Chapter 4

Carbohydrates: Simple Sugars and Complex Chains

Revised by Diane McKay and Emily Mohn

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. Many people choose honey or agave instead of white sugar because they think they are more "natural." What do you think?
4. What are the downsides to including too many carbohydrates in your diet?

CHAPTER Menu

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. Identify healthy carbohydrate selections for an optimal diet.
5. Examine the contributions of carbohydrates to health.

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?

THINK About It 1

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.

Quick Bite

Is Pasta a Chinese Food?

Noodles were used in China as early as the first century; Marco Polo brought them to Italy in the 1300s.

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), hydrogen (H), and oxygen (O) in the ratio of two hydrogen atoms and one oxygen atom for every one carbon atom (CH_2O). Two

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

Cassava: © Vinicius Tupinamba/Shutterstock; rice: © Mircea BEZERGHEANU/Shutterstock; wheat: © Ayd/Shutterstock; corn: © Krunoslav Cestar/Shutterstock.

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

Why Is This Important? The media often discuss "carbs" and "sugars" as a single entity, but sugars are just one family of carbs. Learning how to identify members of the sugar family (and distinguish them from other carbohydrates) will help you understand that not all sugars are created equal and that the consumption of each type has different effects on our bodies.

- **simple carbohydrates** Sugars composed of a single sugar molecule (a monosaccharide) or two joined sugar molecules (a disaccharide).
- **monosaccharides [mon-uh-SACK-uh-rides]** 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.

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.

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.

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.

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.

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

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

▶ **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 [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.

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

▶ **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.

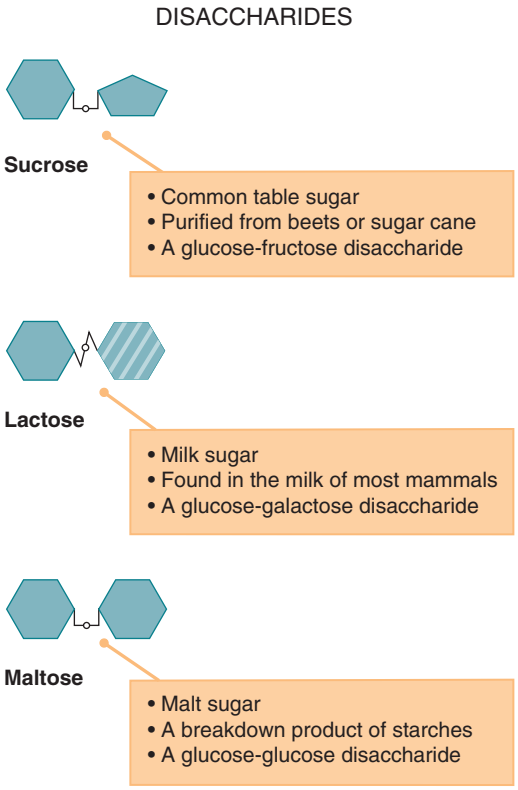


FIGURE 4.2 The disaccharides: sucrose, lactose, and maltose. The three monosaccharides pair up in different combinations to form the three disaccharides.

milk (approximately 4.5 grams per 100 milliliters), so human milk tastes sweeter than cow's milk.

Maltose

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

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

Why Is This Important The complex carbohydrates are a large family of molecules that range from as few as three linked monosaccharides to hundreds or even thousands of linked monosaccharides. Some we can digest, others we cannot. Learning where to find complex carbohydrates in your diet and how they differ in structure will help you understand how they influence health in different ways.

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

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

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. Certain human milk oligosaccharides act as prebiotics—they resist digestion in the small intestine, and after reaching the large intestine they become a food source for the "good bacteria" that are part of the gut microbiota.[3] Milk oligosaccharides also play important roles in children's diets; they can protect infants from disease-causing agents by binding to these agents in the intestines, and they provide sialic acid, a compound essential for normal brain development.[4]

Polysaccharides

▶ **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.

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.[5] 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**. Green bananas and cooked legumes such as peas are high in resistant starch.[6] Foods such as potatoes, rice, pasta, breakfast cereals, and bread are low in resistant starch; however, resistant starch forms when these types of foods are cooked and subsequently cooled.

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.[7] This is because after an animal is slaughtered, enzymes in the muscle tissue break down most glycogen within 24 hours. Plant foods also do not contain glycogen, so 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. Normally, the body can store only about 200 to 500 grams of glycogen at a time.[8] Some athletes practice a carbohydrate-loading regimen, 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]

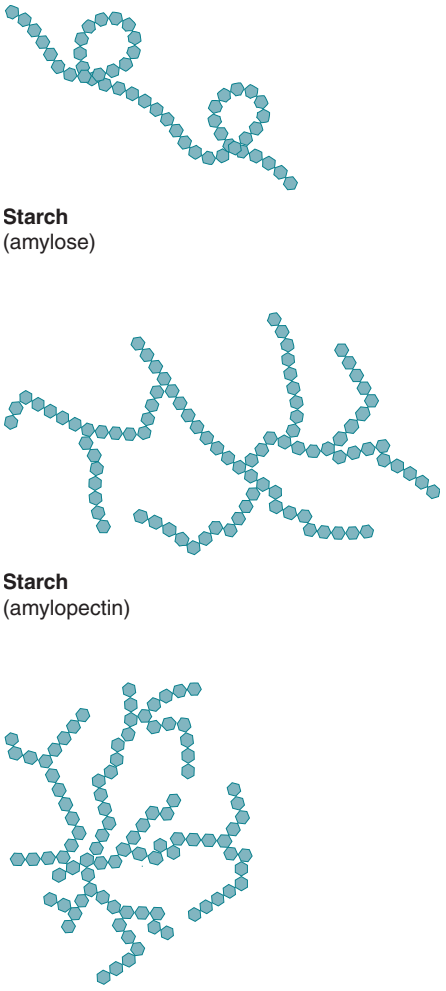


FIGURE 4.3 Starch and glycogen. Plants have two main types of starch—amylose, which has long unbranched chains of glucose, and amylopectin, which has branched chains. Animals store glucose in highly branched chains called glycogen.

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.

- **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.

- **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.
- **soluble fiber** Nondigestible carbohydrates that dissolve in water.
- **insoluble fiber** Nondigestible carbohydrates that do not dissolve in water.
- **cellulose [SELL-you-los]** A straight-chain polysaccharide composed of hundreds of glucose units linked by beta bonds. It is nondigestible by humans and is a component of dietary fiber.

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 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.

Many types of dietary fiber resemble starches—they are polysaccharides, but they are not digested in the human GI tract. Fiber is often classified as being either soluble or insoluble. **Soluble fiber** dissolves easily in water. When it attracts water in the GI tract, it becomes gel-like, slowing digestion and absorption. Examples of soluble fiber include oligosaccharides, some hemicelluloses and beta-glucans (ß-glucans), pectins, gums, and mucilages. Conversely, **insoluble fiber** does not dissolve in water. This type of fiber adds bulk to stools and speeds up their passage through the digestive tract. Examples of insoluble fiber include cellulose, some hemicelluloses and β-glucans, and lignins. 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**).

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.

TABLE 4.1
Foods Rich in Dietary Fiber

Fruits		**Nuts and Seeds**	
Apples	Grapefruit	Almonds	Sesame seeds
Bananas	Mangos	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
Carrots	Sprouts		

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

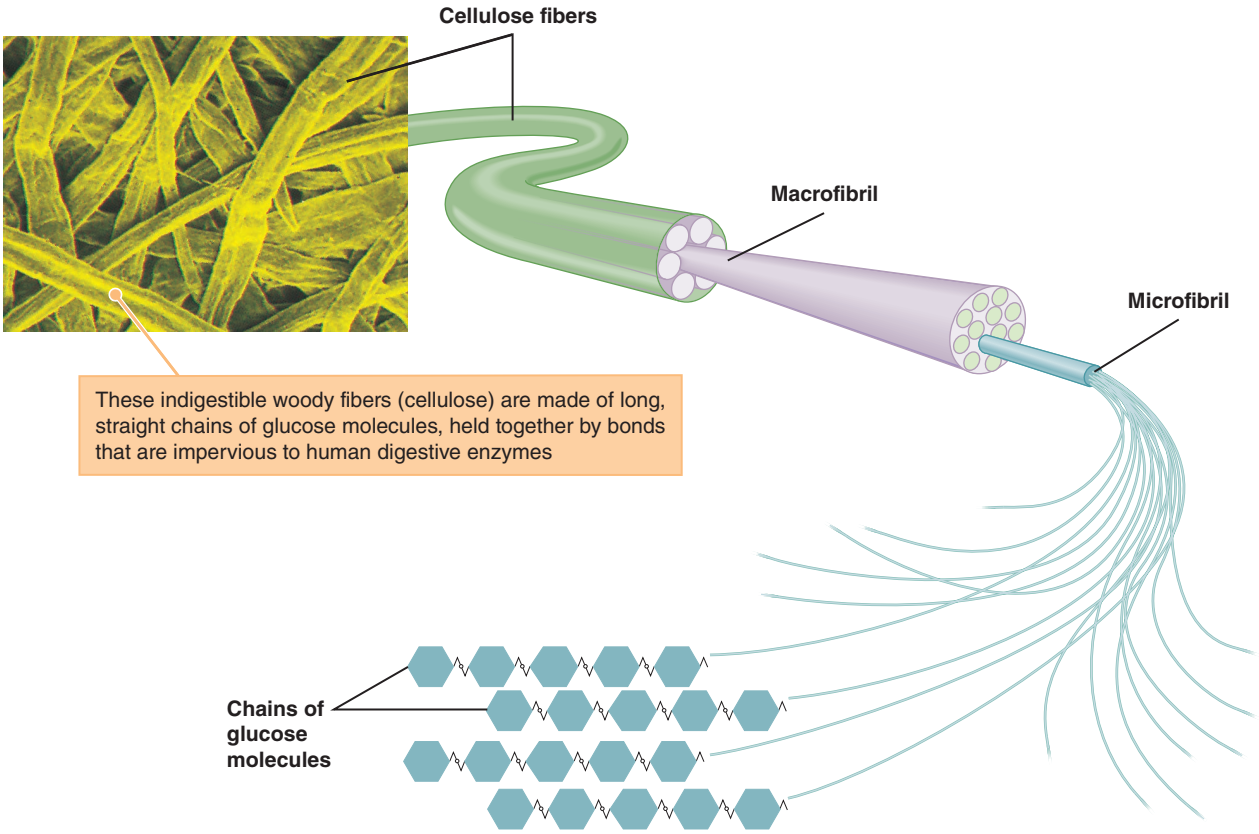


FIGURE 4.4 The structure of cellulose. Cellulose forms the indigestible, fibrous component of plants and is part of grasses, trees, fruits, and vegetables.

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 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.

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 (thick and sticky) when mixed with water. It is the main component in the laxative Metamucil and is added to some breakfast cereals.

- **hemicellulose [hem-ih-SELL-you-los-es]** A group of large polysaccharides in dietary fiber that are fermented more easily than cellulose.
- **pectin** A type of dietary fiber found in fruits.
- **gums** Dietary fibers, which contain galactose and other monosaccharides, found between plant cell walls.
- **mucilage** Gelatinous soluble fiber containing galactose, mannose, and other monosaccharides; found in seaweed.
- **psyllium** The dried husk of the psyllium seed.

- **lignin [LIG-nin]** Insoluble fiber composed of multi-ring alcohol units that constitute the only noncarbohydrate component of dietary fiber.
- **beta-glucan** 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.

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.

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] (See **FIGURE 4.5** for a summary classification of the most important dietary carbohydrates.)

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.

Key Concepts Complex carbohydrates include starch, glycogen, and dietary 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 (both polysaccharides and oligosaccharides) 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.

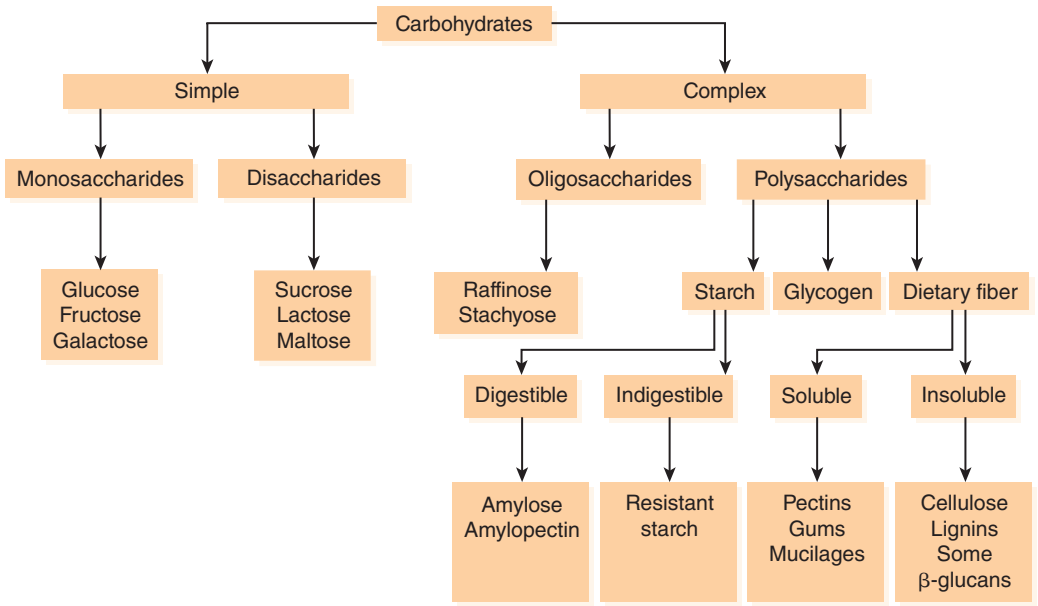


FIGURE 4.5 Summary of types of carbohydrates. Carbohydrates are classified as simple or complex. Simple carbohydrates include monosaccharides, such as glucose, fructose, and galactose, and disaccharides, such as sucrose, lactose, and maltose. Complex carbohydrates include oligosaccharides, such as raffinose and stachyose, as well as polysaccharides, such as glycogen, digestible starch (amylose and amylopectin), indigestible (resistant) starch, soluble dietary fiber (e.g. pectins), and insoluble dietary fiber (e.g. cellulose).

Carbohydrate Digestion and Absorption

Why Is This Important? Before carbohydrates are used as an energy source, you must first digest, absorb, and convert them into glucose molecules. Learning the steps of carbohydrate digestion and absorption can help you better understand why some foods are digested more quickly than others, why certain foods may make you feel full longer after eating, and why some people can enjoy foods like milk and cheese while others must avoid them.

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 4.6** 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

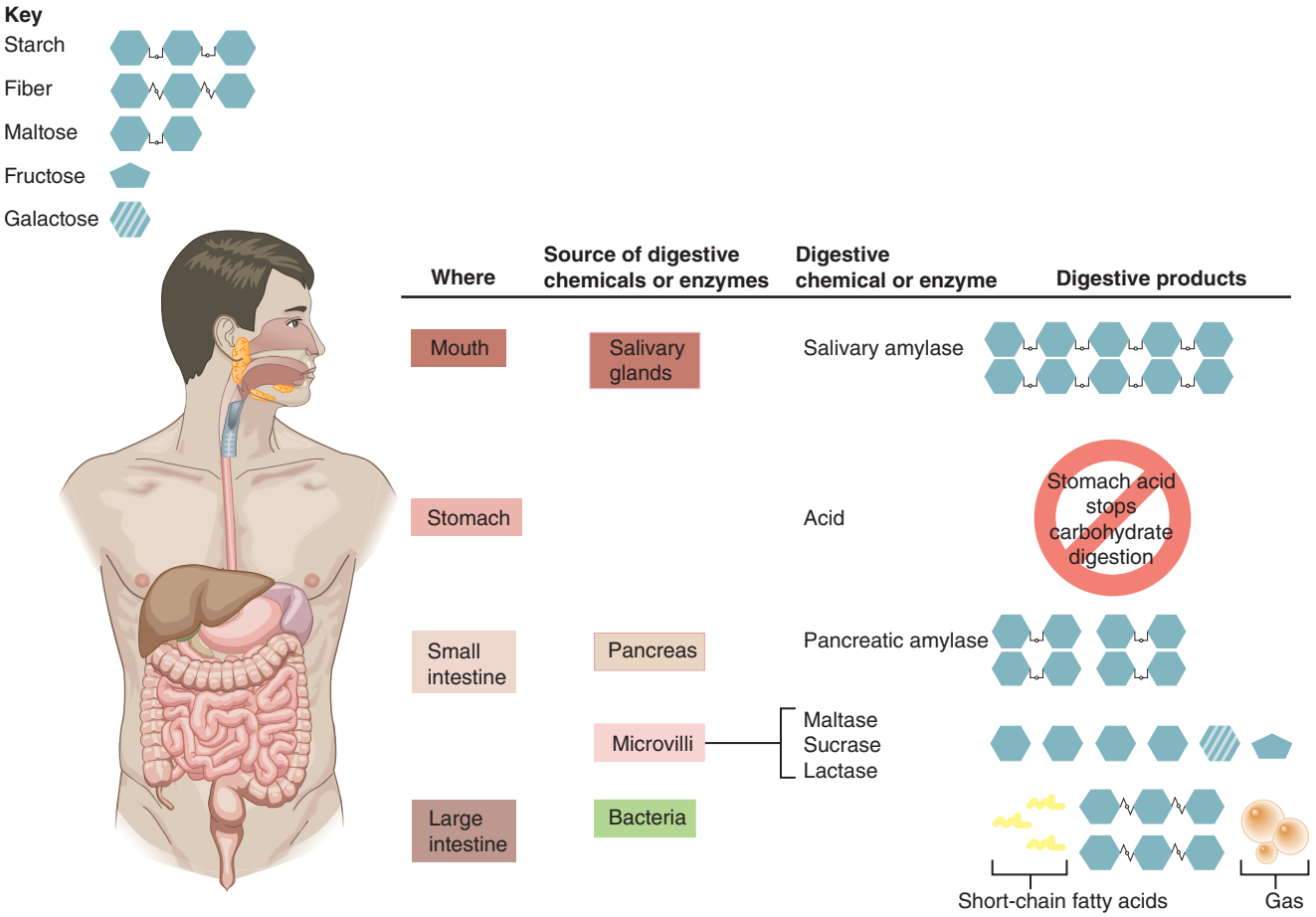


FIGURE 4.6 Carbohydrate digestion. Most carbohydrate digestion takes place in the small intestine.

protein) to lose its shape and function. Carbohydrate digestion starts again in the small intestine. This is how soluble fibers, such as pectins and gums, provide a feeling of fullness—they attract water and 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.

▶ **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 digestible beta bonds, and cellulose contains nondigestible beta bonds.

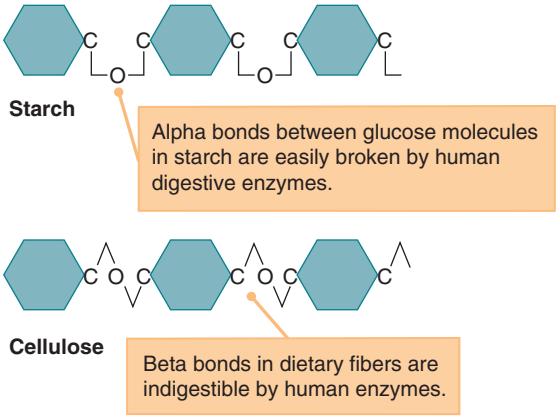


FIGURE 4.7 Alpha bonds and beta bonds. Human digestive enzymes can easily break the alpha bonds in starch, but they cannot break the beta bonds in cellulose.

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 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 4.7**.)

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 cellulose, an insoluble fiber. Fiber remaining intact in the small intestine acts as a bulky barrier between certain nutrients (for example, glucose) and digestive enzymes, delaying their digestion and absorption. Additionally, soluble fiber can bind cholesterol and bile in the small intestine, inhibiting its absorption. This can lead to lower blood cholesterol levels, which is linked to a decreased risk for cardiovascular disease.

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, thereby reducing the symptoms of lactose intolerance. The commercial product Beano is another example of an enzyme preparation designed to break down larger sugars (in this case, 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.

▶ **lactose intolerance** The inability to digest lactose, leading to diarrhea, bloating, and gas whenever lactose-containing foods are consumed.

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

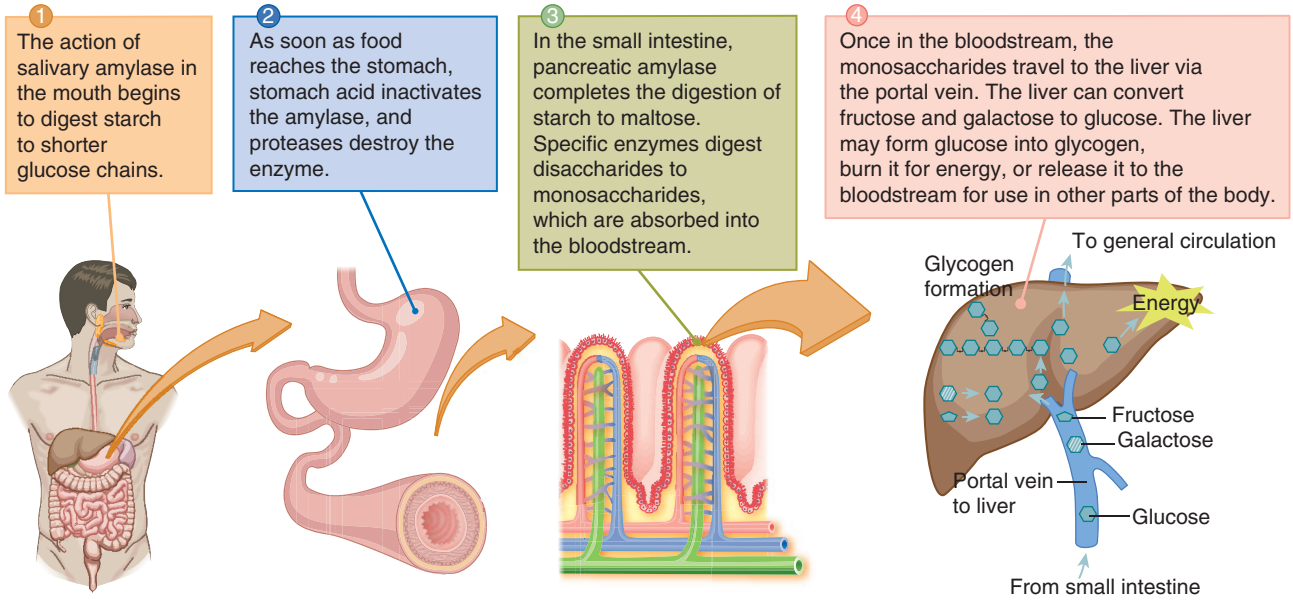


FIGURE 4.8 Travels with carbohydrate. 1. Carbohydrate digestion begins in the mouth. 2. Stomach acid halts carbohydrate digestion. 3. Carbohydrate digestion resumes in the small intestine, where monosaccharides are absorbed. 4. The liver converts fructose and galactose to glucose, which it can assemble into chains of glycogen, release to the blood, or use for energy.

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 that you learned about in Chapter 3. Glucose and galactose are absorbed via active transport, which requires energy in the form of adenosine triphosphate (ATP). Fructose, on the other hand, is absorbed via facilitated diffusion. After absorption, 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 4.8** 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 in the Body

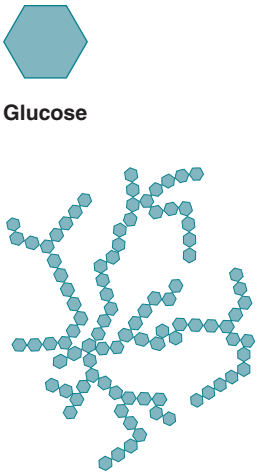
Why Is This Important? In order to fully appreciate glucose's role as the primary energy source for cells (as opposed to fat and protein), it's important to understand the mechanisms by which your body regulates glucose levels in response to food intake and what happens when these processes go awry.

Through the processes of digestion and absorption, most of the carbohydrates in our diet from vegetables, fruits, grains, and milk becomes glucose. (The exceptions are fiber and resistant starch.) Glucose has one major role—to supply energy for the body.

Roles of Glucose

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.



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.

Preventing Ketosis

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, and chronic alcoholism. To prevent **ketosis**, the buildup of ketone bodies, the body needs a minimum of 50 to 100 grams of carbohydrate daily.[20]

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 4.9**.)

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 liver glycogen, releasing glucose into the bloodstream. (See Figure 4.9b.) It also stimulates the synthesis of glucose from protein by a process called gluconeogenesis. Another hormone, **epinephrine** (also called

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

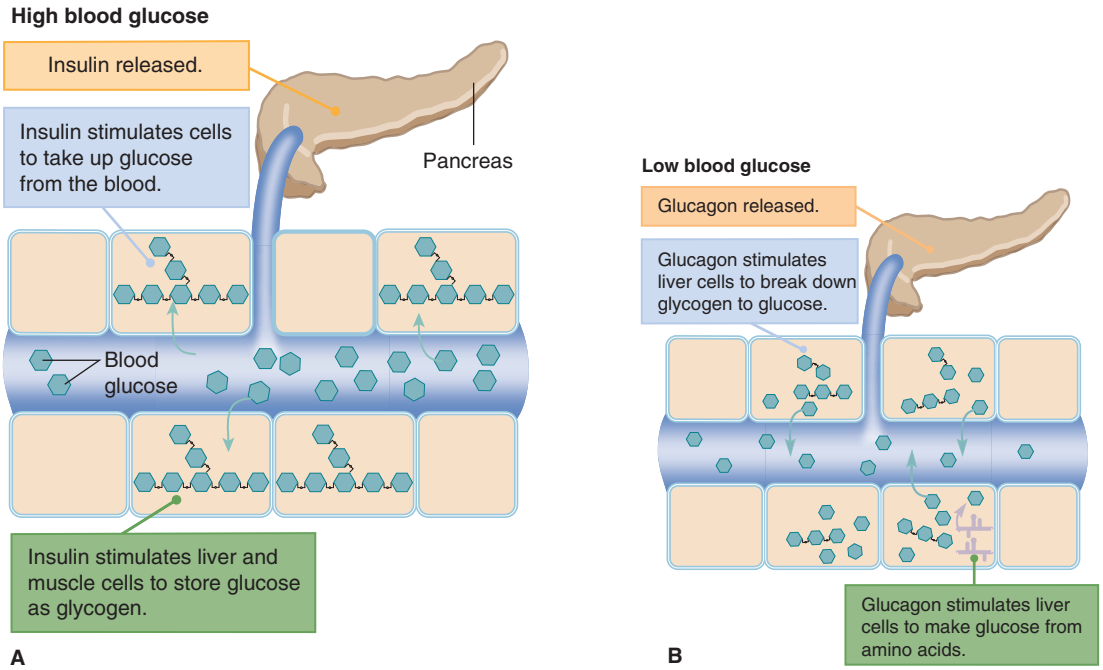


FIGURE 4.9 Regulating blood glucose levels. Insulin and glucagon have opposing actions. **a.** Insulin acts to lower blood glucose levels, and **b.** glucagon acts to raise them.

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.

diabetes mellitus A chronic disease in which uptake of glucose into body cells is impaired, resulting in higher glucose levels in blood and urine. Type 1 is caused by impaired insulin release from the pancreas. Type 2 occurs when body cells, such as fat and muscle cells, have an impaired response to insulin.

glycemic index Measures the effect of food on blood glucose levels. It is the ratio of blood glucose response after eating a test food to blood glucose response after eating the same amount of white bread or glucose.

Diabetes mellitus is a chronic disease in which blood glucose levels are not properly regulated. People suffering from this condition have impaired uptake of blood glucose by body cells, resulting in high glucose levels in their blood and urine. There are two types of diabetes mellitus. Type 1 diabetes is caused by decreased release of insulin from the pancreas. In type 2 diabetes, body cells, such as liver and muscle cells, do not respond normally to insulin action.

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 (see **FIGURE 4.10**).

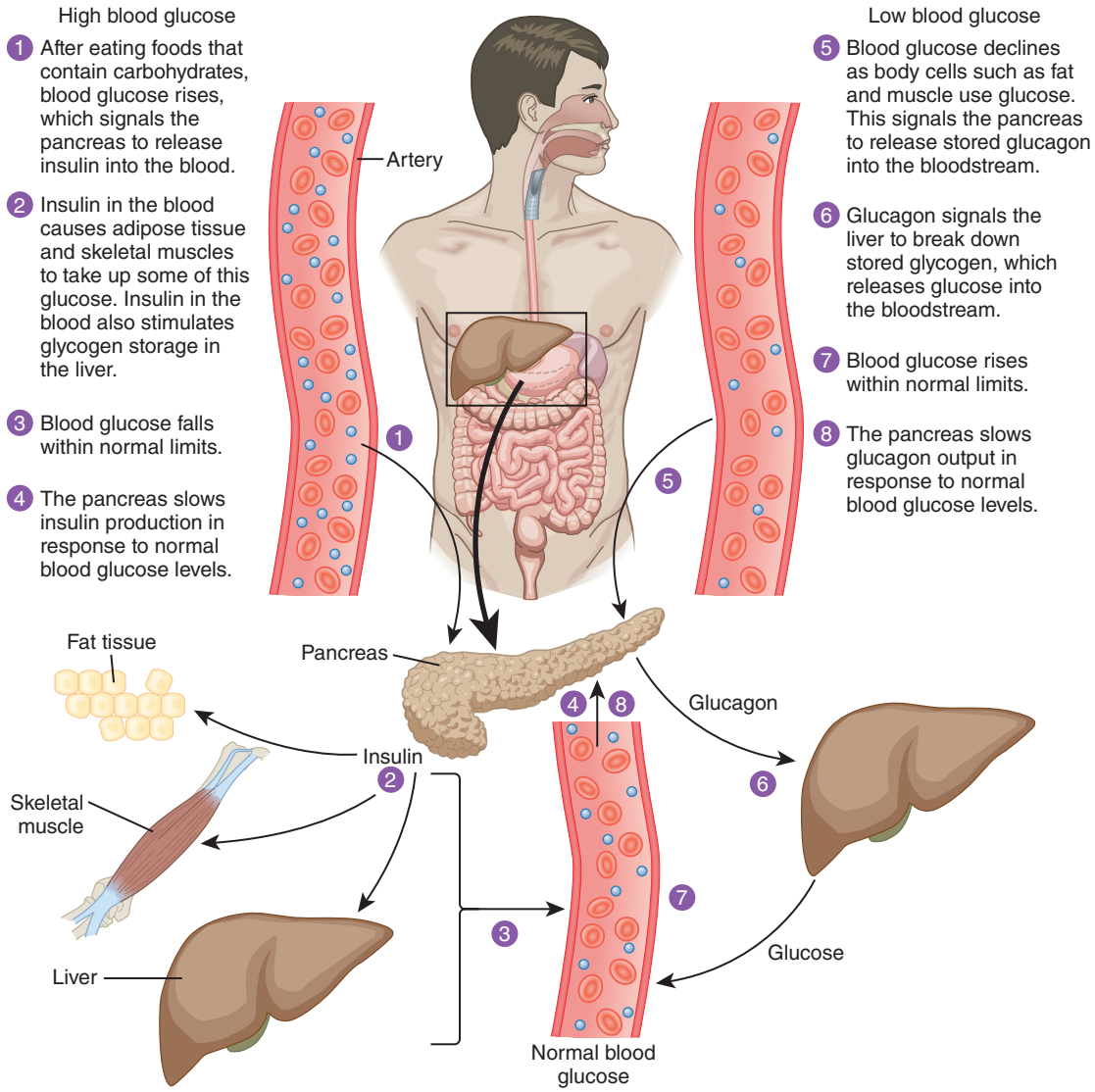


FIGURE 4.10 Blood glucose regulation. The regulatory system for normal blood glucose comes by way of the pancreas monitoring blood glucose and adjusting its concentration as necessary, using the action of two opposing hormones: insulin and glucagon. When blood glucose is too high, the pancreas releases 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.

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

The 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.[a] Several popular weight-loss diets use the glycemic index to guide food choices.

How Is the Glycemic Index Measured?

The glycemic index 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, or from pure glucose. Therefore, the glycemic index is expressed as a percentage, ranging from 1–100, with 100 being the standard food.[b]

Foods with a high glycemic index trigger a sharp rise in blood glucose, followed by a dramatic fall, often to levels that are 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, thereby making blood glucose easier to manage. However, the effects of high or low glycemic index foods on people without diabetes are 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.[c] 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, the cooking process, and the presence of fat, dietary fiber, and other food components in a meal or snack all affect the glycemic response.[d,e] In a person's diet, it is the glycemic index of mixed meals, referred to as the glycemic load, that is more important than the effect of individual foods on blood glucose.[f] Specifically, the glycemic load takes into account the amount of carbohydrate consumed. Glycemic load is calculated by multiplying the glycemic index of a food by the amount of carbohydrate in a serving. Because the glycemic index is a percentage, the resulting value is divided by 100. High-glycemic-index foods do not necessarily have high glycemic loads if there is a relatively small amount of carbohydrate in one serving. For example, watermelon has a high glycemic index (72), but it mostly consists of water, and there is only a small amount of carbohydrate per serving.

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.[g,h] Epidemiological studies suggest that such diets also reduce the risk of colon and other cancers and may help reduce the risk of heart disease.[i,j] Diets with a low glycemic load are associated with favorable blood lipid profiles.[k] Also, studies indicate that the effectiveness of low-fat, high-carbohydrate diets for weight loss can be improved by reducing the glycemic load.[l]

TABLE A
Glycemic Index of Some Foods Compared to Pure Glucose*

Food	Glycemic Index	Food	Glycemic Index
Bakery Products		***Fruits***	
Vanilla cake	42 ± 4	Apples	39 ± 3
Doughnut	75 ± 7	Watermelon	72 ± 13
Bread/Breakfast Foods		Dates	42 ± 4
Bagel	69	***Legumes***	
Wheat and rye bread	40	Baked beans	40 ± 3
Pita bread	68 ± 5	Black-eyed peas	38
All-Bran®	44 ± 6	Pinto beans	33
Froot Loops®	69 ± 9	***Pasta***	
Porridge	55 ± 2	Lasagna	53
Cereal Grains		Spaghetti	49 ± 3
Couscous	65 ± 7	***Vegetables***	
Sweet corn	52 ± 5	Pumpkin	64
Japonica short-grain brown rice	62 ± 5	Carrots	39 ± 4
Instant white rice	87 ± 2	Baked potato	86 ± 6
Dairy Foods		***Candy***	
Ice cream	57	Marshmallow	62 ± 6
Full-fat milk	41 ± 2	M&M's®, peanut	33 ± 3

* Glycemic response to pure glucose is 100.

Data from Atkinson FS, Foster-Powell K, Brand-Miller. International Tables of Glycemic Index Values: 2008. 2008 Diab Care; 31(12).

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, given that these studies can show an association but cannot prove the cause. Additionally, results on the effectiveness of low glycemic index/load diets on health outcomes have been mixed.[m,n]

TABLE B
Sample Substitutions for High-Glycemic-Index Foods*

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

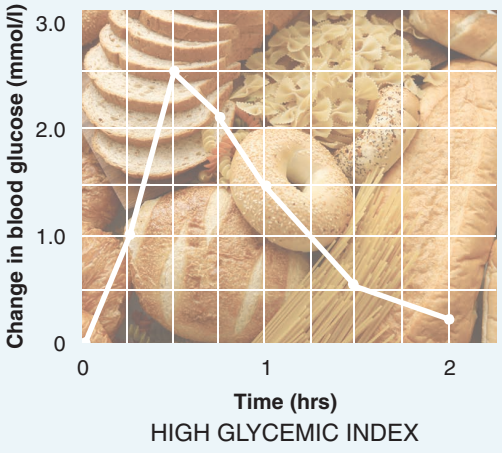
* Low glycemic index = 55 or less; medium = 56–69; high = 70 or more.

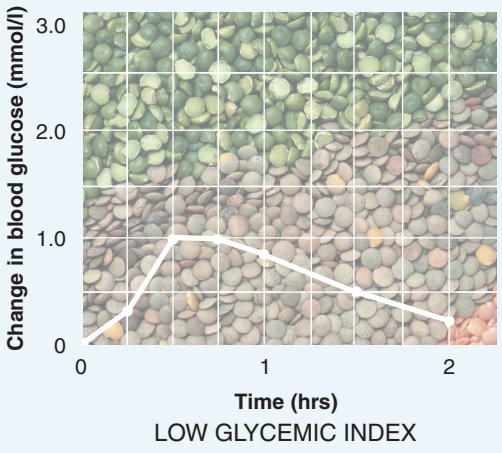
Some believe the glycemic index is too complex for most people to use effectively. A recent study evaluating the reliability of glycemic index values in healthy adults concluded that there are too many factors influencing the accuracy and precision of glycemic index estimates for them to be useful as a basis for making food-based recommendations.[o] The American Diabetes Association has not endorsed widespread adoption of glycemic index diets for those with diabetes.[p]

What's the Bottom Line?

Like many other nutrition issues, the usefulness of the 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 studies on the reliability of glycemic index values should be replicated. 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.[q] 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!

a Mondazzi L, Arcelli, E. Glycemic index in sport nutrition. *J Am Coll Nutr*. 2009;28(Suppl):455S-463S.
b 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.
c Foster-Powell K, Holt SH, Brand-Miller JC. International table of glycemic index and glycemic load values: 2002. *Am J Clin Nutr*. 2002;76:5-56.
d Pi-Sunyer FX. Glycemic index and disease. *Am J Clin Nutr*. 2002;76(Suppl):290S-298S.
e Fernandes G, Velangi A, Wolever T. Glycemic index of potatoes commonly consumed in North America. *J Am Diet Assoc*. 2005;105(4):557-562.
f Franz M, Powers M, Leontos C, et al. The evidence for medical nutrition therapy for type 1 and type 2 diabetes in adults. *J Am Diet Assoc*. 2010;110(12):1852-1889.
g Finley C, Barlow C, Halton T, Haskell W. Glycemic index, glycemic load, and prevalence of the metabolic syndrome in the Copper Center Longitudinal Study. *J Am Diet Assoc*. 2010;110(12):1820-1829.
h Lowering the glycemic index of your diet pays health dividends. *Tufts University Health and Nutrition Letter*. September 2013.
i Hu J, La Vecchia C, Augustin LS, et al. Glycemic index, glycemic load and cancer risk. *Ann Oncol*. 2013;24(1):245-251.
j Mirrahimi A, Chiavaroli L, Srichaikul K, et al. The role of glycemic index and glycemic load in cardiovascular disease and its risk factors: a review of the recent literature. *Curr Atheroscler Rep*. 2014;16(1):381.
k Goff LM, Cowland DE, Hooper L, Frost GS. Low glycemic index diets and blood lipids: a systematic review and meta-analysis of randomized controlled trials. *Nutr Metab Cardiovasc Dis*. 2013;23(1):1-10.
l Cari K. Low-glycemic load diets: How does the evidence for prevention of disease measure up? *J Am Diet Assoc*. 2010;110(12):1818–1819.
m Kristo AS, Matthan NR, Lichtenstein AH. Effect of diets differing in glycemic index and glycemic load on cardiovascular risk factors: review of randomized controlled-feeding trials. *Nutrients*. 2013;5(4):1071-1080.
n Esfahani A, Wong JM, Mirrahimi A, Villa CR, Kendall CW. The application of the glycemic index and glycemic load in weight loss: a review of the clinical evidence. *IUBMB Life*. 2011;63(1):7-13.
o Matthan NR, Ausman LM, Meng H, et al. Estimating the reliability of glycemic index values and potential sources of methodological and biological variability. *Am J Clin Nutr*. 2016;104(4):1004-1013.
p American Diabetes Association. Nutrition recommendations and interventions for diabetes: a position statement of the American Diabetes Association. *Diabetes Care*. 2007;30(Suppl 1):S48-S65.
q Ludwig DS, Eckel RH. The glycemic index at 20 y. *Am J Clin Nutr*. 2002;76(Suppl):264S-265S.





The **glycemic load** is similar to the glycemic index except it accounts for the amount of carbohydrates in a serving of a particular food, whereas the glycemic index does not. Therefore, glycemic load is thought to be a more useful tool because it provides a more practical assessment of a food's actual impact on blood sugar. Foods with a high glycemic index and/or glycemic load cause a faster and higher rise in blood glucose, whereas foods with a low glycemic index/glycemic load 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 and glycemic load, diets that use glycemic index and load as a guide may offer important health benefits.[23]

The Role of Carbohydrates in Our Diet

Why Is This Important? In the United States, current consumption of carbohydrates does not align with recommended intakes, especially regarding fiber and added sugar. It is important to understand the discrepancies between what we currently eat and what we should be eating for optimal health so that nutrition and public health strategies can be developed to help close this gap.

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 4.11** 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 Acceptable Macronutrient Distribution Range (AMDR) for carbohydrate is 45 to 65 percent of daily energy intake. For an adult who eats about 2,000 kilocalories daily, this represents 225 to 325 grams of carbohydrate. The Daily Value for carbohydrate is 300 grams per day, representing 60 percent of the energy in a 2,000-kilocalorie diet.

It's important that sugar doesn't account for too much of this total. Although the 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. For example, the *2015–2020 Dietary Guidelines for Americans* and the World Health Organization recommend limiting added sugar to less than 10 percent of total energy intake. The *Dietary Guidelines*

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.

FIGURE 4.11 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.

further suggests that we "reduce the intake of added sugars in an effort to build healthy eating patterns."[25] One key recommendation is to choose and prepare nutrient-dense foods and beverages with little added sugar.

As far as fiber is concerned, the *2015–2020 Dietary Guidelines for Americans* recommends that we consume a healthy eating pattern that includes a variety of dark green, red, and orange vegetables, as well as legumes (beans and peas) and starchy vegetables, fruits (especially whole fruits), and grains (at least half of which are whole grains).[26] 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?

- **glycemic load** The glycemic index of a food adjusted for the amount of carbohydrate in a serving of a particular food.
- **high-fructose corn syrup** Sweetener made from corn commonly added to food products and beverages in the United States. It is composed of either 42 percent or 55 percent fructose, with the remaining sugar being glucose.

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 carbohydrate consumed. According to National Health and Nutrition Examination Survey (NHANES) data, approximately 13 percent of adults' total caloric intakes came from added sugars. On average, men had an added sugar intake of about 83 grams per day, while women had an added sugar intake of 60 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 in the form of white sugar and **high-fructose corn syrup (HFCS)**. 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 for men and women averaging only 18 and 15 grams per day, respectively.[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—this is a consequence of Americans failing to meet recommendations for fruits, vegetables, and whole grain consumption.[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]

THINK About It 2

Choosing Carbohydrates Wisely

The *2015–2020 Dietary Guidelines for Americans* encourages a healthy eating pattern that contains fruits, vegetables, legumes, whole grains, and fat-free or low-fat milk, but keeps caloric intake under control. Choosing

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 their soda consumption in the late 1970s, but today children consume roughly equal amounts of each.

Quick Bite

Low-Carb Diets

Over the last 20 years, low-carbohydrate diets, such as Atkins and the Paleo diet, have become popular weight loss strategies. Although these diets have been shown to be effective in helping people lose weight, and may even improve markers of cardiovascular disease risk and diabetes, there is also a considerable amount of controversy surrounding them. Many critics of low-carbohydrate diets argue that fruit, vegetable, and whole-grain intake is minimized and is insufficient to meet fiber requirements as well as vitamin and mineral needs. It is important to remember that there is no "magic bullet" for weight loss. Current recommendations to achieve and maintain a healthy weight include monitoring your calories consumed versus calories burned while eating a *balanced* diet that meets all nutrient requirements.

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 vitamins such as A, C, and folate; minerals such as potassium; phytochemicals; and fiber, yet little or no fat. TABLE 4.2 lists various foods that are high in simple and complex carbohydrates.

TABLE 4.2
High-Carbohydrate Foods

High in Complex Carbohydrates	High in Simple Carbohydrates
Bagels	Fruits (naturally present)
Tortillas	Fruit juices
Cereals	Skim milk
Crackers	Plain nonfat yogurt
Rice cakes	Vanilla cake
Legumes	Soft drinks
Corn	Sherbet
Potatoes	Syrups
Peas	Sweetened nonfat yogurt
Squash	Candy
Popcorn	Jellies
	Jams
	Gelatin
	High-sugar breakfast cereals
	Cookies
	Frosting

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 4.12.) 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.
- Incorporate more spiralized vegetables (e.g., zucchini noodles) in place of refined white pasta.
- Eat fruits and vegetables with the peel, if possible. The peel is high in fiber.
- 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 or cauliflower rice instead of white rice.
- Substitute oats for flour in crumb toppings.
- Choose high-fiber cereals.
- Choose whole fruits rather than fruit juices.
- Choose whole vegetables rather than vegetable juices.

When increasing your fiber intake, do so gradually, adding just a few grams a day, because sudden or large increases in fiber can lead to

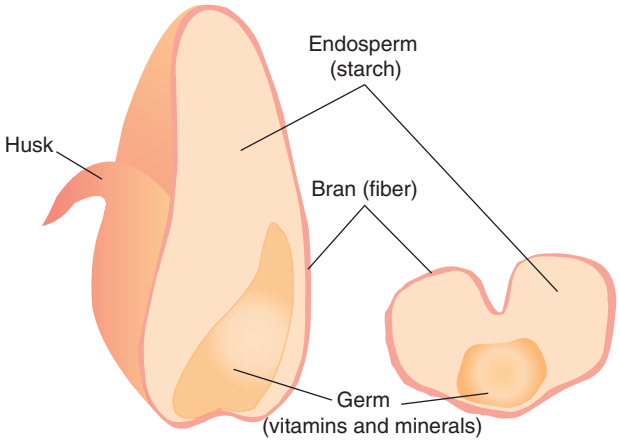


FIGURE 4.12 Anatomy of a kernel of grain. Whole kernels of grains consist of four parts: germ, endosperm, bran, and husk.

▶ **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*.

GI distress. 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.

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.

Moderating Added Sugar Intake

Most of us enjoy the taste of sweet foods, and there's no reason why we should not. But for some individuals, habitually high sugar intake, specifically intake of sugar added during processing of foods, crowds out foods that are higher in fiber, vitamins, and minerals. To reduce added sugars in your diet:

- Use less of all added sugars, including white sugar, brown sugar, honey, agave syrup, and high-fructose corn syrup.
- Limit consumption 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.

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 added sugar list some form of sweetener as the first, second, or third ingredient on labels. The updated Nutrition Facts panel (discussed at the end of this chapter) has a separate line for "added sugar" to provide further help for differentiating between the amount of naturally present sugar versus added sugar in a food product. **TABLE 4.3** lists various forms of sugar used in foods.

TABLE 4.3
Forms of Sugar Used in Foods

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

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 a healthy eating pattern containing 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, agave syrup, high-fructose corn syrup (HFCS), glucose, fructose, xylitol, sorbitol, and mannitol are just some of the many nutritive sweeteners used in foods. One slice of vanilla cake, for example, can contain 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 naturally, all are broken down in the small intestine and absorbed as monosaccharides and provide energy. Because all these absorbed monosaccharides end up as glucose, the body cannot tell whether they came from honey or table sugar.

THINK About It 3

▶ **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*.

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.

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 2005–2010 NHANES study indicate that the average American consumes about 18 teaspoons of added sugars per day. American adults consume about 13 percent of their calories from added sugars; children (ages 2–19) consume about 16 percent of their calories from added sugars.[a,b] Caloric sweetened sodas and fruit drinks (containing less than 100 percent juice by volume) are major sources of added sugars in American diets, contributing an average of 8.78 teaspoons of added sugars each day. Teenagers (ages 12–19) consume 13.88 teaspoons of added sugars from sodas and fruit drinks per day.[c] 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.[d] 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.[e,f]

a Ervin RB, Ogden CL. Consumption of added sugars among U.S. adults, 2005-2010. *NCHS Data Brief.* 2013;122.
b Ervin RB, Kit BK, Carroll MD, Ogden CL. Consumption of added sugar among U.S. children and adolescents, 2005-2008. *NCHS Data Brief.* 2012;87.
c Ogden CL, Kit BK, Carroll MD, Park S. Consumption of sugar drinks in the United States, 2005-2008. *NCHS Data Brief.* 2011;71.
d 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.
e Gibson S, Boyd A. Associations between added sugars and micronutrient intakes and status: further analysis of data from the National Diet and Nutrition Survey of Young People ages 4 to 18 years. *Br J Nutr.* 2009;101(1):100-107.
f Marriott BP, Olsho L, Hadden L, Connor P. Intake of added sugars and selected nutrients in the United States, National Health and Nutrition Examination Survey (NHANES) 2003-2006. *Crit Rev Food Sci Nutr.* 2010;50(3):228-258.

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.

▶ **refined sweeteners** Composed of monosaccharides and disaccharides that have been extracted and processed from other foods, such as high-fructose corn syrup and agave syrup.

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 syrups.

- **polyols** See *sugar alcohols*.
- **nonnutritive sweeteners** Substances that impart sweetness to foods but supply little or no energy to the body. They include acesulfame, aspartame, saccharin, and sucralose. Also called *artificial sweeteners* or *alternative sweeteners*.
- **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 under 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.
- **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 nonnutritive and about 600 times sweeter than sugar.

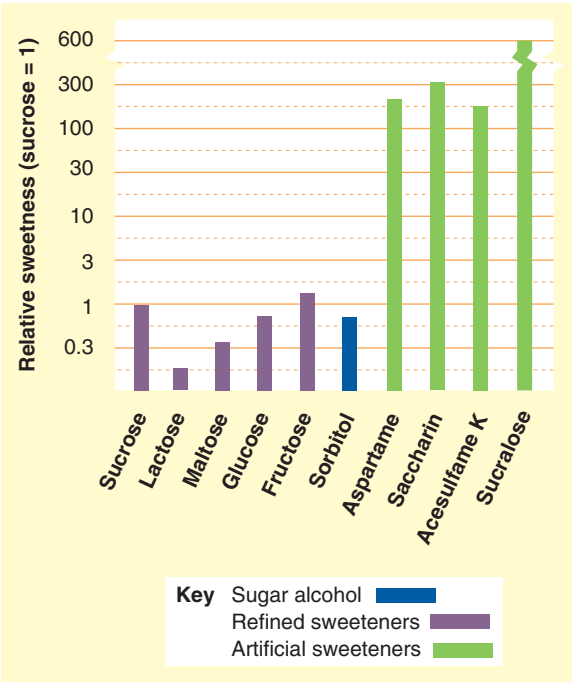


FIGURE 4.13 Comparing the sweetness of sweeteners. Nonnutritive sweeteners are much sweeter than table sugar.

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. HFCS has about the same sweetness as table sugar but costs less to produce. On average, Americans consume 118 calories of HFCS each day. Some studies indicate that increased HFCS consumption can contribute to obesity and high triglyceride levels,[37,38] but it remains unclear whether HFCS *causes* obesity. Caution is perhaps the best advice: Individuals should aim to limit their consumption of HFCS, but can enjoy it in moderation as part of an overall healthy eating pattern.

Another popular sweetener is agave syrup. Agave sweeteners are derived from the blue agave plant, which is also used to make tequila. Similar to HFCS, these sweeteners are highly processed and contain more fructose than glucose. Per tablespoon, agave contains more calories than table sugar, but it is 1.5 times sweeter. Therefore, replacing table sugar with agave sweetener can lower calorie intake, but only if smaller amounts are used. Research on potential health benefits of agave sweeteners is limited. The position of the American Diabetes Association is that agave consumption should be limited, just like consumption of sugar, honey, HFCS, and maple syrup.[39,40]

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.[41]

Nonnutritive (Artificial) Sweeteners

Gram for gram, most **nonnutritive 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 nonnutritive sweeteners do provide energy, their energy contribution is minimal given the small amount used.

Common nonnutritive 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, nonnutritive sweeteners offer an alternative. Also, nonnutritive sweeteners do not contribute to tooth decay. In the United States, our consumption of artificial sweeteners in foods and beverages has increased; however, only 15 percent of the population regularly consumes foods

TABLE 4.4
Summary of Nonnutritive Sweeteners

Nonnutritive Sweetener	Relative Sweetness to Sucrose	FDA Approval?	Typical Foods Where It Is Added	Acceptable Daily Intake (mg/kg body weight)
Saccharin	300x	Yes	Tabletop sweetener, beverages, fruit juices, drink mix	15
Aspartame	200x	Yes	Beverages, gelatin desserts, gums, fruit spreads	50*
Acesulfame K	200x	Yes	Gum, powdered drink mixes, nondairy creamers, gelatins, pudding	15
Sucralose	600x	Yes	Baked goods, beverages, gelatin desserts, frozen dairy desserts, tabletop sweetener	5
Neotame	7,000–13,000x	Yes	Tabletop sweetener	0.3
Stevioside (also known as stevia)	300x	No†	Sold as dietary supplement	–

*Set for general population. Individuals with phenylketonuria (PKU) should control phenylalanine intake from all sources, including aspartame.

†Rebaudioside A (a specific steviol glycoside) has been approved by the FDA as a food additive.

Data from U.S. Department of Health and Human Services, U.S. Food and Drug Administration. Additional information about high-intensity sweeteners permitted for use in food in the United States. http://www.fda.gov/food/ingredientspackaginglabeling/foodadditivesingredients/ucm397725.htm. Accessed August 21, 2017.

with artificial sweeteners, and average intakes are consistently below the acceptable daily intakes set by the FDA.[42] Common nonnutritive sweeteners are summarized in TABLE 4.4.

Carbohydrates and Health

Why Is This Important? As a nutrition expert, you will be inundated with questions such as, "Should I cut carbs to lose weight?" and "Will eating fiber prevent me from getting heart disease?" To address concerns and misconceptions within the general population, it is important to understand the current scientific evidence regarding the role of carbohydrates in health and disease.

THINK About It 4

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.

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 soluble 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

Quick Bites

The Discovery of Saccharin

A German student named Constantin Fahlberg discovered saccharin by accident 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.

Position Statement: Academy of Nutrition and Dietetics

Use of Nutritive and Nonnutritive 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.

Reprinted from *Journal of the Academy of Nutrition and Dietetics*, 112(5), Cindy Fitch and Kathryn S. Keim, Position of the Academy of Nutrition and Dietetics: Use of Nutritive and Non nutritive Sweeteners, Page no. 739-758., 2012, with permission from Elsevier.

in reducing hunger and promoting satiety, studies on specific types of fiber have produced inconsistent results.[43]

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.[44] 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.[45] Current dietary recommendations for people with type 2 diabetes advise a high intake of foods rich in dietary fiber.[46]

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 soluble fiber, show blood cholesterol reductions of 2 percent per gram of intake.[47] 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.[48]

Soluble 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.[49]

Studies also show a relationship between high intake of whole grains and low risk of heart disease.[50] 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.[51] Consuming at least three 1-ounce servings of whole grains each day can reduce heart disease risk.[52]

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.

Fiber can bind small amounts of minerals in the GI tract and prevent them from being absorbed. In particular, 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.[53]

If the diet contains high amounts of fiber, some people, such as young children and the elderly, can become full before meeting their energy and nutrient needs. Because of a limited stomach capacity, they

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.

Reprinted from *Journal of the Academy of Nutrition and Dietetics*, 108(10), Position of the American Dietetic Association: Health Implications of Dietary Fiber, Page no. 1716-1731., 2008, with permission from Elsevier.

TABLE 4.5
Summary of the Effects of Fiber in the GI Tract and Health Benefits

Digestive System	Effect on Digestion/Absorption	Health Benefits
Mouth	• Increased chewing	Eating less at a meal promotes calorie control. Reduces risk for *obesity*.
Stomach	• Increased feeling of fullness/satiety • Delayed stomach emptying	Eating less in-between meals promotes calorie control. Reduces risk for *obesity*
Small intestine	• Delays absorption of nutrients by physically blocking digestive enzymes • Decreases glycemic and insulin response • Binds cholesterol/bile and prevents absorption	Reduces risk for *type 2 diabetes* Reduces risk for *cardiovascular disease*
Large intestine	• Promotes growth of healthy bacteria. • Fermentation produces beneficial short-chain fatty acids. • Adds bulk to feces; decreases intestinal transit time.	Reduces risk of *colon cancer, constipation,* and *diverticular disease*

must be careful that fiber intake does not interfere with their ability to consume adequate energy and nutrients.

Because of the bulky nature of fibers, excess consumption is likely to be self-limiting. Although a high fiber intake might 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. A summary of the health benefits of fiber can be found in **TABLE 4.5**.

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.

Health Effects of Sugar: Causation or Correlation?

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 because it provides 9 kilocalories per gram compared to the 4 kilocalories per gram provided by carbohydrate. 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, with obesity prevalence holding steady in children and increasing slightly in adults. 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, increased added sugar intake is associated with increased total calorie intake because foods high in added sugars often have low nutrient value and become "extras" in the diet.

Sugar and Diabetes Mellitus

It was once believed that eating too much carbohydrate or sugar could cause diabetes. However, contrary to popular beliefs, high intake of carbohydrate or sugar does not cause diabetes. It's actually obesity, specifically abdominal obesity, that 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—then it will raise diabetes risk.

Sugar and Heart Disease

Risk factors for heart disease include a genetic predisposition, smoking, excessive alcohol consumption, physical inactivity, high blood pressure, high blood cholesterol levels, diabetes, and obesity.[54] Sugar by itself does not cause heart disease; however, added sugar intake is correlated with increased risk for cardiovascular disease mortality.[55] For example, when intake of high-sugar foods is part of an unhealthy diet that contributes to obesity, then risk for heart disease increases. In addition, excessive intake of refined sugar can alter blood lipids in carbohydrate-sensitive people, increasing their risk for heart disease. However, a high fat intake can also promote obesity. The take-away message is this: Any calorie imbalance that causes obesity raises the risk of heart disease; sugar should not be singled out as the only cause.

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

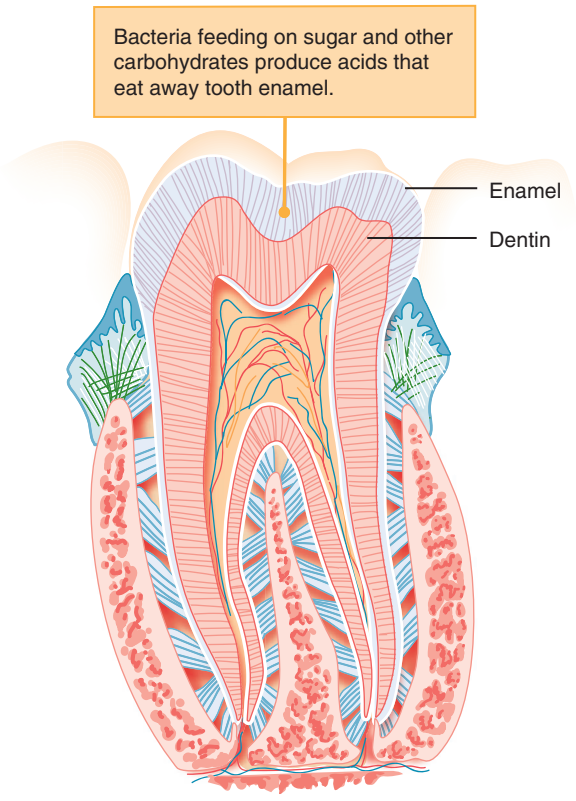


FIGURE 4.14 Dental health. Good dental hygiene, adequate fluoride, and proper nutrition help maintain healthy teeth. A well-balanced diet contains vitamins and minerals crucial for healthy bones and teeth. To help prevent dental caries, avoid continuous snacking on high-sugar foods, especially those that stick to the teeth.

Sugar and ADHD in Children

Many parents and child care professionals will comment that eating sugary foods makes their children hyperactive. Attention-deficit hyperactivity disorder (ADHD) characterized by inattentive, hyperactive, and impulsive behavior is estimated to affect 5 percent of children worldwide.[56] 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 games, prizes, and other exciting activities. A child's hyperactive behavior could be related to the exciting environment and enthusiasm for the special event. Alternatively, a child whose diet is regularly high in sugar is likely eating less nutritious foods overall; therefore, the child's irritable or restless behavior could be attributed to a nutrient deficiency or more generalized malnutrition.

Sugar and Dental Caries

In the previous examples, you learned that sugar intake is associated with potential health problems, but it is unclear whether they actually cause these health conditions. However, there is at least one impact on health where its role is clear: High sugar intake contributes to **dental caries**, or cavities. (See **FIGURE 4.14**.) 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.[57]

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.[58] The FDA sets a maximum allowable daily intake of aspartame of 50 milligrams per kilogram of body weight.[59] This amount of aspartame equals the amount in sixteen 12-ounce diet soft drinks for adults and eight diet soft drinks for children.

Artificial sweeteners can help you lower sugar intake, but foods containing artificial sweeteners 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 use of artificial sweeteners has increased in the United States, so has sugar consumption—an interesting paradox!

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

Recent changes to the Nutrition Facts food label have revised how carbohydrate information is presented to consumers. Look at the center of the original Nutrition Facts label (left panel), 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 37 total grams of carbohydrate, with 1 gram coming from sugars and 4 grams from fiber. This means the remaining 32 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 starch (32 of the 37 grams) and is probably a potato, bread, pasta, or rice food item.

Do you see the "12%" listed to the right of Total Carbohydrate in the original label in the left panel? This doesn't mean that the food item contains 12 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 37 grams per serving, which is 12 percent of the Daily Value of 300 grams per day. Note that the Percent Daily Value for fiber is "16%" and would be considered a "good source" of fiber (defined as 10–19% of the DV).

In May 2016, the FDA introduced a new Nutrition Facts label (right panel) to reflect new scientific evidence on diet and chronic disease. One of the major changes to the label is the addition of "Added Sugars" in grams and percent Daily Value. This change is based on reported evidence that it is difficult to meet nutrient needs within calorie limits if you consume more than 10 percent of total calories from added sugar. Manufacturers have until July 2018 to comply with the new label requirements. Now, in addition to discerning the sugar, starch, and fiber content of foods, you will be able to determine the amount of sugar found naturally in the food versus how much has been added in processing.[a]

Recall that carbohydrates contain 4 kilocalories per gram. Armed with this information and the product's calorie information from the Nutrition Facts label, can you calculate the percentage of calories that come from carbohydrate?

Here's how:

37 g carbohydrate × 4 kcal per g = 148 carbohydrate kcal
148 carbohydrate kcal ÷ 230 total kcal = 0.64, or 64 percent carbohydrate kcal

[a] U.S. Food and Drug Administration. (2016). New Nutrition Facts Label - Side by Side Comparison. Retrieved from, https://www.fda.gov/downloads/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/LabelingNutrition/UCM501646.pdf.

Original Label

Nutrition Facts

Serving Size 2/3 cup (55g)
Servings Per Container About 8

Amount Per Serving

Calories 230 Calories from Fat 72

	% Daily Value*
Total Fat 8g	**12%**
Saturated Fat 1g	**5%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 160mg	**7%**
Total Carbohydrate 37g	**12%**
Dietary Fiber 4g	**16%**
Sugars 1g	
Protein 3g	
Vitamin A	10%
Vitamin C	8%
Calcium	20%
Iron	45%

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

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

New Label

Nutrition Facts

8 servings per container
Serving size 2/3 cup (55g)

Amount Per Serving
Calories 230

	% Daily Value*
Total Fat 8g	**10%**
Saturated Fat 1g	**5%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 160mg	**7%**
Total Carbohydrate 37g	**13%**
Dietary Fiber 4g	**14%**
Total Sugars 12g	
Includes 10g Added Sugars	**20%**
Protein 3g	
Vitamin D 2mcg	10%
Calcium 260mg	20%
Iron 8mg	45%
Potassium 235mg	6%

*The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Learning Portfolio

Key Terms

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acesulfame K	124
alpha (α) bonds	112
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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.
- Fibers are indigestible oligosaccharides and polysaccharides that can be classified as soluble or insoluble.
- 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 whole grains and fiber than is recommended.
- Carbohydrate intake can affect health. Excess sugar can contribute to low nutrient intake, excess energy intake, and dental caries.

Learning Portfolio (continued)

- 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 nonnutritive sweeteners used in the United States?
7. What are potential consequences of habitually high sugar intake?
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!

The Fiber-Type Experiment

This experiment is to help you understand the difference between sources of dietary fiber. Go to the store and buy a small amount of raw bran. It is usually sold in a bin at a health food store or neat the hot cereals in a grocery store. Also purchase some pectin (near the baking items) or some Metamucil (in the pharmacy section). Once you're home, fill two glasses with water and put the raw bran in one glass and the pectin or Metamucil in the other. Stir each glass for a minute or two and watch what happens. Describe the differences. What would happen in your GI tract? What type of fiber is pectin? What type of fiber is in bran?

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