Chapter 4

Carbohydrates: Simple Sugars and Complex Chains

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THINK About It

1 When you think of the word *carbohydrate*, what foods come to mind?

2 Fiber is an important part of a healthy diet—are you eating enough?

3 Is honey more nutritious than white sugar? What do you think?

4 What are the downsides to including too many carbohydrates in your diet?

LEARNING Objectives

1 Differentiate among disaccharides, oligosaccharides, and polysaccharides.

2 Explain how a carbohydrate is digested and absorbed in the body.

3 Explain the functions of carbohydrates in the body.

4 Make healthy carbohydrate selections for an optimal diet.

5 Analyze the contributions of carbohydrates to health.

Quick Bite

Is Pasta a Chinese Food?

Noodles were used in China as early as the first century; Marco Polo did not bring them to Italy until the 1300s.

Does sugar cause diabetes? Will too much sugar make a child hyperactive? Does excess sugar contribute to criminal behavior? What about starch? Does it really make you fat? These and other questions have been raised about sugar and starch—dietary carbohydrates—over the years. But, where do these ideas come from? What is myth, and what is fact? Are carbohydrates important in the diet? Or, as some popular diets suggest, should we eat only small amounts of carbohydrates? What links, if any, are there between carbohydrates in your diet and health?

Most of the world's people depend on carbohydrate-rich plant foods for daily sustenance. In some countries, they supply 80 percent or more of daily calorie intake. Rice provides the bulk of the diet in Southeast Asia, as does corn in South America, cassava in certain parts of Africa, and wheat in Europe and North America. (See **Figure 4.1**.) Besides providing energy, foods rich in carbohydrates, such as whole grains, legumes, fruits, and vegetables, also are good sources of vitamins, minerals, dietary fiber, and phytochemicals that can help lower the risk of chronic diseases.

Generous carbohydrate intake from whole, minimally processed foods should provide the foundation for any healthful diet. Carbohydrates contain only 4 kilocalories per gram, compared with 9 kilocalories per gram from fat. Thus, a diet rich in carbohydrates can provide fewer calories and a greater volume of food than the typical fat-laden American diet. As you explore the topic of carbohydrates, think about some claims you have heard for and against eating a lot of carbohydrates. As you read this chapter, you will learn to distinguish between carbohydrates that are important as the basis of a healthy diet and those that add calories with little additional nutritional value.

What Are Carbohydrates?

Plants use carbon dioxide from the air, water from the soil, and energy from the sun to produce carbohydrates and oxygen through a process called photosynthesis. Carbohydrates are organic compounds that contain carbon (C),

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Figure 4.1 **Cassava, rice, wheat, and corn.** These carbohydrate-rich foods are dietary staples in many parts of the world.

hydrogen (H), and oxygen (O) in the ratio of two hydrogen atoms and one oxygen atom for every one carbon atom (CH_2O). Two or more sugar molecules can be assembled to form increasingly complex carbohydrates. The two main types of carbohydrates in food are simple carbohydrates (sugars) and complex carbohydrates (starches and fiber).

Simple Sugars

Simple carbohydrates are naturally present as simple sugars in fruits, milk, and other foods. Plant carbohydrates also can be refined to produce sugar products such as table sugar or corn syrup. The two main types of sugars are monosaccharides and disaccharides. **Monosaccharides** consist of a single sugar molecule (*mono* meaning "one" and *saccharide* meaning "sugar"). **Disaccharides** consist of two sugar molecules chemically joined together (*di* meaning "two"). Monosaccharides and disaccharides give various degrees of sweetness to foods.

simple carbohydrates Sugars composed of a single sugar molecule (a monosaccharide) or two joined sugar molecules (a disaccharide).

monosaccharides Any sugars that are not broken down further during digestion and have the general formula $C_nH_{2n}O_n$, where $n = 3$ to 7. The common monosaccharides glucose, fructose, and galactose all have six carbon atoms ($n = 6$).

disaccharides [dye-SACK-uh-rides] Carbohydrates composed of two monosaccharide units linked by a glycosidic bond. They include sucrose (common table sugar), lactose (milk sugar), and maltose.

Monosaccharides: The Single Sugars

The most common monosaccharides in the human diet are the following:

- Glucose
- Fructose
- Galactose

All three monosaccharides have six carbons, and all have the chemical formula $C_6H_{12}O_6$, but each has a different arrangement of these atoms. The carbon and oxygen atoms of glucose and galactose form a six-sided ring.

Glucose

The monosaccharide **glucose** is the most abundant simple carbohydrate unit in nature. Also referred to as dextrose, glucose plays a key role in both foods and the body. Glucose gives food a mildly sweet flavor. It doesn't usually exist as a monosaccharide in food but is instead joined to other sugars to form disaccharides, starch, or dietary fiber. Glucose makes up at least one of the two sugar molecules in every disaccharide.

In the body, glucose supplies energy to cells. The body closely regulates blood glucose (blood sugar) levels to ensure a constant fuel source for vital body functions. Glucose is virtually the only fuel used by the brain, except during prolonged starvation, when the glucose supply is low.

glucose [GLOO-kose] A common monosaccharide containing six carbons that is present in the blood; also known as dextrose or blood sugar. It is a component of the disaccharides sucrose, lactose, and maltose and various complex carbohydrates.

Fructose

Fruit sugar, **fructose**, tastes the sweetest of all the sugars and occurs naturally in fruits and vegetables. Although the sugar in honey is about half fructose and half glucose, fructose is the primary source of its sweet taste. Food manufacturers use high-fructose corn syrup as an additive to sweeten many foods, including soft drinks, fruit beverages, desserts, candies, jellies, and jams. The term *high fructose* is a little misleading—the fructose content of this sweetener is around 50 percent.

fructose [FROOK-tose] A common monosaccharide containing six carbons that is naturally present in honey and many fruits; often added to foods in the form of high-fructose corn syrup. Also called *levulose* or *fruit sugar*.

Galactose

Galactose rarely occurs as a monosaccharide in food. It usually is chemically bonded to glucose to form lactose, the primary sugar in milk and dairy products.

galactose [gah-LAK-tose] A monosaccharide containing six carbons that can be converted into glucose in the body. In foods and living systems, galactose usually is joined with other monosaccharides.

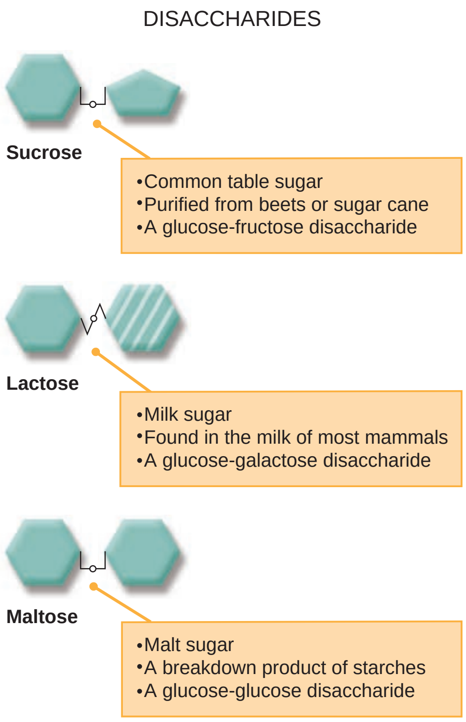


Figure 4.2 **The disaccharides: sucrose, lactose, and maltose.** The three monosaccharides pair up in different combinations to form the three disaccharides.

sucrose [SOO-crose] A disaccharide composed of one molecule of glucose and one molecule of fructose joined together. Also known as *table sugar*.

maltose [MALL-tose] A disaccharide composed of two glucose molecules; sometimes called *malt sugar*. Maltose seldom occurs naturally in foods but is formed whenever long molecules of starch break down.

lactose [LAK-tose] A disaccharide composed of glucose and galactose; also called *milk sugar* because it is the major sugar in milk and dairy products.

complex carbohydrates Chains of more than two monosaccharides. May be oligosaccharides or polysaccharides.

oligosaccharides Short carbohydrate chains composed of 3 to 10 sugar molecules.

Disaccharides: The Double Sugars

Disaccharides consist of two monosaccharides linked together. The following disaccharides (see **Figure 4.2**) are important in human nutrition:

- Sucrose (common table sugar)
- Lactose (major sugar in milk)
- Maltose (product of starch digestion)

Sucrose

Sucrose, most familiar to us as table sugar, is made up of one molecule of glucose and one molecule of fructose. Sucrose provides some of the natural sweetness of honey, maple syrup, fruits, and vegetables. Manufacturers use a refining process to extract sucrose from the juices of sugar cane or sugar beets. Full refining removes impurities; white sugar and powdered sugar are so highly refined that they are virtually 100 percent sucrose. When a food label lists sugar as an ingredient, the term refers to sucrose.

Lactose

Lactose, or milk sugar, is composed of one molecule of glucose and one molecule of galactose. Lactose gives milk and other dairy products a slightly sweet taste. Human milk has a higher concentration (approximately 7 grams per 100 milliliters) of lactose than cow's milk (approximately 4.5 grams per 100 milliliters), so human milk tastes sweeter than cow's milk.

Maltose

Maltose is composed of two glucose molecules. Maltose seldom occurs naturally in foods, but is formed whenever long molecules of starch break down. Human digestive enzymes in the mouth and small intestine break starch down into maltose. When you chew a slice of fresh bread, you may detect a slightly sweet taste as starch breaks down into maltose. Starch also breaks down into maltose in germinating seeds. Maltose is fermented in the production of beer.

Key Concepts Carbohydrates can be categorized as simple or complex. Simple carbohydrates include monosaccharides and disaccharides. The monosaccharides glucose, fructose, and galactose are single sugar molecules. The disaccharides sucrose, lactose, and maltose are double sugar molecules.

Complex Carbohydrates

Complex carbohydrates are chains of more than two sugar molecules. Short carbohydrate chains are called oligosaccharides and contain 3 to 10 sugar molecules. Long carbohydrate chains can contain hundreds or even thousands of monosaccharide units.

Oligosaccharides

Oligosaccharides (*oligo* meaning "scant") are short carbohydrate chains of 3 to 10 sugar molecules. Dried beans, peas, and lentils contain the two most common oligosaccharides—raffinose and stachyose.[1] Raffinose is formed from three monosaccharide molecules—one galactose, one glucose, and one fructose. Stachyose is formed from four monosaccharide molecules—two galactose, one glucose, and one fructose. The body cannot break down raffinose or stachyose, but they are readily broken down by intestinal bacteria and are responsible for the familiar gaseous effects of foods such as beans.

Human milk contains more than 200 different oligosaccharides, which vary according to the length of a woman's pregnancy, how long she has been nursing, and her genetic makeup.[2] For breastfed infants, oligosaccharides serve a function similar to dietary fiber in adults—making stools easier to pass. Some of these oligosaccharides also protect infants from disease-causing agents by binding to them in the intestines. Oligosaccharides in human milk also provide sialic acid, a compound essential for normal brain development.[3]

Polysaccharides

Polysaccharides (*poly* meaning "many") are long carbohydrate chains of monosaccharides. Some polysaccharides form straight chains whereas others branch off in all directions. Such structural differences affect how the polysaccharide behaves in water and with heating. The way the monosaccharides within them are linked makes the polysaccharides either digestible (e.g., starch) or indigestible (e.g., fiber).

Starch

Plants store energy as **starch** for use during growth and reproduction. Rich sources of starch include (1) grains, such as wheat, rice, corn, oats, millet, and barley; (2) legumes, such as peas, beans, and lentils; and (3) tubers, such as potatoes, yams, and cassava. Starch imparts a moist, gelatinous texture to food. For example, it makes the inside of a baked potato moist, thick, and almost sticky. The starch in flour absorbs moisture and thickens gravy.

Starch takes two main forms in plants: amylose and amylopectin. **Amylose** is made up of long, unbranched chains of glucose molecules, whereas **amylopectin** is made up of branched chains of glucose molecules. (See **Figure 4.3**.) Wheat flour contains a higher proportion of amylose, whereas cornstarch contains a higher proportion of amylopectin.

In the body, amylopectin is digested more rapidly than amylose.[4] Although the body easily digests most starches, a small portion of the starch in plants may remain enclosed in cell structures and escape digestion in the small intestine. Starch that is not digested is called **resistant starch**. Some legumes, such as white beans, contain large amounts of resistant starch. Resistant starch also is formed during the processing of starchy foods.

Glycogen

Living animals, including humans, store carbohydrate in the form of **glycogen**, also called animal starch. Although some organ meats, such as kidney, heart, and liver, contain small amounts of carbohydrate, meat from muscle contains none.[5] This is because after an animal is slaughtered, enzymes in the muscle tissue break down most glycogen within 24 hours. Since plant foods also do not contain glycogen, it is a negligible carbohydrate source in our diets. Glycogen does, however, play an important role in our bodies as a readily mobilized store of glucose.

Glycogen is composed of long, highly branched chains of glucose molecules. Its structure is similar to amylopectin, but glycogen is much more highly branched. When we need extra glucose, for example during exercise, the glycogen in our cells can be broken down rapidly into single glucose molecules. Because enzymes can attack only the ends of glycogen chains, the highly branched structure of glycogen multiplies the number of sites available for enzyme activity.

Most glycogen is stored in skeletal muscle and the liver. In muscle cells, glycogen provides a supply of glucose for its own cells involved in strenuous muscular activity. Liver cells also use glycogen to regulate blood glucose levels throughout the body. If necessary, liver glycogen can provide as much as 100 to 150 milligrams of glucose per minute to the blood at a sustained rate for up to 12 hours.[6,7] Normally, the body can store only about 200 to 500 grams of glycogen at a time.[8] Some athletes practice a carbohydrate-loading regimen,

polysaccharides Long carbohydrate chains composed of more than 10 sugar molecules. Polysaccharides can be straight or branched.

starch The major storage form of carbohydrate in plants; starch is composed of long chains of glucose molecules in a straight (amylose) or branching (amylopectin) arrangement.

amylose [AM-ih-los] A straight-chain polysaccharide composed of glucose units.

amylopectin [am-ih-low-PEK-tin] A branched-chain polysaccharide composed of glucose units.

resistant starch A starch that is not digested.

glycogen [GLY-ko-jen] A very large, highly branched polysaccharide composed of multiple glucose units. Sometimes called animal starch, glycogen is the primary storage form of glucose in animals.

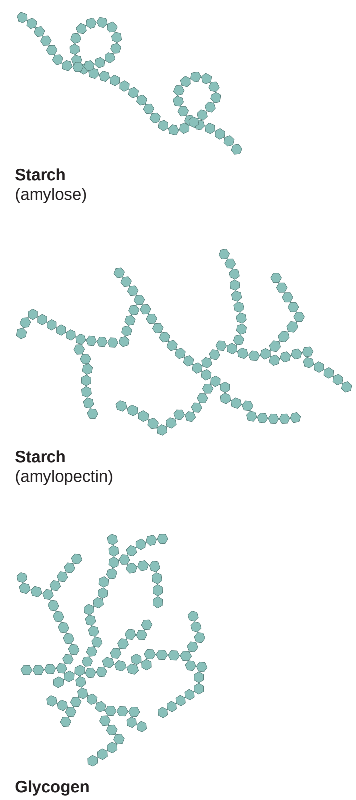


Figure 4.3 **Starch and glycogen.** Plants have two main types of starch—amylose, which has long unbranched chains of glucose, and amylopectin, which has branched chains. Animals store glucose in highly branched chains called glycogen.

which increases the amount of stored glycogen by 20 to 40 percent above normal, providing a competitive edge for marathon running and other endurance events.[9,10]

Fiber

All types of plant foods—including fruits, vegetables, legumes, and whole grains—contain dietary fiber. Animal sources of food, such as beef, pork, chicken and eggs, do not contain fiber. **Dietary fiber** consists of indigestible carbohydrates (such as cellulose, or soluble and insoluble fiber) and lignins that are intact and intrinsic in plants. Although not digested by the human gastrointestinal system and used as an energy source, these indigestible carbohydrates can enhance the process of digestion and provide other health benefits. **Functional fiber** refers to isolated, indigestible carbohydrates that have beneficial physiological effects in humans. Examples of functional fiber include extracted plant pectins, gums and resistant starches, chitin and chitosan, and commercially produced nondigestible polysaccharides. **Total fiber** is the sum of dietary fiber and functional fiber. Many types of dietary fiber resemble starches—they are polysaccharides, but are not digested in the human GI tract. Examples of these nonstarch polysaccharides include cellulose, hemicellulose, pectins, gums, and beta-glucans (ß-glucans). Dried beans, peas, and lentils contain short-chain carbohydrates called oligosaccharides, which are also considered to be dietary fiber. Whole-grain foods such as brown rice, rolled oats, and whole-wheat breads and cereals; legumes such as kidney beans, garbanzo beans (chickpeas), peas, and lentils; fruits; and vegetables are all rich sources of dietary fiber (see **Table 4.1**).

dietary fiber Carbohydrates and lignins that are naturally in plants and are nondigestible; that is, they are not digested and absorbed in the human small intestine.

functional fiber Isolated nondigestible carbohydrates, including some manufactured carbohydrates, that have beneficial effects in humans.

total fiber The sum of dietary fiber and functional fiber.

Cellulose

In plants, **cellulose** makes the walls of cells strong and rigid. It forms the woody fibers that support tall trees. It also forms the brittle shafts of hay and straw and the stringy threads in celery. Cellulose is made up of long, straight chains of glucose molecules. (See **Figure 4.4**.) Grains, fruits, vegetables, and nuts all contain cellulose.

cellulose [SELL-you-los] A straight-chain polysaccharide composed of hundreds of glucose units linked by beta bonds. It is nondigestible by humans and a component of dietary fiber.

Hemicelluloses

The **hemicelluloses** are a diverse group of polysaccharides that vary from plant to plant. They are mixed with cellulose in plant cell walls.[11] Hemicelluloses

hemicelluloses [hem-ih-SELL-you-los-es] A group of large polysaccharides in dietary fiber that are fermented more easily than cellulose.

Table 4.1 Foods Rich in Dietary Fiber

Fruits		**Nuts and Seeds**	
Apples	Grapefruit	Almonds	Sesame seeds
Bananas	Mango	Peanuts	Sunflower seeds
Berries	Oranges	Pecans	Walnuts
Cherries	Pears	**Legumes**	
Cranberries		Most legumes	
Vegetables		**Grains**	
Asparagus	Green peppers	Brown rice	Wheat-bran cereals
Broccoli	Red cabbage	Oat bran	Wheat-bran breads
Brussels sprouts	Spinach	Oatmeal	
Carrots	Sprouts		

Source: Adapted from Shils ME, Shike M, Ross AC, Caballero B, Cousins RJ, eds. *Modern Nutrition in Health and Disease*. 11th ed. Philadelphia: Lippincott Williams & Wilkins, WoltersKluwer Health; 2013.

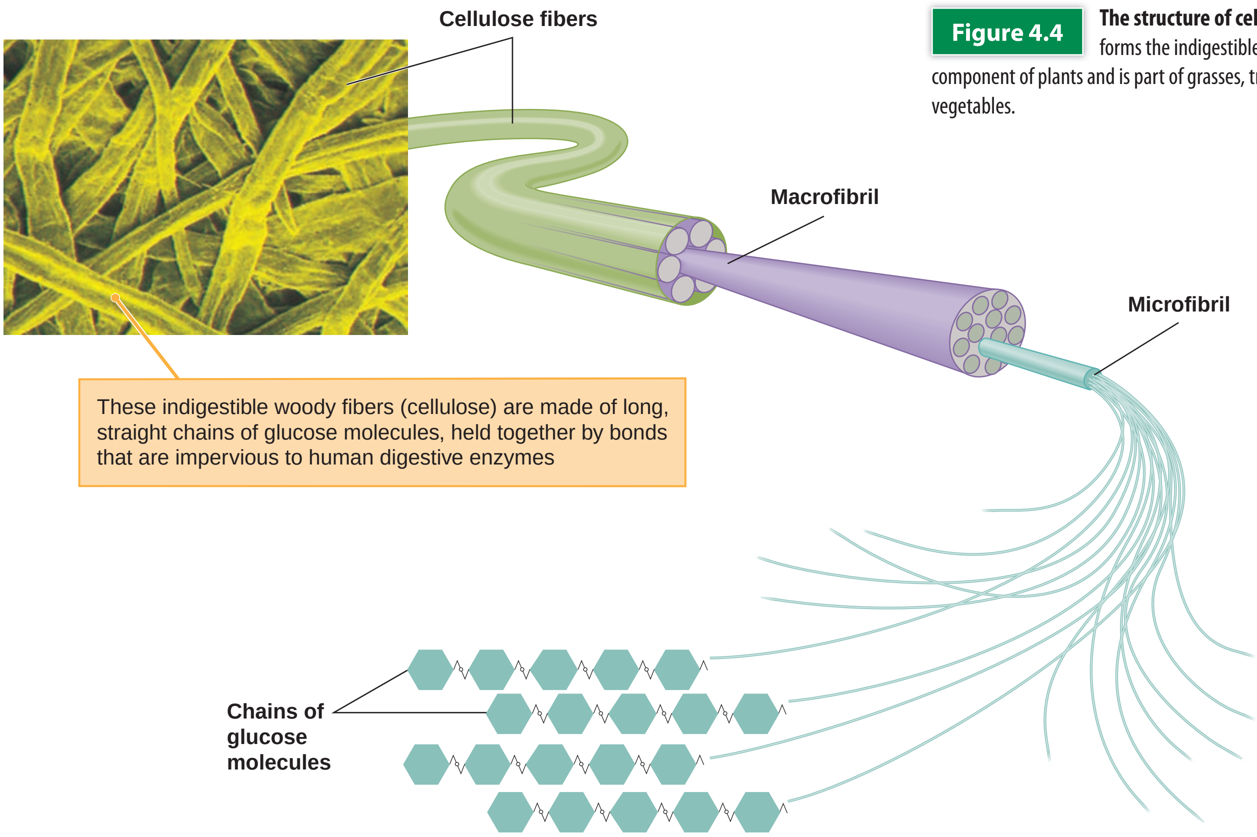


Figure 4.4 **The structure of cellulose.** Cellulose forms the indigestible, fibrous component of plants and is part of grasses, trees, fruits, and vegetables.

are composed of a variety of monosaccharides with many branching side chains. The outer bran layer on many cereal grains is rich in hemicelluloses, as are legumes, vegetables, and nuts.

Pectins

Found in all plants, but especially fruits, **pectins** are gel-forming polysaccharides. The pectin in fruits acts like a cement that gives body to fruits and helps them keep their shape. When fruit becomes overripe, pectin breaks down into monosaccharides and the fruit becomes mushy. When mixed with sugar and acid, pectin forms a gel used to add firmness to jellies, jams, sauces, and salad dressings.

pectins A type of dietary fiber found in fruits.

Gums and Mucilages

Like pectin, **gums** and **mucilages** are thick, gel-forming fibers that help hold plant cells together. The food industry uses plant gums (gum Arabic, guar gum, locust bean gum, and xanthan gum, for example) and mucilages (such as carrageenan) to thicken, stabilize, or add texture to foods such as salad dressings, puddings, pie fillings, candies, sauces, and even drinks. **Psyllium** (the husk of psyllium seeds) is a mucilage that becomes very viscous when mixed with water. It is the main component in the laxative Metamucil and is added to some breakfast cereals.

gums Dietary fibers, which contain galactose and other monosaccharides, found between plant cell walls.

mucilages Gelatinous soluble fibers containing galactose, mannose, and other monosaccharides; found in seaweed.

psyllium The dried husk of the psyllium seed.

Lignins

Not actually carbohydrates, **lignins** are indigestible substances that make up the woody parts of vegetables such as carrots and broccoli and the seeds of fruits such as strawberries.

lignins [LIG-nins] Insoluble fibers composed of multi-ring alcohol units that constitute the only noncarbohydrate component of dietary fiber.

beta-glucans Functional fiber, consisting of branched polysaccharide chains of glucose, that helps lower blood cholesterol levels. Found in barley and oats.

chitin A long-chain structural polysaccharide of slightly modified glucose. Found in the hard exterior skeletons of insects, crustaceans, and other invertebrates; also occurs in the cell walls of fungi.

chitosan Polysaccharide derived from chitin.

Beta-glucans

Beta-glucans are polysaccharides of branched glucose units. These fibers are found in large amounts in barley and oats. Beta-glucan fiber is especially effective in lowering blood cholesterol levels (see the "Carbohydrates and Health" section later in this chapter).

Chitin and Chitosan

Chitin and **chitosan** are polysaccharides found in the exoskeletons of crabs and lobsters, and in the cell walls of most fungi. Chitin and chitosan are primarily consumed in supplement form. Marketed as being useful for weight control, chitosan supplements may impair the absorption of fat-soluble vitamins and some minerals[12]; however, published research has identified concerns with using chitosan supplements, such as their interacting with vitamins and causing malabsorption issues.[13]

Key Concepts Complex carbohydrates include starch, glycogen, and fiber. Starch is composed of straight or branched chains of glucose molecules and is the storage form of energy in plants. Glycogen is composed of highly branched chains of glucose molecules and is the storage form of energy in humans and animals. Fibers include many different substances that cannot be digested by enzymes in the human intestinal tract and are found in plant foods, such as whole grains, legumes, vegetables, and fruits.

Quick Bite

"An Apple a Day Keeps the Doctor Away"

Most likely this adage persisted over time because of the actual health benefits from apples. Apples have a lot of pectin, which is a soluble fiber known to be effective as a GI tract regulator.

Carbohydrate Digestion and Absorption

Although glucose is a key building block of carbohydrates, you can't exactly find it on the menu at your favorite restaurant. You must first drink that chocolate milkshake or eat that hamburger bun so that your body can convert the food carbohydrate into glucose in the body. Let's see what happens to the carbohydrate foods you eat.

Digestion of Carbohydrates

Carbohydrate digestion begins in the mouth, where the starch-digesting enzyme salivary amylase breaks down starch into shorter polysaccharides and maltose. Chewing stimulates saliva production and mixes salivary amylase with food. Disaccharides, unlike starch, are not digested in the mouth. In fact, only about 5 percent of the starches in food are broken down by the time the food is swallowed. **Figure 4.5** provides an overview of the digestive process.

When carbohydrate enters the stomach, the acidity of stomach juices eventually halts the action of salivary amylase by causing the enzyme (a protein) to lose its shape and function. Carbohydrate digestion starts again in the small intestine. This is how certain fibers, such as pectins and gums, provide a feeling of fullness because they tend to delay digestive activity by slowing stomach emptying.

Most carbohydrate digestion takes place in the small intestine. As the stomach contents enter the small intestine, the pancreas secretes pancreatic amylase into the small intestine. **Pancreatic amylase** continues the digestion of starch, breaking it into many units of the disaccharide maltose. Meanwhile, enzymes attached to the brush border (microvilli) of the mucosal cells lining the intestinal tract go to work. These digestive enzymes break disaccharides into monosaccharides for absorption. The enzyme maltase splits maltose into two glucose molecules. The enzyme sucrase splits sucrose into glucose and fructose. The enzyme lactase splits lactose into glucose and galactose.

pancreatic amylase Starch-digesting enzyme secreted by the pancreas.

The bonds that link glucose molecules in complex carbohydrates are called glycosidic bonds. This type of covalent bond joins two simple sugars within a disaccharide or polysaccharide. Depending on the position of the

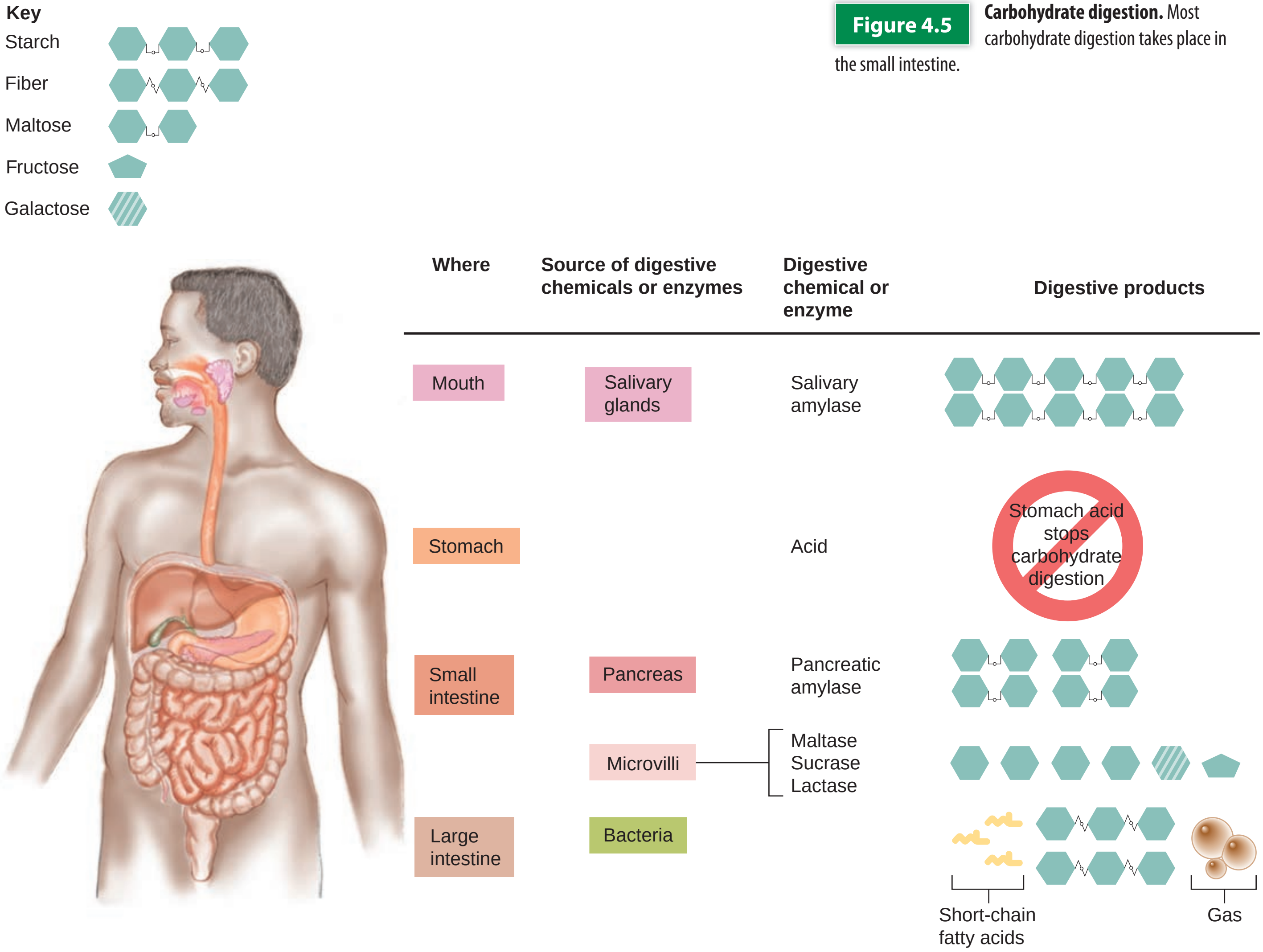


Figure 4.5 **Carbohydrate digestion.** Most carbohydrate digestion takes place in the small intestine.

OH group on the first carbon atom of the monosaccharide, the bond itself is identified as either an **alpha (α) bond** or a **beta (β) bond**. (See **Figure 4.6**.)

Human enzymes easily break alpha bonds, making glucose available from the polysaccharides starch and glycogen. Beta links are stronger than alpha links because they are more stable. Our bodies don't have enzymes to break most beta bonds, such as those that link the glucose molecules in

alpha (α) bonds Chemical bonds linking monosaccharides, which can be broken by human intestinal enzymes, releasing the individual monosaccharides. Starch, maltose, and sucrose contain alpha bonds.

beta (β) bonds Chemical bonds linking monosaccharides, which sometimes can be broken by human intestinal enzymes. Lactose contains digestable beta bonds, and cellulose contains nondigestible beta bonds.

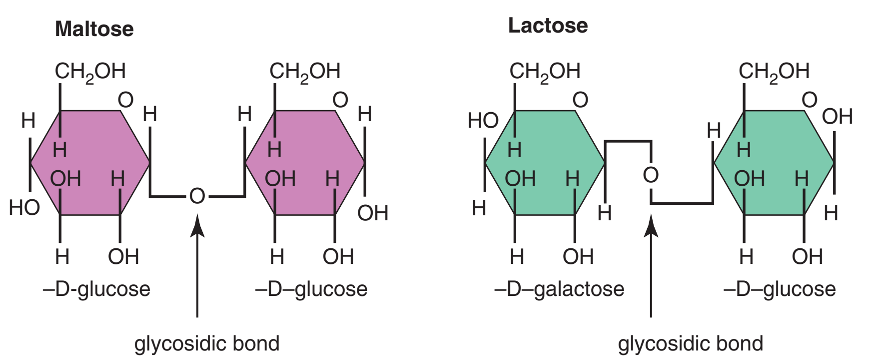


Figure 4.6 **Alpha bonds and beta bonds.** Human digestive enzymes can easily break the alpha bonds in starch, but they cannot break the beta bonds in cellulose.

Quick Bite

Banana Facts

You may know that bananas are high in potassium, but did you also know that they have an unusually high carbohydrate content? Before ripening, a banana is almost entirely starch. After ripening, certain bananas are almost entirely sugar—as much as 20 percent by weight.

cellulose, an indigestible polysaccharide. Beta bonds also link the galactose and glucose molecules in the disaccharide lactose, but the enzyme lactase is specifically tailored to attack this small molecule. People with a sufficient supply of the enzyme lactase can break these bonds; however, people with lactose intolerance do not have adequate lactase enzymes, so the beta bonds remain unbroken and lactose remains undigested until it interacts with bacteria in the colon. Symptoms associated with lactose intolerance can occur 30 minutes to 2 hours after consuming lactose, and include abdominal pain, bloating, flatulence, diarrhea, and nausea. People who are not able to make enough lactase can take lactase pills to aid in the digestion of lactose and thereby reducing the symptoms of lactose intolerance. The commercial product Beano is another example of an enzyme preparation designed to break oligosaccharides in beans into monosaccharides so that the body can absorb them. In this way, Beano also helps to minimize the flatulence caused by nondigestible carbohydrates reaching gas-producing bacteria in the large intestine.

Some carbohydrate remains intact as it enters the large intestine. This carbohydrate may be fiber or resistant starch or the small intestine may have lacked the necessary enzymes to break it down. In the large intestine, bacteria partially ferment (break down) undigested carbohydrate and produce gas plus a few short-chain fatty acids. These fatty acids are absorbed into the colon and are used for energy by the colon cells. In addition, these fatty acids change the composition of the GI tract flora, which contributes to reduced risk of developing gastrointestinal disorders, cancers, and cardiovascular disease.[14]

Some fibers, particularly cellulose and psyllium, pass through the large intestine unchanged and therefore produce little gas. Instead, these fibers add to the stool weight and water content, making it easier to pass.

Absorption

Monosaccharides are absorbed into the mucosal cells lining the small intestine by two different mechanisms. Glucose, galactose, and fructose molecules travel to the liver through the portal vein, where galactose and fructose are converted to glucose. The liver stores and releases glucose as needed to maintain constant blood glucose levels. **Figure 4.7** summarizes the digestion and absorption of carbohydrates.

Key Concepts Carbohydrate digestion takes place primarily in the small intestine, where digestible carbohydrates are broken down and absorbed as monosaccharides. Bacteria in the large intestine partially ferment resistant starch and certain types of fiber, producing gas and a few short-chain fatty acids that can be absorbed by the large intestine and used for energy. The liver converts absorbed monosaccharides into glucose.

Carbohydrates and Glucose in the Body

Through the processes of digestion and absorption, the various carbohydrates in our diet from vegetables, fruits, grains, and milk becomes glucose. Glucose has one major role—to supply energy for the body.

Carbohydrate Metabolism

Cells throughout the body depend on glucose for energy to drive chemical processes. Although most—but not all—cells also can burn fat for energy, the body needs some glucose to burn fat efficiently.

When we eat food, our bodies immediately use some glucose to maintain normal blood glucose levels. We store excess glucose as glycogen in liver and muscle tissue.

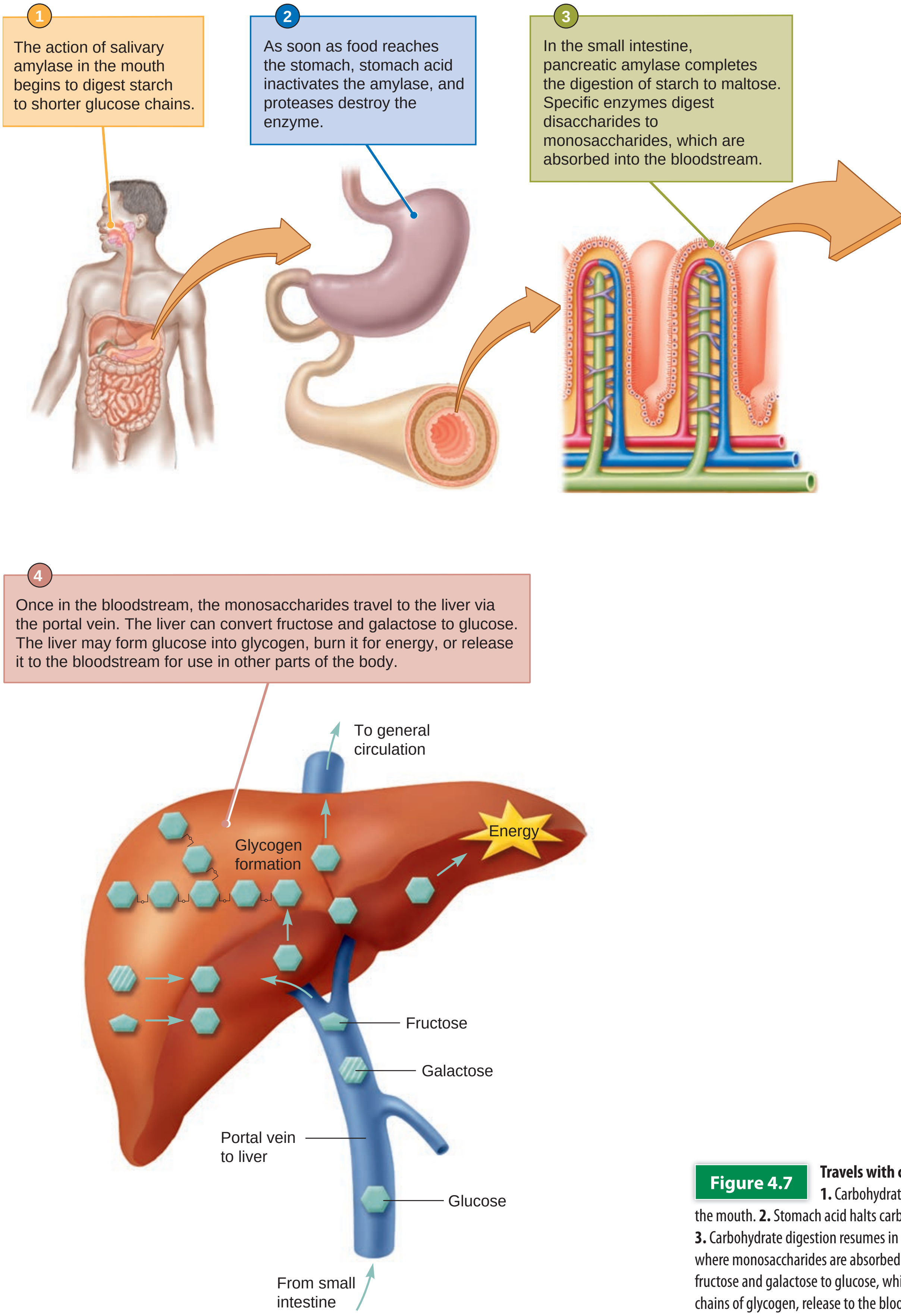
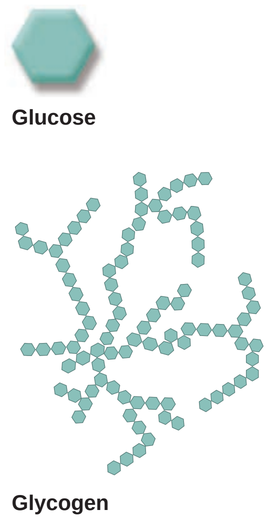


Figure 4.7 **Travels with carbohydrate.** **1.** Carbohydrate digestion begins in the mouth. **2.** Stomach acid halts carbohydrate digestion. **3.** Carbohydrate digestion resumes in the small intestine, where monosaccharides are absorbed. **4.** The liver converts fructose and galactose to glucose, which it can assemble into chains of glycogen, release to the blood, or use for energy.



Glucose and glycogen.

Using Glucose for Energy

Glucose is the primary fuel for most cells in the body and the preferred fuel for the brain, red blood cells, and nervous system, as well as for the fetus and placenta in a pregnant woman. Even when fat is burned for energy, a small amount of glucose is needed to break down fat completely. To obtain energy from glucose, cells must first take up glucose from the blood. Once glucose enters cells, a series of reactions breaks it down into carbon dioxide and water, releasing energy in a form that is usable by the body.[15]

Storing Glucose as Glycogen

To store excess glucose, the body assembles it into the long, branched chains of glycogen. Glycogen can be broken down quickly, releasing glucose for energy when needed. Liver glycogen stores are used to maintain normal blood glucose levels throughout the body. Liver glycogen accounts for about one-third of the body's total glycogen stores. Muscle glycogen stores are used to fuel muscle activity, and account for about two-thirds of the body's total glycogen stores.[16] The body can store only limited amounts of glycogen—usually enough to last from a few hours to one day, depending on activity level.[17]

Sparing Body Protein

If carbohydrate is not available, both protein and fat can be used for energy. Although most cells can break down fat for energy, brain cells and developing red blood cells require a constant supply of glucose.[18] The availability of glucose for the brain is critical for survival because it takes an extended period of starvation for the brain to be able to use some by-products of fat breakdown for part of its energy needs. What happens if glucose stores (glycogen in liver and muscles) are depleted and the diet supplies no carbohydrate? To maintain blood glucose levels and supply glucose to the brain, the body can make glucose from body proteins. Adequate consumption of dietary carbohydrate spares body proteins from being broken down and used to make glucose.

Ketone Bodies

Even when fat provides fuel for the body, the cells will still require a small amount of carbohydrate, in the form of glucose, to completely break down fat to release energy. When no carbohydrate is available, the liver cannot break down fat completely. Instead, it produces small compounds called **ketone bodies**.[19] Most cells can use ketone bodies for energy. The ability of the body to successfully produce and use ketone bodies from fat is essential for the body to adapt to times of inadequate energy and essential to survival during starvation.

ketone bodies Molecules formed when insufficient carbohydrate is available to completely metabolize fat. Formation of ketone bodies is promoted by a low glucose level and high acetyl CoA level within cells. Acetone, acetoacetate, and beta-hydroxybutyrate are ketone bodies. Beta-hydroxybutyrate is sometimes improperly called a ketone.

Ketone bodies are produced normally in very small amounts. Increased production of ketones is most commonly caused by very low carbohydrate diets, starvation, uncontrolled diabetes mellitus, and chronic alcoholism. To prevent the **ketosis**, the buildup of ketone bodies, the body needs a minimum of 50 to 100 grams of carbohydrate daily.[20]

ketosis [kee-TOE-sis] Abnormally high concentration of ketone bodies in body tissues and fluids.

Key Concepts Glucose circulates in the blood to provide immediate energy to cells. The body stores excess glucose in the liver and muscle as glycogen. The body needs adequate carbohydrate intake so that body proteins are not broken down to fulfill energy needs. The body requires some carbohydrate to completely break down fat and prevent the buildup of ketone bodies in the blood.

Regulating Blood Glucose Levels

The body closely regulates blood glucose levels (also known as blood sugar levels) to maintain an adequate supply of glucose for cells. If blood glucose levels drop too low, a person becomes shaky and weak. If blood glucose levels rise too high, a person becomes sluggish and confused and may have difficulty breathing.

Two hormones produced by the pancreas, insulin and glucagon, tightly control blood glucose levels.[21] When blood glucose levels rise after a meal, special pancreatic cells called beta cells release the hormone insulin into the blood. **Insulin's** action can be thought of like a key, "unlocking" the cells of the body and allowing glucose to enter and fuel them. It also stimulates liver and muscle cells to store glucose as glycogen. As glucose enters cells to deliver energy or be stored as glycogen, blood glucose levels return to normal. (See **Figure 4.8**.)

When an individual has not eaten for a number of hours and blood glucose levels begin to fall, the pancreas releases another hormone, **glucagon**. Glucagon stimulates the body to break down stored glycogen, releasing glucose into the bloodstream (see **Figure 4.8b**). It also stimulates the synthesis of glucose from protein by a process called gluconeogenesis. Another hormone, **epinephrine** (also called adrenaline), exerts effects similar to glucagon to ensure that all body cells have adequate energy for emergencies. Released by the adrenal glands in response to sudden stress or danger, epinephrine is called the fight-or-flight hormone.

insulin [IN-suh-lin] Produced by beta cells in the pancreas, this polypeptide hormone stimulates the uptake of blood glucose into muscle and adipose cells, the synthesis of glycogen in the liver, and various other processes.

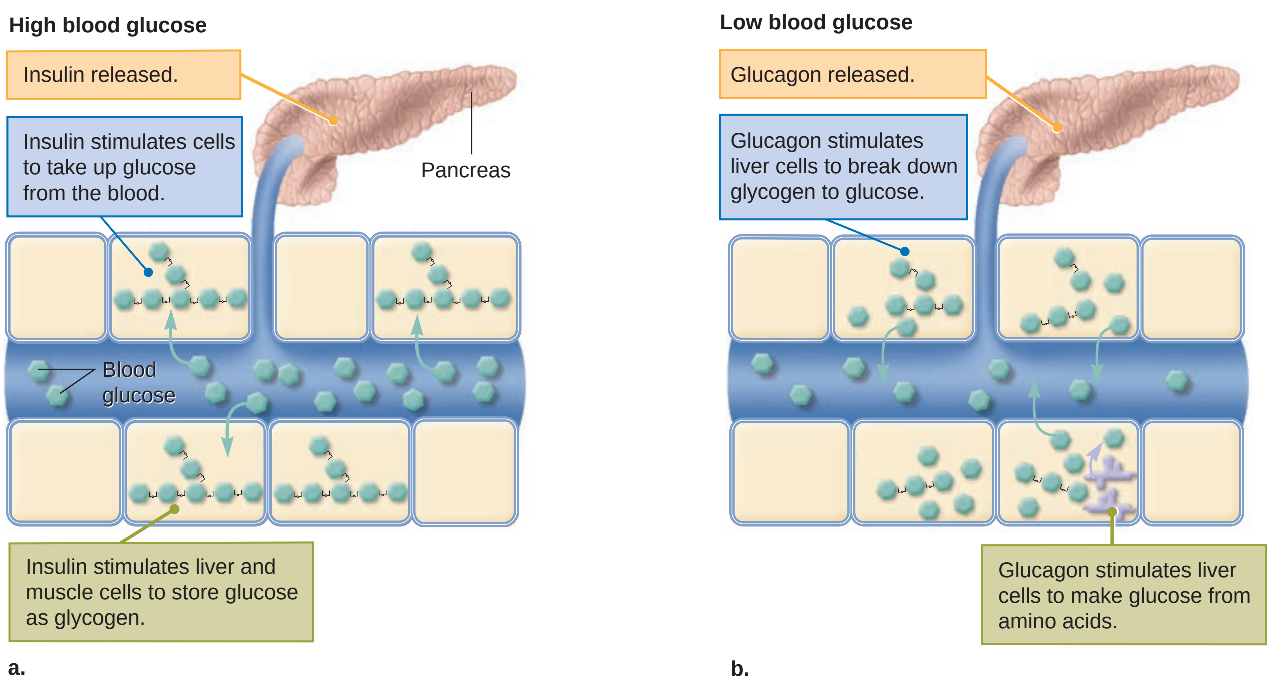
glucagon [GLOO-kuh-gon] Produced by alpha cells in the pancreas, this polypeptide hormone promotes the breakdown of liver glycogen to glucose, thereby increasing blood glucose. Glucagon secretion is stimulated by low blood glucose levels and by growth hormone.

epinephrine A hormone released in response to stress or sudden danger, epinephrine raises blood glucose levels to ready the body for "fight or flight." Also called *adrenaline*.

Glycemic Index of Foods

Different foods vary in their effect on blood glucose levels. The glycemic index measures the effect of a food on blood glucose levels (**Figure 4.9**). Foods with a high glycemic index cause a faster and higher rise in blood glucose, whereas foods with a low glycemic index cause a slower rise in blood glucose. Foods rich in simple carbohydrates or starch but low in fat or fiber tend to be digested and absorbed rapidly. This rapid absorption causes a corresponding large and rapid rise in blood glucose levels.[22] The body reacts to this rise by pumping out extra insulin, which rapidly lowers blood glucose levels. Other foods—especially those rich in dietary fiber, resistant starch, or fat—cause a less dramatic blood glucose response accompanied by smaller swings in blood glucose levels. Although some experts disagree on the usefulness of the glycemic index, diets that emphasize foods with a low glycemic index may offer important health benefits.[23]

Figure 4.8 **Regulating blood glucose levels.** Insulin and glucagon have opposing actions. **a.** Insulin acts to lower blood glucose levels, and **b.** glucagon acts to raise them.



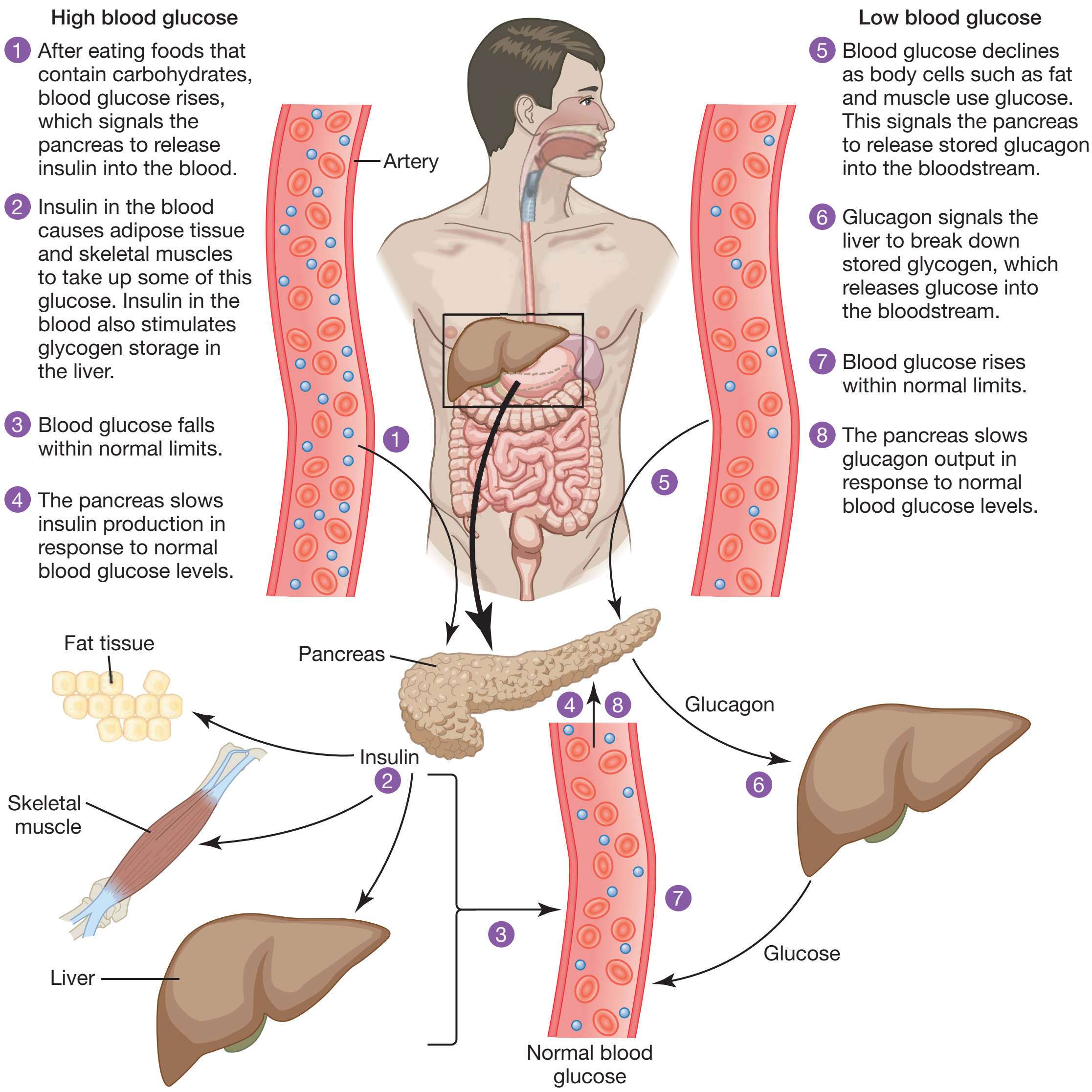


Figure 4.9 **Blood Glucose Regulation.** The regulatory system for normal blood glucose comes by way of the pancreas monitoring blood glucose and adjusting its concentration as necessary, using the action of two opposing hormones; insulin and glucagon. When blood glucose is too high, the pancreas releases insulin and glucose is shifted to other cells, which helps to decrease blood glucose levels. When insulin is too low, the pancreas releases glucagon, which signals the liver to break down stored glycogen, which releases glucose into the bloodstream. Both actions work to bring blood glucose levels back to normal.

Quick Bite

Carbohydrate Companions

The word *companion* comes from the Latin word *companio*, meaning "one who shares bread."

The Role of Carbohydrates in Our Diet

The minimum amount of carbohydrate required by the body is based on the brain's requirement for glucose. This glucose can come either from dietary carbohydrate or from synthesis of glucose from protein in the body. What foods supply our dietary carbohydrates? **Figure 4.10** shows many foods rich in carbohydrates. Plant foods are our main dietary sources of carbohydrates: Grains, legumes, and vegetables provide starches and fibers; fruits provide sugars and fibers. Additional sugar (mainly lactose) is found in dairy foods, and various sugars are found in beverages, jams, jellies, candy, and sweet desserts.

Recommended Intake of Carbohydrate

Because adaptation to using protein for glucose and ketone bodies for energy may be incomplete, relying on protein alone is not recommended.[24] Therefore, a Recommended Dietary Allowance (RDA) for carbohydrate of 130 grams per day has been set for individuals age 1 year or older. The RDA for carbohydrate rises to 175 grams per day during pregnancy and 210 grams per day during lactation.

The *Dietary Guidelines for Americans* suggests that we "reduce the intake of added sugars."[25] One key recommendation is to choose and prepare foods and beverages with little added sugar. Although the Acceptable Macronutrient Distribution Range (AMDR) for added sugars is no more than 25 percent of daily energy intake, a point at which the micronutrient quality of the diet declines, many sources suggest that added sugar intake should be lower. The *Dietary Guidelines for Americans* also recommends that we choose foods such as whole grains, vegetables, fruits, and cooked dry beans and peas as staples in our diet and to consume at least half of all grains as whole grains.[26] Fruits, vegetables, and whole grains, along with legumes, are good sources of fiber. The Adequate Intake (AI) value for total fiber is 38 grams per day for men ages 19 to 50 years and 25 grams per day for women in the same age group. This AI value is based on a level of intake (14 grams per 1,000 kilocalories) that provides the greatest risk reduction for heart disease.[27] The Daily Value for fiber used on food labels is 25 grams.

Current Consumption: How Much Carbohydrate Do You Eat?

The AMDR for carbohydrate is 45 to 65 percent of kilocalories. For an adult who eats about 2,000 kilocalories daily, this represents 225 to 325 grams of carbohydrate. The Daily Value for carbohydrates is 300 grams per day, representing 60 percent of the calories in a 2,000-kilocalorie diet.

Adult Americans currently consume about 49 to 50 percent of their energy intake as carbohydrate; however, this does not account for the quality of the carbohydrates consumed. According to National Health and Nutrition Examination Survey (NHANES) data, 13 percent of the population has an added sugar intake of more than 25 percent of calories, with a mean equivalent of added sugar intake of about 80 grams per day.[28] Increased consumption of added sugars has been linked to a decrease in intake of essential micronutrients and an increase in body weight.[29] About one-third of Americans' added sugar intake comes from sugar-sweetened soft drinks. This is of concern because as soft drink consumption rises, energy intake increases, but milk consumption and the vitamin and mineral quality of the diet decline.[30] Many studies suggest that rising soft drink consumption is a factor in overweight and obesity, even among very young children.[31] Regular soft drinks, sugary sweets, sweetened grains, and regular fruit flavored beverages comprise 72 percent of the intake of added sugar.[32] Studies also show that consumption of sugar-sweetened beverages is associated with higher concentrations of insulin and leptin, both of which may be early markers of metabolic dysfunction, which can increase the risk of developing cardiovascular disease and diabetes.[33]

Most Americans do not consume enough dietary fiber, with usual intakes averaging only 15 grams per day.[34] With the exception of older women (51 years and older), only 0 to 5 percent of individuals in all other life stage groups have fiber intakes meeting or exceeding the AI.[35] The major sources of dietary fiber in the American diet are white flour and potatoes, not because they are concentrated fiber sources but because they are widely consumed.[36]

© Photodisc.

Table sugar, corn syrup, and brown sugar are rich in sucrose, a simple carbohydrate.

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Milk and milk products are rich in lactose, a simple carbohydrate.

Photo by Keith Weller. Courtesy of USDA.

Fruits and vegetables provide simple sugars, starch, and fiber.

© Morgan Lane Photography/ShutterStock, Inc.

Bread, flour, cornmeal, rice, and pasta are rich in starch and, sometimes, dietary fiber.

Figure 4.10 **Sources of carbohydrates.** Table sugar, corn syrup, and brown sugar are rich in sucrose, a simple carbohydrate. Milk and milk products are rich in lactose, a simple carbohydrate. Fruits and vegetables provide simple sugars, starch, and fiber. Bread, flour, cornmeal, rice, and pasta are rich in starch and, sometimes, dietary fiber.

Is Glycemic Index a Useful Tool for Constructing a Healthy Diet with Carbohydrates?

Glycemic index is a valuable tool and easy-to-use concept that may be important for individuals with diabetes to help 'fine tune' their blood glucose control.[1] Several popular weight-loss diets use the glycemic index to guide food choices.

How Is the Glycemic Index Measured?

The glycemic index is a measure of the change in blood glucose following consumption of carbohydrate-containing foods. It compares the change in blood glucose after eating a sample food to the change expected from eating an equal amount of available carbohydrate from a standard food such as white bread.[2]

Foods with a high glycemic index trigger a sharp rise in blood glucose, followed by a dramatic fall, often to levels that are well below normal. This explains why these foods could be undesirable for a person with diabetes. In contrast, low-glycemic-index foods trigger slower and more modest changes in blood glucose levels, therefore making blood glucose easier to manage. However, the effects of high or low glycemic index foods on people without diabetes is questionable, especially when eating a mixed diet.

What Factors Affect the Glycemic Index of a Food or Meal?

The glycemic index of a food is not always easy to predict. Would you expect a sweet food such as ice cream to have a high glycemic index? Ice cream actually has a low glycemic value because its fat slows sugar absorption. On the other hand, wouldn't you expect complex carbohydrates such as bread or potatoes to have a low glycemic index? In fact, the starch in white bread and cooked potatoes is readily absorbed, so each has a high value.[3] The glycemic indices of some common foods are listed in Table A, and lower-glycemic-index substitutions are provided in Table B.

The type of carbohydrate, degree of processing, method of cooking, and presence of fat, dietary fiber, and other food components in a meal or snack all affect the glycemic response.[4,5] The glycemic index of mixed meals, referred to as the glycemic load, is more important than the effect of individual foods on blood glucose.[6]

Table A Glycemic Index of Some Foods Compared to Pure Glucose[a]

Food	Glycemic Index	Food	Glycemic Index
Bakery Products		Skim milk	36
Angel food cake	67	***Fruits***	
Waffles	76	Apples	38
Bread		Bananas	52
White bread	73	Pineapple	59
Whole-wheat bread, whole meal flour	71	***Legumes***	
Breakfast Cereals		Black-eyed peas	42
All bran	42	Lentils	29
Corn flakes	81	***Pasta***	
Oatmeal	58	Spaghetti	42
Cereal Grains		Macaroni	47
Barley	25	***Vegetables***	
Sweet corn	53	Carrots	47
White rice, long grain	56	Baked potatoes	85
Bulgur	45	Green peas	48
Dairy Foods		***Candy***	
Ice cream	61	Jelly beans	78
		Life Savers	70

[a] Glycemic response to pure glucose is 100.

Source: Data from Foster-Powell K, Holt SHA, Brand-Miller JC. International table of glycemic index and glycemic load values: 2002. *Am J Clin Nutr.* 2002;76:5–56.

Why Do Some Researchers Believe the Glycemic Index Is Useful?

Health benefits of following a low glycemic index diet can be significant. Diets that emphasize low-glycemic-index foods decrease the risk of developing type 2 diabetes and improve blood glucose control in people who are already afflicted.[7,8] Epidemiological studies suggest that such diets also reduce the risk of colon and other cancers[9] and may help reduce the risk of heart disease as well. Diets with a low glycemic load are associated with higher high-density lipoprotein (HDL) cholesterol levels and reduced incidence of heart attack.[10] Also, studies indicate that the effectiveness of low-fat, high-carbohydrate diets for weight loss can be improved by reducing the glycemic load.[11]

Why Do Some Researchers Believe the Glycemic Index Is Useless?

Whether a person is diabetic trying to control blood glucose levels, attempting weight loss, or reducing risk for heart disease, there is no 'best way' to improve your diet. Some researchers question the usefulness of conclusions drawn primarily from epidemiological studies.[12,13] Epidemiological studies can show association, but they cannot prove causation.

Some believe the glycemic index is too complex for most people to use effectively. The position of the American Diabetes Association has not endorsed widespread adoption of the glycemic index diets for those with diabetes, and the 2010 Dietary Guidelines for Americans Advisory Committee reviewed the current research on glycemic

Table B **Sample Substitutions for High-Glycemic-Index Foods[a]**

High-Glycemic-Index Food	Low-Glycemic-Index Alternative
Bread, wheat or white	Oat bran, rye, or pumpernickel bread
Processed breakfast cereal	Unrefined cereal such as oats (either muesli or oatmeal) or bran cereal
Plain cookies and crackers	Cookies made with nuts and whole grains such as oats
Cakes and muffins	Cakes and muffins made with fruit, oats, or whole grains
Bananas	Apples
White potatoes	Sweet potatoes, pastas, or legumes

[a] Low glycemic index = 55 or less; medium = 56–69; high = 70 or more.

index and concluded that strong evidence does not yet exist for the association between glycemic index and body weight and therefore is not necessary to consider for weight management.[14]

What Is the Bottom Line?
Like many other nutrition issues, the usefulness of glycemic index as a tool to help make healthier carbohydrate choices continues to be studied. More information is still needed about the influence of processing techniques on the glycemic index, and about an agreement on methodologies and standards for measuring it. Most researchers also call for prospective, long-term clinical trials to evaluate the effects of low-glycemic-index and low-glycemic-load diets in chronic disease risk reduction and treatment.[15] Until then, for healthy eating, focus on consuming more whole grains and high-fiber carbohydrates, including minimally refined cereal products. Other low-glycemic-index foods won't hurt, and may help to improve health!

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2 Udani J, Singh B, Barrett M, Preuss H. Lowering the glycemic index of white bread using a white bean extract. *Nutr J*. 2009;8:52.
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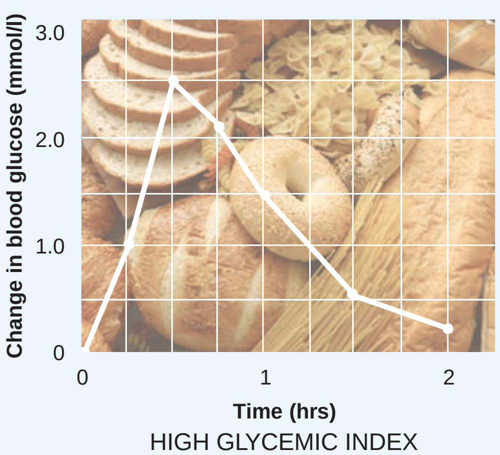
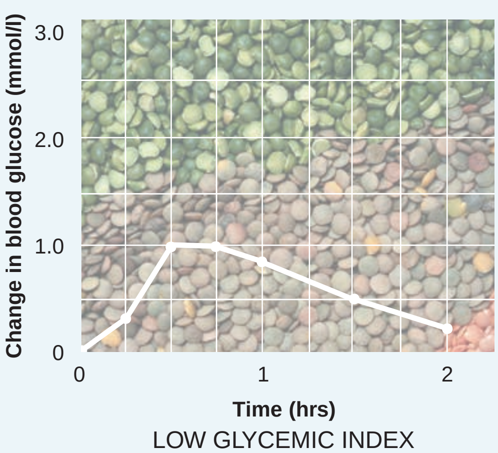




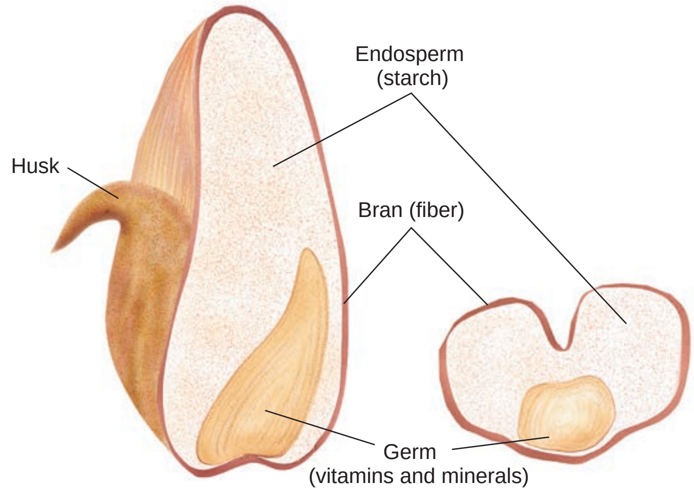


Figure 4.11 **Anatomy of a kernel of grain.** Whole kernels of grains consist of four parts: germ, endosperm, bran, and husk.

Choosing Carbohydrates Wisely

Fruits, vegetables, whole grains, and fat-free or low-fat milk are all good sources of carbohydrates and provide vitamins, minerals, and phytochemicals, along with fiber and little or no fat. Choosing a variety of fruits and vegetables, and particularly including choices from all five vegetable subgroups (dark green vegetables, orange vegetables, legumes, starchy vegetables, and other vegetables) provides vitamin A, vitamin C, folate, potassium, and fiber.

Fiber in Our Diet

Along with fruits and vegetables, whole grains are important sources of fiber. Whole kernels of grain consist of four parts: germ, endosperm, bran, and husk. (See **Figure 4.11**.) The **germ**, the innermost part at the base of the kernel, is the portion that grows into a new plant. It is rich in protein, oils, vitamins, and minerals. The **endosperm** is the middle portion (and largest part) of the grain kernel. It is high in starch and provides food for the growing plant embryo. The **bran** is composed of layers of protective coating around the grain kernel and is rich in dietary fiber. The **husk** is an inedible covering.

When grains are refined—making white flour from wheat, for example, or making white rice from brown rice—the process removes the outer husk and bran layers and sometimes the inner germ of the grain kernel. Because the bran and germ portions of the grain contain much of the dietary fiber, vitamins, and minerals, the nutrient content of whole grains is far superior to that of refined grains. Although food manufacturers add iron, thiamin, riboflavin, folate, and niacin back to white flour through enrichment, they usually do not add back lost dietary fiber and nutrients such as vitamin B_6, calcium, phosphorus, potassium, magnesium, and zinc, which are lost in processing.

Read labels carefully to choose foods that contain whole grains. Terms such as *whole-wheat*, *whole-grain*, *rolled oats*, and *brown rice* indicate that the entire grain kernel is included in the food. Even better, look for the words *100 percent whole grain* or *100 percent whole wheat*.

To increase your fiber intake:

- Eat more whole-grain breads, cereals, pasta, and rice as well as more fruits, vegetables, and legumes.
- Eat fruits and vegetables with the peel, if possible. The peel is high in fiber.

germ The innermost part of a grain, located at the base of the kernel, that can grow into a new plant. The germ is rich in protein, oils, vitamins, and minerals.

endosperm The largest, middle portion of a grain kernel. The endosperm is high in starch to provide food for the growing plant embryo.

bran The layers of protective coating around the grain kernel that are rich in dietary fiber and nutrients.

husk The inedible covering of a grain kernel. Also known as the *chaff*.

- Add fruits to muffins and pancakes.
- Add legumes—such as lentils and pinto, navy, kidney, and black beans—to casseroles and mixed dishes as a meat substitute.
- Substitute whole-grain flour for all-purpose flour in recipes whenever possible.
- Use brown rice instead of white rice.
- Substitute oats for flour in crumb toppings.
- Choose high-fiber cereals.
- Choose whole fruits rather than fruit juices.

When increasing your fiber intake, do so gradually, adding just a few grams a day. Parents and caregivers should also emphasize foods rich in fiber for children older than 2 years, but must take care that these foods do not fill a child up before energy and nutrient needs are met. **Table 4.2** lists various foods that are high in simple and complex carbohydrates.

Although health food stores, pharmacies, and even grocery stores sell many types of fiber supplements, most experts agree that you should get fiber from food rather than from a supplement.

Table 4.2 High-Carbohydrate Foods

High in Complex Carbohydrates	High in Simple Carbohydrates
Bagels	**Naturally Present**
Tortillas	Fruits
Cereals	Fruit juices
Crackers	Skim milk
Rice cakes	Plain nonfat yogurt
Legumes	**Added**
Corn	Angel food cake
Potatoes	Soft drinks
Peas	Sherbet
Squash	Syrups
Popcorn	Sweetened nonfat yogurt
	Candy
	Jellies
	Jams
	Gelatin
	High-sugar breakfast cereals
	Cookies
	Frosting

Health Effects of Fiber

Foods rich in dietary fiber contain a variety of fibers as well as vitamins, minerals, and other phytochemicals that offer important health effects. High fiber foods are often lower in sugar and fat than refined wheat products, making them more healthy choices because of the fiber and nutrients the food provides while at the same time minimizing fat, calories, and sugar.

Fiber and Obesity

Foods rich in fiber usually are low in fat and energy. They offer a greater volume of food for fewer calories, take longer to eat, and are filling. Once eaten, foods high in dietary fiber take longer to leave the stomach and they attract water, adding to the feeling of fullness. Consider, for example, three apple products with the same energy but different fiber content: a large apple (5 grams fiber), 1/2 cup of applesauce (2 grams fiber), and 3/4 cup of apple juice (0.2 grams fiber). Most of us would find the whole apple more filling and satisfying than the applesauce or apple juice.

Studies show that people who consume more fiber weigh less than those who consume less fiber, suggesting that fiber intake has a role in weight control. Although research supports a role for dietary fiber in reducing hunger and promoting satiety, studies on specific types of fiber have produced inconsistent results.[37]

Fiber and Type 2 Diabetes

People who consume plenty of dietary fiber, especially the fiber in whole grains and cereal, have a low incidence of type 2 diabetes.[38] Evidence suggests that the intake of certain fibers may delay glucose uptake and smooth out the blood glucose response, thus providing a protective effect against diabetes.[39] Current dietary recommendations for people with type 2 diabetes advise a high intake of foods rich in dietary fiber.[40]

Fiber and Cardiovascular Disease

High blood cholesterol levels increase the risk for heart disease. Dietary trials using high doses of oat bran, which is high in dietary fiber, show blood cholesterol reductions of 2 percent per gram of intake.[41] Because every 1 percent decrease in blood cholesterol levels decreases the risk of heart disease by 2 percent, high fiber intake can decrease the risk of heart disease substantially. Studies show a 20 to 40 percent difference in heart disease risk between the highest and lowest fiber-intake groups.[42] Dietary fiber is known to have a protective effect against certain gastrointestinal diseases, constipation, hemorrhoids, colon cancer, gastroesophageal reflux disease, duodenal ulcer, diverticulitis, obesity, diabetes, stroke, hypertension, and cardiovascular disease.[43]

Fiber from oat bran, legumes, and psyllium can lower blood cholesterol levels. Your body uses cholesterol to make bile, which is secreted into the intestinal tract to aid fat digestion. Most bile is reabsorbed and recycled. In the gastrointestinal tract, fiber can bind bile and reduce the amount available for reabsorption. With less reabsorbed bile, the body makes up the difference by removing cholesterol from the blood and making new bile. The short-chain fatty acids produced from bacterial breakdown of fiber in the large intestine also may prevent cholesterol formation.[44] Studies also show a relationship between high intake of whole grains and low risk of heart disease.[45] Whole grains contain fiber as well as antioxidants and other compounds that may protect against cellular damage that promotes heart disease. It is likely that the combination of compounds found in grains, rather than any one component, explains the protective effects against heart disease.[46] Consuming at least three 1-ounce servings of whole grains each day can reduce heart disease risk.[47]

Position Statement: Academy of Nutrition and Dietetics

Health Implications of Dietary Fiber

It is the position of the Academy of Nutrition and Dietetics that the public should consume adequate amounts of dietary fiber from a variety of plant foods.

Source: Reproduced from Slavin JL. Position of the American Dietetic Association: Health implications of dietary fiber. *J Am Diet Assoc*. 2008;108(10):1716–1731.

Fiber and Gastrointestinal Disorders

Eating plenty of dietary fiber, especially the types found in cereal grains, helps promote healthy gastrointestinal functioning. Diets rich in fiber add bulk and increase water in the stool, softening the stool and making it easier to pass. Fiber also accelerates passage of food through the intestinal tract, promoting regularity. If fluid intake is also ample, high fiber intake helps prevent and treat constipation, hemorrhoids (swelling of rectal veins), and diverticular disease (development of pouches on the intestinal wall).

Negative Health Effects of Excess Fiber

Despite its health advantages, high fiber intake can cause problems, especially for people who drastically increase their fiber intake in a short period of time. If you increase your fiber intake, you also need to increase your water intake to prevent the stool from becoming hard and impacted. A sudden increase in fiber intake also can cause increased intestinal gas and bloating. You can prevent these problems both by increasing fiber intake gradually over several weeks and by drinking plenty of fluids.

Quick Bite

Fierce Fiber and Flatulence

The Jerusalem artichoke surpasses even dry beans in its capacity for facilitating flatulence. This artichoke contains large amounts of nondigestible carbohydrate. After passing through the small intestine undigested, the fiber is attacked by gas-generating bacteria in the colon.

Just as fiber binds cholesterol, it also can bind small amounts of minerals in the GI tract and prevent them from being absorbed. Fiber binds the minerals zinc, calcium, and iron. For people who get enough of these minerals, however, the recommended amounts of dietary fiber do not affect mineral status significantly.[48]

Some people who eat high-fiber diets, such as young children and the elderly, may feel full before meeting energy and nutrient needs. Because of a limited stomach capacity, they must be careful that fiber intake does not interfere with their ability to consume adequate energy and nutrients.

Due to the bulky nature of fibers, excess consumption is likely to be self-limiting. Although a high fiber intake may cause occasional adverse gastrointestinal symptoms, serious chronic adverse effects have not been observed. As part of an overall healthy diet, a high intake of fiber will not produce significant deleterious effects in healthy people. Therefore, a Tolerable Upper Intake Level (UL) is not set for fiber.

Key Concepts High intake of foods rich in dietary fiber offers many health benefits, including reduced risk of obesity, type 2 diabetes, cardiovascular disease, and gastrointestinal disorders. Increase fiber intake gradually while drinking plenty of fluids; children and the elderly with small appetites should take care that energy needs are still met. No UL is set for fiber.

Carbohydrates and Health

Carbohydrates contribute both positively and negatively to health. On the upside, foods rich in fiber help keep the gastrointestinal tract healthy and may reduce the risk of heart disease and cancer. On the downside, excess sugar can contribute to weight gain, poor nutrient intake, and tooth decay.

Sugar in Our Diet

Most of us enjoy the taste of sweet foods, and there's no reason why we should not. But for many, habitually high sugar intake takes the place of foods that are higher in fiber, vitamins, and minerals.

Our Sugar Intake

Health Effects of Sugar Sugar has become the vehicle used by some diet zealots to create a new crusade. Cut sugar to trim fat! Bust sugar! Break the sugar habit! These battle cries demonize sugar as a dietary villain. But what are the facts?

Sugar and Obesity

Excess energy intake—not sugar intake—is associated with a greater risk of obesity. Take a look at fat. Fat is a more concentrated source of energy than carbohydrates as it provides 9 kilocalories per gram. Many foods high in sugar, such as doughnuts and cookies, are also high in fat. Excess energy intake from any source will cause obesity, but sugar by itself is no more likely to cause obesity than starch, fat, or protein. The increased availability of low-fat and fat-free foods has not reduced obesity rates in the United States; in fact, the incidence of obesity is still climbing. Some speculate that consumers equate fat-free with calorie-free and eat more of these foods, not realizing that fat-free foods often have a higher sugar content, which makes any calorie savings negligible. Also, foods high in added sugars often have low nutrient value and become "extras" in the diet.

Sugar and Diabetes Mellitus

Diabetes Mellitus is a disease of impaired blood sugar control leading to high levels of glucose in the blood. It was once believed that eating too much carbohydrates or sugar could cause diabetes. However, contrary to popular beliefs, high intake of carbohydrates or sugar does not cause diabetes. Obesity, however, is the single largest modifiable risk factor in the development of diabetes. If high sugar intake contributes to caloric excess leading to weight gain, increased body fat, and obesity, those individuals will be more likely to develop diabetes.

Sugar and Heart Disease

Risk factors for heart disease include a genetic predisposition, smoking, high blood pressure, high blood cholesterol levels, diabetes, and obesity. Sugar by itself does not cause heart disease.[49] However, if intake of high-sugar foods contributes to obesity, then risk for heart disease increases. In addition, excessive intake of refined sugar can alter blood lipids in carbohydrate-sensitive

Quick Bite

Liquid Candy

In the United States, corn sweeteners are primarily consumed in carbonated soft drinks (25.4 pounds per year), fruit flavored beverages (8.2 pounds), and syrup and sweet toppings (4.1 pounds). In all, 36.3 percent of sugar and corn sweeteners are consumed in carbonated soft drinks, fruit flavored beverages, and other nonalcoholic drinks.

Quick Bite

Sugar Overload

Americans consume very large quantities of carbonated soft drinks each year. Soft drink manufacturers produce enough of the sweet beverage to provide 557 12-ounce cans to every man, woman, and child in the United States each year. That equals over 52 gallons of soft drink each year! Today, adults consume nearly twice as many ounces of sugar-sweetened sodas as milk. Children's milk consumption was more than three times that of their soda consumption in the late 1970s, but today children consume roughly equal amounts of each.

people, increasing their risk for heart disease. However, a high fat intake is more likely to promote obesity than a high sugar intake. Thus, total fats, saturated fat, cholesterol, and obesity have a significantly more important relationship to heart disease than sugar.

Sugar and ADHD in Children

Many parents and child care professionals will comment that eating sugary foods makes their child hyperactive. Attention-deficit hyperactivity disorder (ADHD) characterized by inattentive, hyperactive, and impulsive behavior is estimated to affect five percent of children worldwide.[50] What could be making this relationship so hard to understand? It is important to keep other environmental factors in mind when assessing the relationship between high sugar foods and behavior. Take, for example, a child's birthday party, where a large dose of high-sugar foods such as cake, ice cream, soda, and 'goodie bags' are all part of the celebration that involves some games, prizes, and maybe even a clown or other activity. A child's hyperactive behavior could be related to the exciting environment and enthusiasm for the special event. Alternatively, children whose diet is regularly high in sugar is likely to be less nutritious overall and, therefore, the possibility that the child's irritable or restless behavior could be attributed to a nutrient deficiency or more generalized malnutrition should be considered.

dental caries [KARE-ees] Destruction of the enamel surface of teeth caused by acids resulting from bacterial breakdown of sugars in the mouth.

Sugar and Dental Caries

High sugar intake contributes to **dental caries**, or cavities. (See **Figure 4.12**.) When bacteria in your mouth feed on sugars, they produce acids that eat away tooth enamel and dental structure, causing dental caries. Although these bacteria quickly metabolize sugars, they feed on any carbohydrate, including starch. The longer a carbohydrate remains in the mouth, or the more frequently it is consumed, the more likely it is to promote dental caries. Foods that stick to your teeth, such as caramel, licorice, crackers, sugary cereals, and cookies, are more likely to cause dental caries than foods that are quickly washed out of your mouth. High-sugar beverages such as soft drinks are likely to cause dental caries when they are sipped slowly over an extended period of time. A baby should never be put to bed with a bottle, because the warm milk or juice may remain in the mouth for long periods of time, providing a ready source of carbohydrate for bacteria to break down.

Snacking on high-sugar foods throughout the day provides a continuous supply of carbohydrates that nourish the bacteria in your mouth, promoting the formation of dental caries. Good dental hygiene, adequate fluoride, and a well-balanced diet for strong tooth formation can help prevent such cavities.[51]

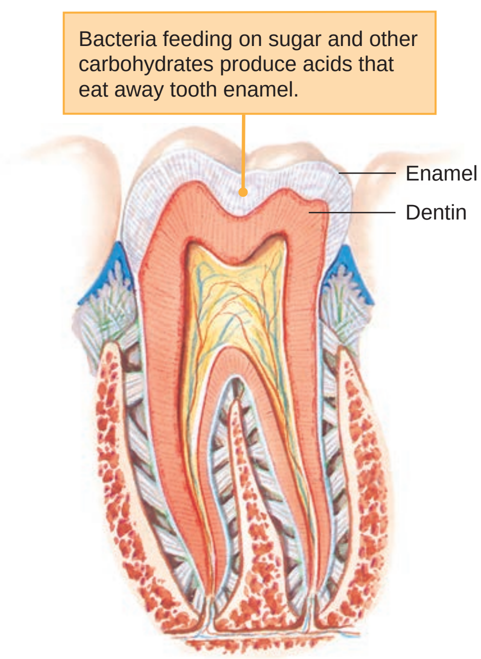


Figure 4.12 **Dental health.** Good dental hygiene, adequate fluoride, and proper nutrition help maintain healthy teeth. A well-balanced diet contains vitamins and minerals crucial for healthy bones and teeth. To help prevent dental caries, avoid continuous snacking on high-sugar foods, especially those that stick to the teeth.

Moderating Your Sugar Intake

Because of its desired flavor, it is easy to eat too much sugar! Be aware of added sugar in your diet and evaluate if you need to cut back. The following are a few simple ways to reduce added sugars in your diet:

- Use less of all added sugars, including white sugar, brown sugar, honey, and syrups.
- Limit use of soft drinks, high-sugar breakfast cereals, candy, ice cream, and sweet desserts.
- Use fresh or frozen fruits and fruits canned in natural juices or light syrup for dessert and to sweeten waffles, pancakes, muffins, and breads.

FYI For Your Information

Excessive Sugar in the American Diet

Foods high in sugar are popular in American diets. These empty-calorie foods (e.g., candy, caloric soft drinks, sweetened gelatin, some desserts) provide energy but contain little or no dietary fiber, vitamins, or minerals. Data from the 1999–2004 NHANES study indicate that the average American consumes 22.5 teaspoons of added sugars per day. American adults consume 21.6 teaspoons of added sugars per day, and children (ages 2–19) consume 24.9 teaspoons. Caloric sweetened sodas and fruit drinks (containing less than 100% juice by volume) are major sources of added sugars in American diets, contributing an average of 10.58 teaspoons of added sugars each day. Children consume 11.96 teaspoons of added sugars from sodas and fruit drinks per day (47% of their total intake of added sugars).[1] Soda and other sugar-sweetened beverages are the largest source of added sugar in the diets of both children and adults in the United States.

Studies have linked the increasing prevalence of obesity in children to consumption of sugar-sweetened drinks.[2] Consider that one 12-ounce soft drink contains 10 to 12 teaspoons of sugar. Would you add that much sugar to a glass of iced tea?

People with high energy needs, such as active teenagers and young adults, can afford to get a bit more of their calories from high-sugar foods. People with low energy needs, such as some elderly or sedentary people or people trying to lose weight, cannot afford as many calories from high-sugar foods. Most people can include moderate amounts of sugar in their diet and still meet other nutrient needs. But, as the amount of added sugar in the diet increases, intake of vitamins and minerals tends to decrease.[3,4]

1. Smith T, Lin B-H, Lee J-Y. *Taxing Caloric Sweetened Beverages: Potential Effects on Beverage Consumption, Calorie Intake, and Obesity*. 2010. USDA Economic Research Report no. 100. http://www.ers.usda.gov/Publications/err100/err100.pdf. Accessed June 23, 2014.
2. Evans AE, Springer AE, Evans MH, et al. A descriptive study of beverage consumption among an ethnically diverse sample of public school students in Texas. *J Am Coll Nutr.* 2010;29(4):387–396.
3. Smith T, Lin B-H, Lee J-Y. Op. cit.
4. Babey SH, Waostein J, Goldstein H. *Still Bubbling Over: California Adolescents Drinking More Soda and Other Sugar-Sweetened Beverages*. Health Policy Brief UCLA Cent Health Policy Res. 2009 Sep;1–8.

Read ingredient lists carefully. Food labels list the total grams of sugar in a food, which includes both sugars naturally present in foods and sugars added to foods. Many terms for added sweeteners appear on food labels. Foods likely to be high in sugar list some form of sweetener as the first, second, or third ingredient on labels. **Table 4.3** lists various forms of sugar used in foods.

Key Concepts Current recommendations suggest that Americans consume at least 130 grams of carbohydrate per day. An intake of total carbohydrates representing between 45 and 65 percent of total energy intake and a fiber intake of 14 grams per 1,000 kilocalories are associated with reduced heart disease risk. Added sugar should account for no more than 25 percent of daily energy and ideally should be much less. Americans generally eat too little fiber. An emphasis on consuming whole grains, legumes, fruits, and vegetables would help to increase fiber intake.

Nutritive Sweeteners

Nutritive sweeteners are digestible carbohydrates and therefore provide energy. They include monosaccharides, disaccharides, and **sugar alcohols** from either natural or refined sources. White sugar, brown sugar, honey, maple syrup, glucose, fructose, xylitol, sorbitol, and mannitol are just some of the many nutritive sweeteners used in foods. One slice of angel food cake, for example, contains about 5 teaspoons of sugar. Fruit-flavored yogurt contains about 7 teaspoons of sugar. Even two sticks of chewing gum contain about 1 teaspoon of sugar. Whether sweeteners are added to foods or are present

Quick Bite

Why Is Honey Dangerous for Babies?

Because honey and Karo syrup (corn syrup) can contain spores of the bacterium *Clostridium botulinum*, they should never be fed to infants younger than 1 year of age. Infants do not produce as much stomach acid as older children and adults, so *C. botulinum* spores can germinate in an infant's GI tract and cause botulism, a deadly foodborne illness.

nutritive sweeteners Substances that impart sweetness to foods and that can be absorbed and yield energy in the body. Simple sugars, sugar alcohols, and high-fructose corn syrup are the most common nutritive sweeteners used in food products.

sugar alcohols Compounds formed from monosaccharides by replacing a hydrogen atom with a hydroxyl group (–OH); commonly used as nutritive sweeteners. Also called *polyols*.

naturally, all are broken down in the small intestine and absorbed as monosaccharides and provide energy.

The sugar alcohols in sugarless chewing gums and candies are also nutritive sweeteners, but the body does not digest and absorb them fully, so they provide only about 2 kilocalories per gram, compared with the 4 kilocalories per gram that other sugars provide.

Natural Sweeteners Natural sweeteners such as honey and maple syrup contain monosaccharides and disaccharides that make them taste sweet. Honey contains a mix of fructose and glucose—the same two monosaccharides that make up sucrose. Bees make honey from the sucrose-containing nectar of flowering plants. Real maple syrup contains primarily sucrose and is made by boiling and concentrating the sap from sugar maple trees. Most maple-flavored syrups sold in grocery stores, however, are made from corn syrup with maple flavoring added.

Many fruits also contain sugars that impart a sweet taste. Usually the riper the fruit, the higher its sugar content—a ripe pear tastes sweeter than an unripe one.

Refined Sweeteners **Refined sweeteners** are monosaccharides and disaccharides that have been extracted from plant foods. White table sugar is sucrose extracted from either sugar beets or sugar cane. Molasses is a by-product of the sugar-refining process. Most brown sugar is really white table sugar with molasses added for coloring and flavor.

Manufacturers make high-fructose corn syrup (HFCS) by treating cornstarch with acid and enzymes to break down the starch into glucose. Then different enzymes convert about half the glucose to fructose. High-fructose corn syrup has about the same sweetness as table sugar but costs less to produce. As some studies indicate, increased HFCS consumption may contribute to obesity and high triglyceride levels.[52] On average, Americans consume 132 calories of HFCS each day. HFCS can be found in approximately 40 percent of items purchased at local grocery stores[53]

Sugar Alcohols The sugar alcohols sorbitol, xylitol, and mannitol occur naturally in a wide variety of fruits and vegetables and are commercially produced from other carbohydrates such as sucrose, glucose, and starch. Also known as **polyols**, these sweeteners are not as sweet as sucrose, but they do have the advantage of being less likely to cause tooth decay. The body does not digest and absorb sugar alcohols fully, so they provide only 2 kilocalories per gram compared with the 4 kilocalories per gram that other sugars provide. When sugar alcohols are used as the sweetener, the product may be sugar- (sucrose-) free, but it is not calorie-free. Check the label to be sure. Manufacturers use sugar alcohols to sweeten sugar-free products, such as gum and mints, and to add bulk and texture, provide a cooling sensation in the mouth, and retain moisture in foods. An excess intake of sugar alcohols may cause diarrhea.[54]

Non-nutritive Sweeteners

Gram for gram, most **non-nutritive sweeteners** (also called *artificial sweeteners*) are many times sweeter than nutritive sweeteners. As a consequence, food manufacturers can use much less artificial sweetener to sweeten foods. **Figure 4.13** compares the sweetness of sweeteners. Although some non-nutritive sweeteners do provide energy, their energy contribution is minimal given the small amount used.

Common non-nutritive sweeteners in the United States are saccharin, aspartame, acesulfame K, and sucralose. For people who want to decrease their intake of sugar and energy while still enjoying sweet foods, non-nutritive

Table 4.3 Forms of Sugar Used in Foods

Brown sugar
Concentrated fruit juice sweetener
Confectioners' sugar
Corn syrup
Dextrose
Galactose
Glucose
Granulated sugar
High-fructose corn syrup
Invert sugar
Lactose
Levulose
Maltose
Mannitol
Maple sugar
Molasses
Natural sweeteners
Raw sugar
Sorbitol
Turbinado sugar
White sugar
Xylitol

refined sweeteners Composed of monosaccharides and disaccharides that have been extracted and processed from other foods.

polyols See *sugar alcohols.*

Quick Bites

The Discovery of Saccharin

A German student named Constantin Fahlberg discovered saccharin in 1879 while working with organic chemicals in the lab of Ira Remsen at Johns Hopkins University. One day, while eating some bread, he noticed a strong sweet flavor. He deduced that the flavor came from the compound on his hands, $C_6H_4CONHSO_2$. Fahlberg then patented saccharin himself, without Remsen.

non-nutritive sweeteners Substances that impart sweetness to foods but supply little or no energy to the body; also called *artificial sweeteners* or *alternative sweeteners*. They include acesulfame, aspartame, saccharin, and sucralose.

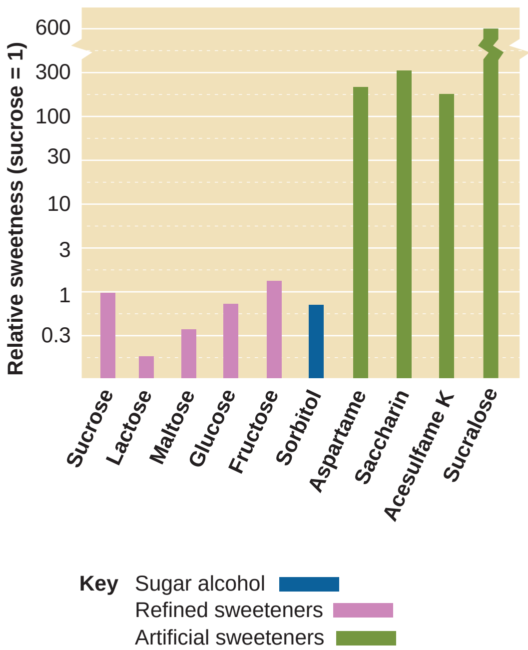


Figure 4.13 **Comparing the sweetness of sweeteners.** Non-nutritive sweeteners are much sweeter than table sugar.

sweeteners offer an alternative. Also, non-nutritive sweeteners do not contribute to tooth decay. In the U.S., our consumption of artificial sweeteners in foods and beverages has increased; however, only 15% of the population regularly consume foods with artificial sweeteners and average intakes are consistently below the acceptable daily intakes set by the FDA.[55]

Saccharin Discovered in 1879 and used in foods ever since, **saccharin** tastes about 300 times sweeter than sucrose. In the 1970s, research indicated that very large doses of saccharin were associated with bladder cancer in laboratory animals. As a result, in 1977, the U.S. Food and Drug Administration (FDA) proposed banning saccharin from use in food. Widespread protests by consumer and industry groups, however, led Congress to impose a moratorium on the saccharin ban. Every few years, the moratorium was extended, and products containing saccharin had to display a warning label about saccharin and cancer risk in animals. In 2000, convincing evidence of safety led to saccharin's removal from the National Toxicology Program's list of potential cancer-causing agents,[56] and the U.S. Congress repealed the warning label requirement. In Canada, although saccharin is banned from food products, it can be purchased in pharmacies and carries a warning label.

Aspartame The artificial sweetener **aspartame** is a combination of two amino acids, phenylalanine and aspartic acid. When digested and absorbed, it provides 4 kilocalories per gram. However, aspartame is so many times sweeter than sucrose that the amount used to sweeten foods contributes virtually zero calories to the diet, and it does not promote tooth decay. The FDA approved aspartame for use in some foods in 1981 and for use in soft drinks in 1983. More than 90 countries allow aspartame in products such as beverages, gelatin desserts, gums, and fruit spreads. Because heating destroys the sweetening power of aspartame, this sweetener cannot be used in products that require cooking.

Acesulfame K Marketed under the brand name Sunette, **acesulfame K** is about 200 times sweeter than table sugar. The FDA approved its use in the

Position Statement: Academy of Nutrition and Dietetics

Use of Nutritive and Non-nutritive Sweeteners

It is the position of the Academy of Nutrition and Dietetics that consumers can safely enjoy a range of nutritive and non-nutritive sweeteners when consumed in a diet that is guided by current federal nutrition recommendations, such as the *Dietary Guidelines for Americans* and the Dietary Reference Intakes, as well as individual goals and personal preference.

Source: Reproduced from Position of the American Dietetic Association: Use of nutritive and non-nutritive sweeteners. *J Am Diet Assoc*. 2012;112(5):739–758.

saccharin [SAK-ah-ren] An artificial sweetener that tastes about 300 to 700 times sweeter than sucrose.

aspartame [AH-spar-tame] An artificial sweetener composed of two amino acids. It is 200 times sweeter than sucrose and sold by the trade name NutraSweet.

acesulfame K [ay-see-SUL-fame] An artificial sweetener that is 200 times sweeter than common table sugar (sucrose). Because it is not digested and absorbed by the body, acesulfame contributes no calories to the diet and yields no energy when consumed.

United States in 1988. Acesulfame K provides no energy, because the body cannot digest it. Food manufacturers use acesulfame K in chewing gum, powdered beverage mixes, nondairy creamers, gelatins, and puddings. Heat does not affect acesulfame K, so it can be used in cooking.

sucralose An artificial sweetener made from sucrose; it was approved for use in the United States in 1998 and has been used in Canada since 1992. Sucralose is non-nutritive and about 600 times sweeter than sugar.

Sucralose Sold under the trade name Splenda, **sucralose** was approved for use in the United States in 1998 and has been used in Canada since 1992. Sucralose is made from sucrose, but the resulting compound is non-nutritive and about 600 times sweeter than sugar. Sucralose has been approved for use in a wide variety of products, including baked goods, beverages, gelatin desserts, and frozen dairy desserts. It also can be used as a tabletop sweetener, with consumers adding it directly to food.

Neotame Neotame was approved as a food additive in 2002. It can be used as a tabletop sweetener or added to foods. Neotame is a derivative of a dipeptide containing aspartic acid and phenylalanine—the same two amino acids that make up aspartame. However, chemical modifications to the structure make it 30 to 40 times sweeter than aspartame, or about 7,000 to 13,000 times sweeter than sucrose.

stevia See *stevioside.*

Stevioside Stevioside (also known as **stevia**) is derived from the stevia plant found in South America. This plant's leaves have been used for centuries to sweeten beverages and make tea. In Japan, stevioside has been used as a sweetener since the 1970s. This substance is 300 times sweeter than sucrose, but its effect on metabolism in the body has been incompletely investigated. Because the FDA has not approved stevioside as an additive nor accepted it as a GRAS substance, it cannot be used in food in the United States. With demands for low-carbohydrate, low-sugar, all-natural food products, stevia has gained attention as a natural sweetener.

Recommendations for Artificial Sweetener Intake

In attempt to control body weight, many Americans have turned to artificial sweeteners to reduce calorie intake. Non-nutritive sweeteners have been determined to be safe and have been approved by the FDA for use in the U.S. food supply. Academy of Nutrition and Dietetics (AND) states that consumers can safely use artificial sweeteners in moderation as part of a well-balanced and nutritious diet by following recommendation of the Dietary Guidelines for Americans and the Dietary Reference Intakes.[57] Recommendations for the American Diabetes Association and The National Cancer Institute echo that artificial sweeteners are safe and do not cause cancer when used at levels that do not exceed those established by the FDA.[58,59]

Health Effects of Artificial Sweeteners

Several safety concerns have been raised regarding the regular use of artificial sweeteners. Some groups claim that aspartame, for example, could cause high blood levels of phenylalanine. In reality, high-protein foods such as meats contain much more phenylalanine than foods sweetened with aspartame. The amounts of phenylalanine in aspartame-sweetened foods are not high enough to cause concern for most people. However, people with a genetic disease called **phenylketonuria (PKU)** cannot properly metabolize the amino acid phenylalanine, so they must carefully monitor their phenylalanine intake from all sources, including aspartame.

phenylketonuria (PKU) An inherited disorder caused by a lack or deficiency of the enzyme that converts phenylalanine to tyrosine.

Although some people report headaches, dizziness, seizures, nausea, or allergic reactions with aspartame use, scientific studies have failed to confirm these effects, and most experts believe aspartame is safe for healthy people.[60] The FDA sets a maximum allowable daily intake of aspartame of

50 milligrams per kilogram of body weight.[61] This amount of aspartame equals the amount in sixteen 12-ounce diet soft drinks for adults and eight diet soft drinks for children.

Sugar substitutes can help you lower sugar intake, but foods with these substitutes may not provide less energy than similar products containing nutritive sweeteners. Rather than sugar, other energy-yielding nutrients, such as fat, are the primary source of the calories in these foods. Also, as sugar-substitute use in the United States has increased, so has sugar consumption—an interesting paradox!

Key Concepts Sweeteners add flavor to foods. Nutritive sweeteners provide energy, whereas non-nutritive sweeteners provide little or no energy. The body cannot tell the difference between sugars derived from natural and refined sources.

This label highlights all the carbohydrate-related information you can find on a food label. Look at the center of the Nutrition Facts label and you'll see the Total Carbohydrates along with two of the carbohydrate "subgroups"—Dietary Fiber and Sugars. Recall that carbohydrates are classified into simple carbohydrates and the two complex carbohydrates starch and fiber.

Using this food label, you can determine all three of these components. There are 19 total grams of carbohydrate, with 14 grams coming from sugars and 0 grams from fiber. This means the remaining 5 grams must be from starch, which is not required to be listed separately on the label. Without even knowing what food this label represents, you can decipher that it contains a high proportion of sugar (14 of the 19 grams) and is probably sweet. If this is a fruit juice, that level of sugar would be expected; but, if this is cereal, you'd be getting a lot more sugar than complex carbohydrates and probably wouldn't be making the best choice!

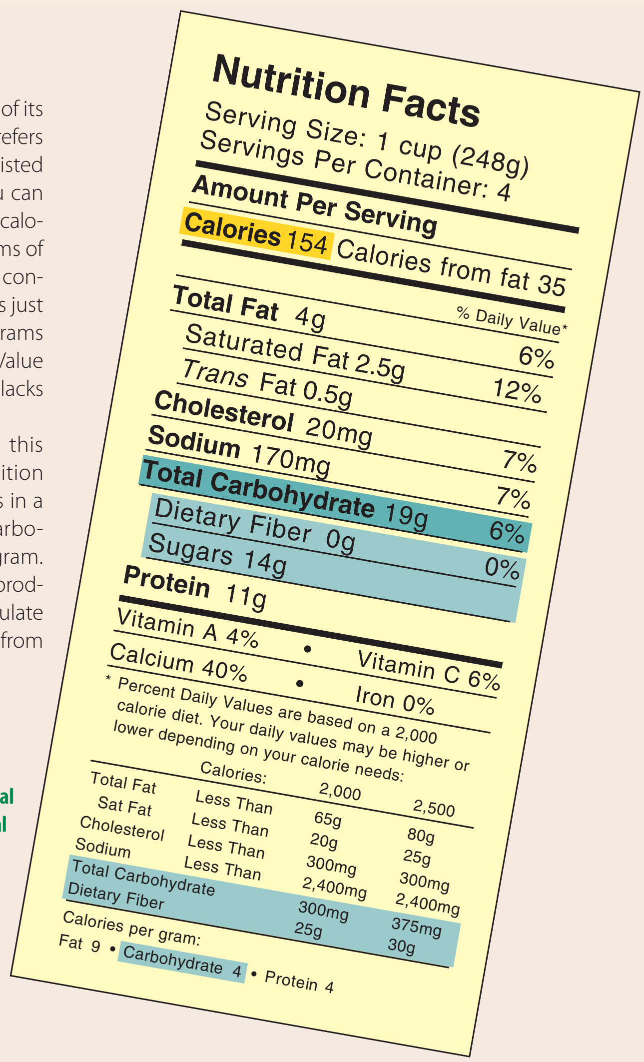
Do you see the "6%" listed to the right of "Total Carbohydrate"? This doesn't mean that the food item contains 6 percent of its calories from carbohydrate. Instead, it refers to the Daily Value for carbohydrates listed at the bottom of the label. There you can see that a person consuming 2,000 kilocalories per day should consume 300 grams of carbohydrates each day. This product contributes 19 grams per serving, which is just 6 percent of the Daily Value of 300 grams per day. Note that the Percent Daily Value for fiber is "0%" because this food item lacks fiber.

The last highlighted section on this label, at the bottom of some Nutrition Facts labels, is the number of calories in a gram of carbohydrate. Recall that carbohydrates contain 4 kilocalories per gram. Armed with this information and the product's calorie information, can you calculate the percentage of calories that come from carbohydrate?

Here's how:

19 g carbohydrate × 4 kcal per g = 76 carbohydrate kcal

76 carbohydrate kcal ÷ 154 total kcal = 0.49, or 49 percent carbohydrate kcal



Learning Portfolio

Key Terms

	page		
acesulfame K	119	insulin	107
alpha (α) bonds	103	ketone bodies	106
amylopectin	99	ketosis	106
amylose	99	lactose	98
aspartame	119	lignins	101
beta (β) bonds	103	maltose	98
beta-glucans	102	monosaccharides	97
bran	112	mucilages	101
cellulose	100	non-nutritive sweeteners	118
chitin	102	nutritive sweeteners	117
chitosan	102	oligosaccharides	98
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dental caries	116	pectins	101
dietary fiber	100	phenylketonuria	120
disaccharides	97	polyols	118
endosperm	112	polysaccharides	99
epinephrine	107	psyllium	101
fructose	97	refined sweeteners	118
functional fiber	100	resistant starch	99
galactose	97	saccharin	119
germ	112	simple carbohydrates	97
glucagon	107	starch	99
glucose	97	stevia	120
glycogen	99	sucralose	120
gums	101	sucrose	98
hemicelluloses	100	sugar alcohols	117
husk	112	total fiber	100

Study Points

- Carbohydrates include the simple sugars and complex carbohydrates.
- Monosaccharides are the building blocks of carbohydrates.
- Three monosaccharides are important in human nutrition: glucose, fructose, and galactose.
- The monosaccharides combine to make disaccharides: sucrose, lactose, and maltose.
- Starch, glycogen, and fiber are long chains (polysaccharides) of monosaccharide units; starch and glycogen contain only glucose.
- Carbohydrates are digested by enzymes from the mouth, pancreas, and small intestine and absorbed as monosaccharides.
- The liver converts the monosaccharides fructose and galactose to glucose.
- Blood glucose levels rise after eating and fall between meals. Two pancreatic hormones, insulin and glucagon, regulate blood glucose levels, preventing extremely high or low levels.
- The main function of carbohydrates in the body is to supply energy. In this role, carbohydrates spare protein for use in making body proteins and allow for the complete breakdown of fat as an additional energy source.
- Carbohydrates are found mainly in plant foods as starch, fiber, and sugar.
- In general, Americans consume more sugar and less starch and fiber than is recommended.
- Carbohydrate intake can affect health. Excess sugar can contribute to low nutrient intake, excess energy intake, and dental caries.
- Diets high in complex carbohydrates, including fiber, have been linked to reduced risk for GI disorders, heart disease, and cancer.

Study Questions

1. What are the differences among a monosaccharide, disaccharide, and polysaccharide?
2. What advantage does the branched-chain structure of glycogen provide compared to a straight chain of glucose?
3. Describe the difference between starch and fiber.
4. Which blood glucose regulation hormone is secreted in the fed state? The fasting state?
5. Which foods contain carbohydrates?
6. What are the most common non-nutritive sweeteners used in the United States?
7. How will eating excessive amounts of added sugars affect health?
8. List the benefits of eating more fiber. What are the consequences of eating too much? Too little?

Try This

Banana Basics

Purchase one banana that is covered with brown spots (if necessary, let it sit on the counter for several days). Purchase another banana with a yellow skin, possibly with a greenish tinge, and no brown spots. Note that this may require two trips to the market.

Now it's time for the taste test. Mash each banana separately so both have the same consistency and texture. Taste each one. Which is sweeter?

As ripening begins, starch is converted to sugar. As fruit continues to ripen, sugar content increases. The sugar content of ripe, spotted bananas is higher than that of a green banana—by 20 percent or more!

The Sweetness of Soda

This experiment is to help you understand the amount of sugar found in a can of soda. Take a glass and fill it with 12 ounces (1 1/2 cups) of water. Using a measuring spoon, add 10 to 12 teaspoons of sugar to the water. Stir the sugar water until all the sucrose has dissolved. Now sip the water. Does it taste sweet? It shouldn't taste any sweeter than a can of regular soda. This is the amount of sugar found in one 12-ounce can!

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