CHAPTER 3

Complementary Nutrition

Functional Foods and Dietary Supplements

THINK About It

1. When choosing food, what consideration do you give to health benefits beyond basic nutrition?
2. What are your feelings about the safety of high doses of nutrient supplements?
3. Would you ask your physician before taking an herbal supplement?
4. If a friend told you about a new herbal extract that is guaranteed to tone muscles, would you try it?

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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.

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.

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. 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.

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. It is flavor that 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

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.

is the well-known flavor of coffee.

Many nutritionists have suggested that fat has no taste and that its appeal is due solely to its texture. However, this may not be the case. Animal studies have found a taste receptor for fat, and 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**.[2] 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; but eating continues the stimulation of the salivary and gastric cells.

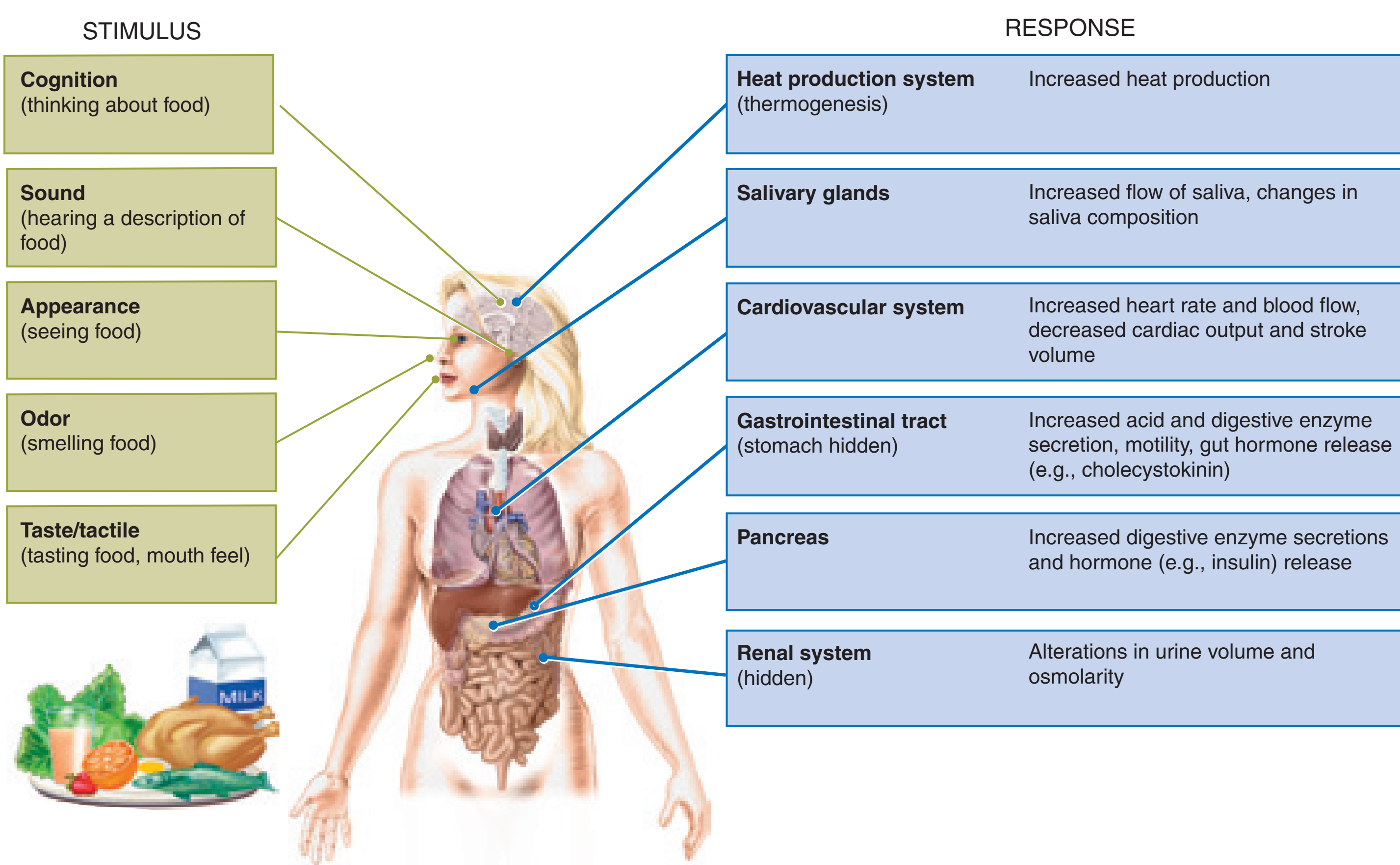
cephalic phase responses The responses of the parasympathetic nervous system to the sight, smell, thought, taste, and sound of food. Also called preabsorptive phase responses.

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

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



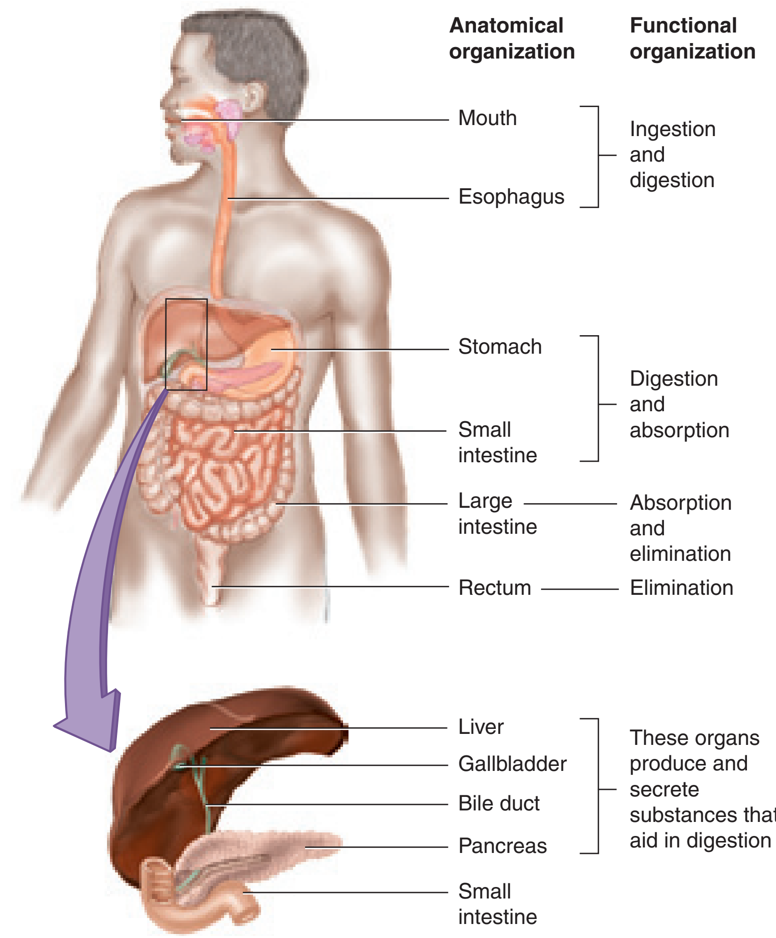


Figure 3.2 **Anatomic and functional organization of the GI tract.** Although digestion begins in the mouth, most digestion occurs in the stomach and small intestine. Absorption primarily takes place in the small and large intestines. For a detailed description of the GI tract and assisting organs, see Appendix E.

Dietary Guidelines for Americans, 2009
Key Recommendations

- To avoid microbial foodborne illness:
  - Clean hands, food contact surfaces, and fruits and vegetables. Meat and poultry should not be washed or rinsed.
  - Separate raw, cooked, and ready-to-eat foods while shopping, preparing, or storing foods.
  - Cook foods to a safe temperature to kill microorganisms.
  - Chill (refrigerate) perishable food promptly and defrost foods properly.
  - Avoid raw (unpasteurized) milk or any products made from unpasteurized milk, raw or partially cooked eggs or foods containing raw eggs, raw or undercooked meat and poultry, unpasteurized juices, and raw sprouts.

Key Recommendations for Specific Population Groups

- *Infants and young children, pregnant women, older adults, and those who are immunocompromised.* Do not eat or drink raw (unpasteurized) milk or any products made from unpasteurized milk, raw or partially cooked eggs or foods containing raw eggs, raw or undercooked meat and poultry, raw or undercooked fish or shellfish, unpasteurized juices, and raw sprouts.
- *Pregnant women, older adults, and those who are immunocompromised:* Only eat certain deli meats and frankfurters that have been reheated to steaming hot.

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 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 will help you see just how amazing this organ system is.

THINK About It 1

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 transport, storage, and **excretion** of waste products

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 that 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.*

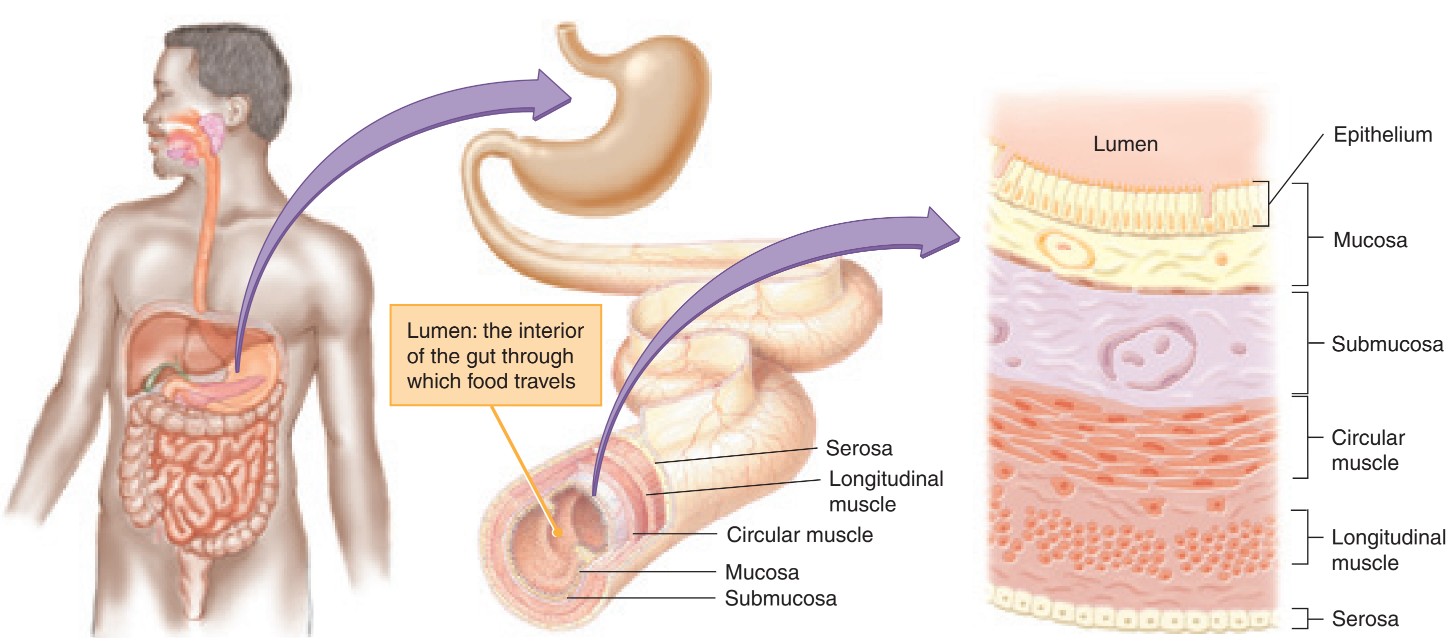
gastrointestinal (GI) tract [GAS-troh-in-TES-tin-al] The connected series of organs and structures used for digestion of food and absorption of nutrients; also called the alimentary canal or the digestive tract. The GI tract contains the mouth, esophagus, stomach, small intestine, large intestine (colon),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

excretion The process of separating and eliminating waste products of metabolism and undigested food from the body.

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.

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.



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.

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.

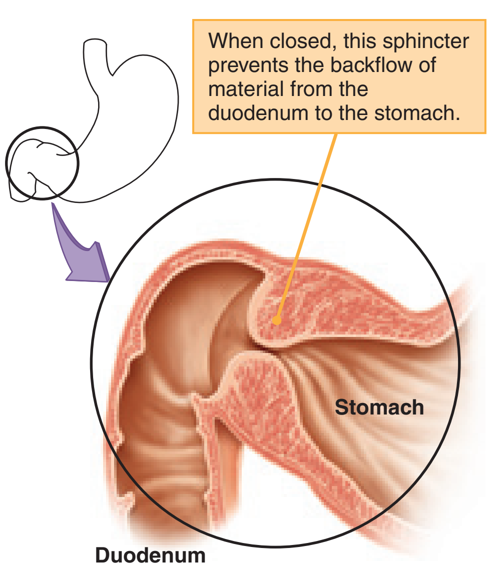


Figure 3.4 **Sphincters in action.** Movement from one section of the GI tract to the next is controlled by muscular valves called sphincters.

Overview of Digestion: Physical and Chemical Processes

The breakdown of food into smaller units and finally into absorbable nutrients involves both chemical and physical processes. First, there is the physical breaking of food into smaller pieces, such as 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 tract. Enzymes, along with other chemicals, help complete the breakdown process and promote absorption.

The Physical Movement and Breaking Up of Food

Distinct muscular actions of the GI tract take the food on its long 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).

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.

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 sucrose is sucrase.

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 71/2 quarts) per day.[3] **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.*

Overview of Absorption

Food is broken apart during digestion and 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. At this point, we need to outline how nutrients are moved from the interior, or **lumen**, of the gut through the lining cells (mucosa) and into circulation.

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**). Let's take a look at each one in turn.

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

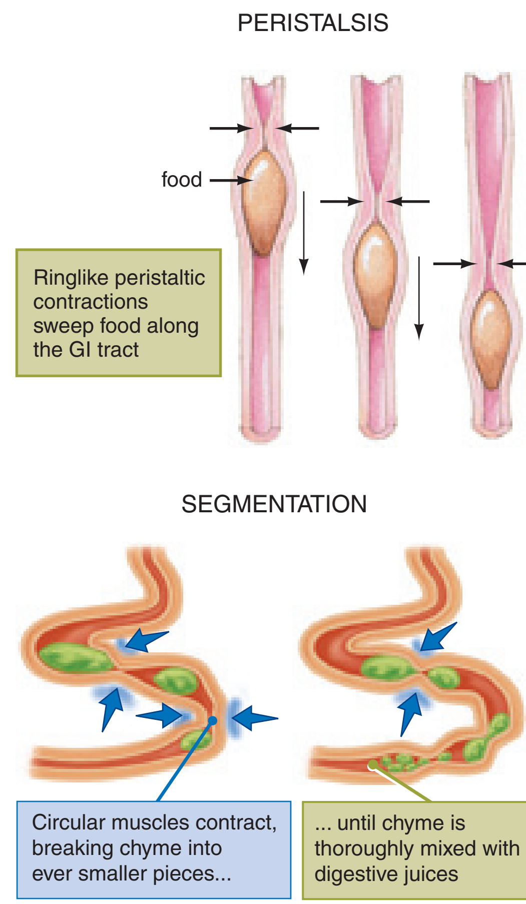


Figure 3.5 **Peristalsis and segmentation.** Peristalsis and segmentation help break up, mix, and move food through the GI tract.

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.

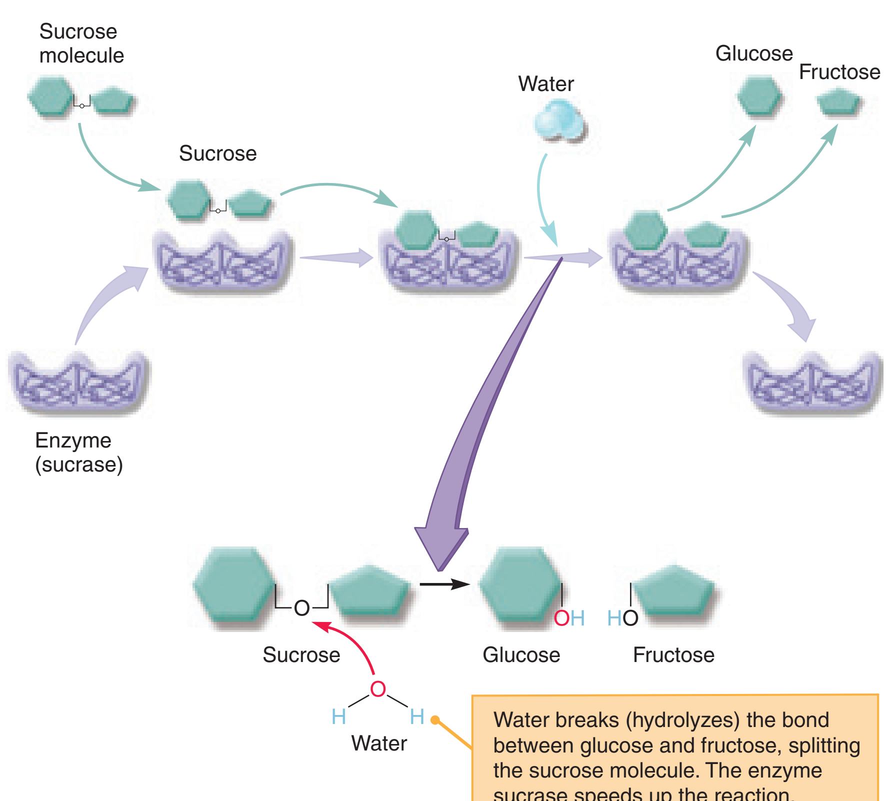


Figure 3.6 **Water and enzymes in chemical reactions.** Enzymes speed up (catalyze) chemical reactions. When water breaks a chemical bond, the action is called hydrolysis.

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: Klein S, Cohn SM, Alpers DH. Alimentary tract in nutrition. In: Shils ME, Shike M, Ross AC, Cabellero B, Cousins RJ, eds. Modern Nutrition in Health and Disease. 10th ed. Philadelphia: Lippincott Williams & Wilkins, 2006:1115–1142.

Since 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 via passive diffusion. They need help to cross into the intestinal cells. This help comes in the form of a carrier, and may also require energy.

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**. This occurs, for example, when a newborn infant absorbs antibodies from breast milk.[4] 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 to transport a substance (e.g., glucose or 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).*

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.

concentration gradients Differences between the solute concentrations of two substances.

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

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 a 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.

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 valvelike flap of tissue that closes off your air passages so you don't choke. The bolus then moves rapidly through the **esophagus** to the stomach, where it will be digested further. **Figure 3.10** shows the process of swallowing.

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."

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.

Going Green

Are you familiar with the terms *eco-friendly, carbon footprint, greenhouse gases, global climate* and *global warming*? These recently coined phrases reflect new perspectives on our interrelated world, signaling our recent awareness of an environment in trouble. Our continuing abuse of our environment has resulted in a global climatic backlash with widespread disruptions threatening irreversible damage to our planet. The result would be a planet inhospitable and far less livable to a way of life we have taken for granted for much too long. Some green protesters are taking action: To stop Brazilian planters from destroying more rainforest to cultivate their soy plantations some soya traders refuse to sell soy from deforested areas of the Amazon.

In this revision of Nutrition we will focus on our nutrition environment. In each chapter you will see a brief box called "**Going Green**," which will relate the environmental concern to the chapter's topic. Here are several examples of the new green technology. Only three kinds of plants supply 65% of the global food supply. You might be surprised to learn that they are rice, wheat and corn. With amazing efficiency farmers can turn plant products into animal protein with aquaculture, a fancy word for fish farming, which has realized the fastest growth of global food production and now accounts for more than 30% of fish consumption in the world. Again, while modern agricultural methods depend heavily on fertilizers, pesticides, and herbicides, newer ecologically friendly farming technologies are increasingly used to lower cost and preserve the quality of soils. And although surrounded by controversy, genetically modified crops and foods are used to resist pests and increase yields and are finding a niche in our nutrition environment.

Are you taking part in the green revolution? What are your environmental concerns?

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

- Hydrochloric acid makes the stomach contents extremely acidic, dropping the pH to 2, compared with a neutral pH of 7. (See

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 due to 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 far 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 may 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.

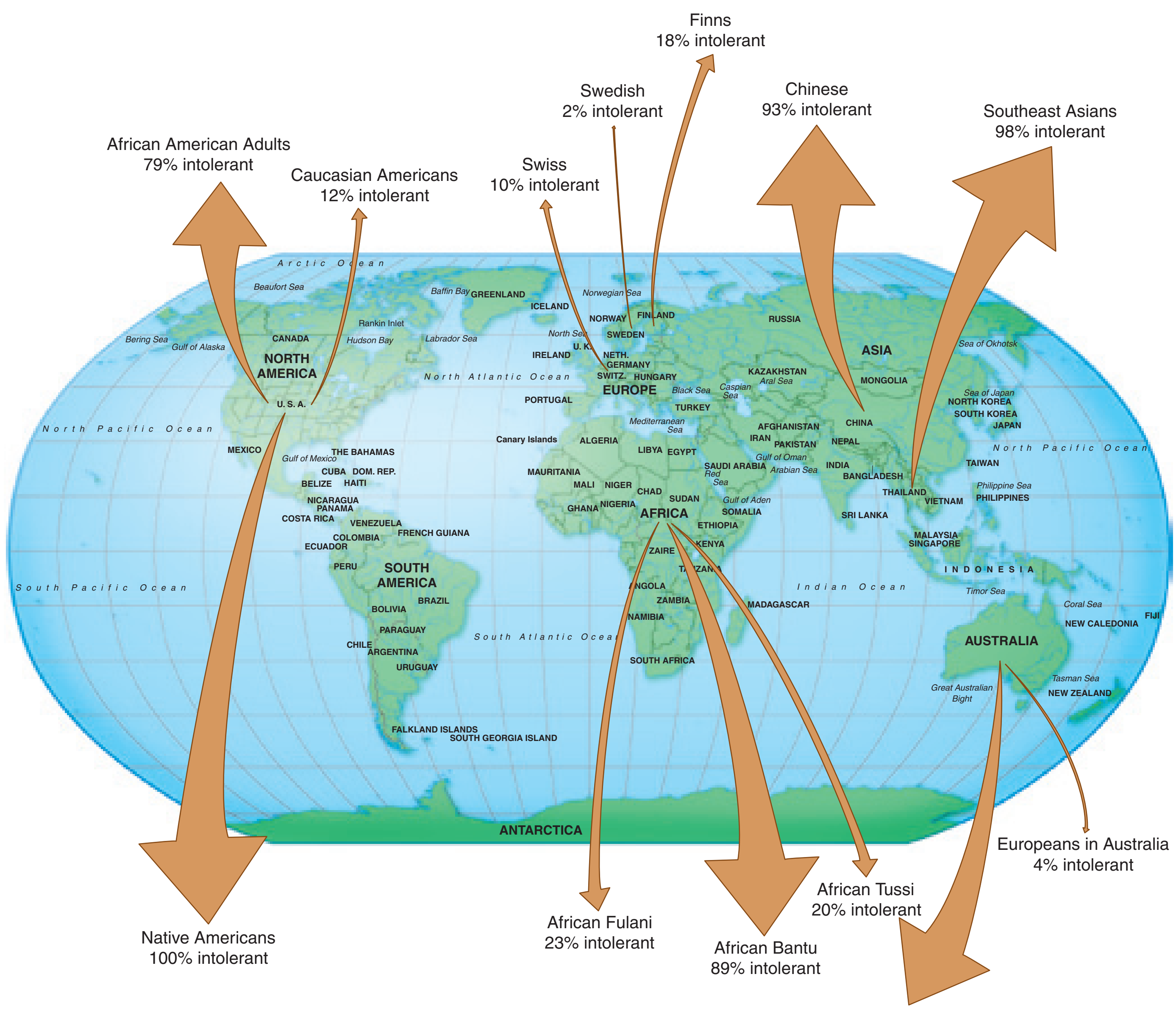
With the exception of the few individuals who are sensitive to even very small amounts of lactose, avoiding all lactose is neither necessary nor recommended because some lactase is still being produced. Lactose maldigesters need to determine the amount of lactose they can comfortably consume at any one 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., 1/2 cup). Gradually increase the serving size until symptoms begin to appear, 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 may be tolerated better than low-fat milk, and chocolate milk may be tolerated better than unflavored milk. Many cheeses (e.g., Cheddar, Swiss, Parmesan) contain considerably less lactose than does milk. Aged cheeses generally have negligible amounts of lactose. Yogurts with live, active cultures are another option; these bacteria will digest lactose. Sweet acidophilus milk, yogurt milk, and other nonfermented dairy foods may be tolerated better than regular milk by lactose maldi-gesters. However, factors such as the strain of bacteria used may 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.

Figure 3.11.) This acidic environment kills many pathogenic (disease-causing) bacteria that may 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;

Distribution of lactose intolerance worldwide.



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

American Heart Association

High-Protein Diets

The American Heart Association doesn't recommend high-protein diets for weight loss. Some of these diets restrict healthful foods that provide essential nutrients and don't provide the variety of foods needed to adequately meet nutritional needs. People who stay on these diets very long may not get enough vitamins and minerals and face other potential health risks.

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.
- 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 B12 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 B12 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.[5] The stomach slowly releases the chyme through the pyloric sphincter and into the small intestine. The pyloric sphincter then closes to prevent the chyme from returning to the stomach (see **Figure 3.12**).

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? You'll learn later in this textbook (in the Carbohydrates chapter) that a healthy intake of fiber may 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:

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

This means if you make a sandwich with 2 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

Nutrition Facts

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

Calories 100
Calories from Fat 15

Amount Per Serving	% Daily Value*
Total Fat 2g	**3%**
Saturated Fat 0g	**0%**
Trans Fat 0g	
Cholesterol 0mg	**0 %**

Amount Per Serving	% Daily Value*
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	2,400mg	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).

Nutrition Science *in Action*

NEAT Energy

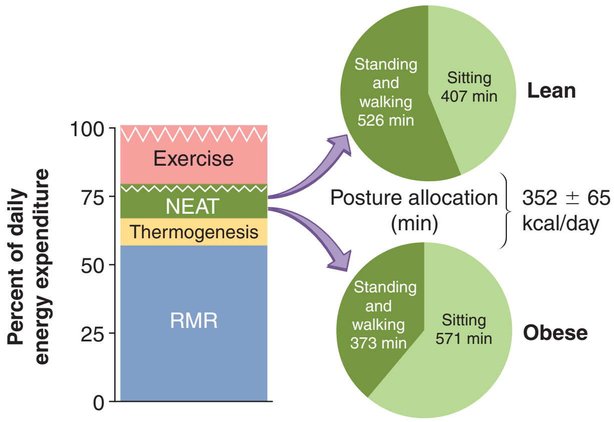
Background: Nonexercise activity thermogenesis (NEAT) is a component of total energy expenditure and includes energy expended in daily activities such as sitting, standing, fidgeting, walking, and talking. To investigate NEAT, investigators have developed and validated a sensitive and reliable technology for measuring body position and motion 120 times per minute.

Hypothesis: Obese people expend less energy for NEAT than lean people.

Experimental Plan: Recruit 20 healthy volunteers who are self-proclaimed "couch potatoes." Ten participants are lean, and 10 are mildly obese with no complications of obesity. Monitor their total NEAT expenditure for 10 days as they continue their usual daily activities and occupations.

Results: The hypothesis is confirmed. Obese participants remained seated for about 2.5 hours per day longer than lean participants, for an average energy savings of 352 kcal/day.

Conclusion and Discussion: Weight gain is a dynamic process that results from a long-term sustained imbalance between energy intake and energy expenditure. The "energy gap" required to explain the increased prevalence of obesity is only 100 to 200 kcal/day—less than the observed differences in NEAT between lean and obese people. Obesity might be prevented by simply increasing NEAT expenditures—limiting sedentary activities or increasing active behaviors such as standing, walking, and fidgeting. The underlying mechanisms for an individual's propensity to fidget are unknown and may be investigated by additional studies.



Source: Based on Levine JA, Lanningham-Foster LM, McCrady SK, et al. Interindividual variation in posture allocation: possible role in human obesity. Science. 2005;307:584–586. Photo used with permission from AAAS.

Table 3.1 **Amount of Energy Expended in Specific Activities**

			kcal/h at Different Body Weights				
Description	*kcal/h/kg*	*kcal/h/lb*	*50 kg 110 lb*	*57 kg 125 lb*	*68 kg 150 lb*	*80 kg 175 lb*	*91 kg 200 lb*
Aerobics							
Light	3.0	1.36	150	170	205	239	273
Moderate	5.0	2.27	250	284	341	398	455
Heavy	8.0	3.64	400	455	545	636	727
Bicycling							
Leisurely <10 mph	4.0	1.82	200	227	273	318	364
Light 10–11.9 mph	6.0	2.73	300	341	409	477	545
Moderate 12–13.9 mph	8.0	3.64	400	455	545	636	727
Fast 14–15.9 mph	10.0	4.55	500	568	682	795	909
Racing 16–19 mph	12.0	5.45	600	682	818	955	1091
BMX or mountain	8.5	3.86	425	483	580	676	773
Daily Activities							
Sleeping	1.2	0.55	60	68	82	95	109
Studying, reading, writing	1.8	0.82	90	102	123	143	164
Cooking, food preparation	2.5	1.14	125	142	170	199	227
Home Activities							
House painting, outside	4.0	1.82	200	227	273	318	364
General gardening	5.0	2.27	250	284	341	398	455
Shoveling snow	6.0	2.73	300	341	409	477	545
Running							
Jogging	7.0	3.18	350	398	477	557	636
Running 5 mph	8.0	3.64	400	455	545	636	727
Running 6 mph	10.0	4.55	500	568	682	795	909
Running 7 mph	11.5	5.23	575	653	784	915	1045
Running 8 mph	13.5	6.14	675	767	920	1074	1227
Running 9 mph	15.0	6.82	750	852	1023	1193	1364
Running 10 mph	16.0	7.27	800	909	1091	1273	1455
Sports							
Frisbee, ultimate	3.5	1.59	175	199	239	278	318
Hacky sack	4.0	1.82	200	227	273	318	364
Wind surfing	4.2	1.91	210	239	286	334	382
Golf	4.5	2.05	225	256	307	358	409
Skateboarding	5.0	2.27	250	284	341	398	455
Rollerblading	7.0	3.18	350	398	477	557	636
Soccer	7.0	3.18	350	398	477	557	636
Field hockey	8.0	3.64	400	455	545	636	727
Swimming, slow to moderate laps	8.0	3.64	400	455	545	636	727
Skiing downhill, moderate effort	6.0	2.73	300	341	409	477	545
Skiing cross country, moderate effort	8.0	3.64	400	455	545	636	727
Tennis, doubles	6.0	2.73	300	341	409	477	545
Tennis, singles	8.0	3.64	400	455	545	636	727
Walking							
Strolling <2 mph, level	2.0	0.91	100	114	136	159	182
Moderate pace ~3 mph, level	3.5	1.59	175	199	239	278	318
Moderate pace ~3 mph, uphill	6.0	2.73	300	341	409	477	545
Brisk pace ~3.5 mph, level	4.0	1.82	200	227	273	318	364
Very brisk pace ~4.5 mph, level	4.5	2.05	225	256	307	358	409

Source: Adapted from Nieman DC. Exercise Testing and Prescription. 4th ed. Mountain View, CA: Mayfield Publishing, 1999.

Learning Portfolio

Key Terms

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acrolein	131
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autonomic nervous system	127
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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, and 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. What is the purpose of mucus in the GI tract? What would happen if it didn't line the stomach?
3. Where in the GI tract does the majority of nutrient digestion and absorption take place?
4. List the organs (in order) that make up the GI tract.
5. Name three "assisting" organs that are not part of the GI tract but are needed for proper digestion. What are their roles in digestion?
6. List the four major hormones involved in regulating digestion and absorption. What are their roles?
7. 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. Refresh yourself with her day of eating by reviewing page XX.

How do you think Bobbie did in terms of fiber? She did pretty well! At 19 grams of fiber, she's just below the recommended range of 20 to 35 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. Here's a list of Bobbie's drinks:

Breakfast—10 ounces coffee
Snack—none
Lunch—12 ounces diet soda

Snack—16 ounces water
Dinner—12 ounces diet soda
Snack—none

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, since 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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