
    Italian salad dressing
12 fluid ounces diet soda
1 small chocolate chip cookie

3:30 P.M.
16 fluid ounces water
1½ ounces regular tortilla chips
½ cup salsa

6:00 P.M.
Spaghetti with meatballs
  1½ cups pasta
  3 ounces ground beef (meatballs)
  3 ounces spaghetti sauce
  2 tablespoons Parmesan cheese
1 piece garlic bread
½ cup green beans
  1 teaspoon butter
12 fluid ounces diet soda

10:15 P.M.
1 slice cheese pizza

How do you think Bobbie did in terms of fiber? She did pretty well! At 25 grams of fiber, she's right at the Adequate Intake (AI) for fiber for women for her age—25 grams per day. Here are her best fiber sources:

Food	Fiber (grams)
Spaghetti (pasta)	3.5
Tortilla chips	3
Banana	3
Salsa	2
Sourdough bread	2

Are you surprised by the tortilla chips and the amount of fiber they add? Don't misinterpret this to mean that tortilla chips are a great source of fiber. There are two reasons why the chips rank so high. First, the other grain choices were not whole wheat and therefore didn't contribute a lot of fiber. Second, her afternoon snack consisted of just over 200 calories of tortilla chips. What could Bobbie have done differently if she wanted to keep her fiber intake high, but reduce calories and fat by avoiding the tortilla chips? Here are a few small changes that she could make:

- By choosing a whole-wheat bagel, she'd add 4 grams of fiber.
- By having her sandwich on whole-wheat bread, she'd add at least 3 grams of fiber.
- By substituting the 2 tablespoons of croutons with 2 more tablespoons of kidney beans, she'd add 1.5 grams of fiber.
- If she ate another piece of fruit as a snack sometime in her day, it would add 1 to 3 grams of fiber.

Now let's look at Bobbie's fluid intake. Remember, when you increase your fiber, it is critical to increase your fluid intake so you don't become constipated. How do you think she did? Her total fluid intake is 50 ounces

(1,500 milliliters). Her food also contains fluids and contributes another 1,000 milliliters. The AI for total fluid intake for adult women is 2,700 milliliters per day. If Bobbie's intake is assumed to be about 2,500 milliliters, this is close to the AI. She could add another beverage with one or both of her snacks and be right on target. She also could improve her fluid choices because most contain caffeine, which is a mild diuretic.

What suggestions do you have that will improve Bobbie's fluid intake? Any of the following would work:

- Carry a water bottle to sip throughout the day.
- Wash down the morning banana snack with a cup or two of water.
- Consider decaffeinated coffee or decaffeinated soda.
- Drink more water with the tortilla chips in the afternoon.
- Add a fluid to dinner.
- Drink water with the piece of pizza at night.

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