test yourself

1. T F Carbohydrates are fattening.
2. T F Diets high in sugar cause hyperactivity in children.
3. T F Alternative sweeteners, such as aspartame, are safe for us to consume.

Test Yourself answers are located at the end of the chapter.

Carbohydrates
Plant-derived energy nutrients

4

learning objectives

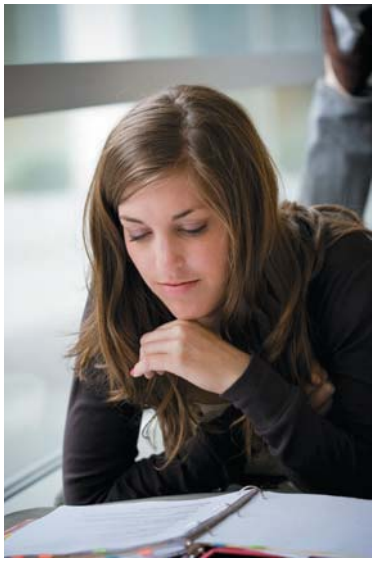
After studying this chapter you should be able to:

1. Distinguish between simple and complex carbohydrates, pp. 110–113.
2. List four functions of carbohydrates in our bodies, pp. 115–118.
3. Explain how carbohydrates are digested and absorbed by our bodies, pp. 118–121.
4. Define the glycemic index and glycemic load, pp. 123–124.
5. Define the Acceptable Macronutrient Distribution Range for carbohydrates, and the Adequate Intake for fiber, pp. 125 and 131.
6. Identify the most common dietary sources of added sugars and the potential health risks of a diet high in added sugars, pp. 125–128.
7. List five foods that are good sources of fiber-rich carbohydrates, pp. 128–129 and pp. 131–132.
8. Compare and contrast a variety of alternative sweeteners, pp. 132–135.

When Khalil lived at home, he snacked on whatever was around. That typically meant fresh fruit or his mom's homemade flatbread and either plain water or skim milk. His parents never drank soda, and the only time he ate sweets was on special occasions. Now Khalil is living on campus. When he gets hungry between classes, he visits the snack shack in the Student Union for one of their awesome chocolate-chunk cookies and washes it down with a large cola. Studying at night, he munches on cheese curls or corn chips and drinks more cola to help him stay awake. Not suprisingly, Khalil has noticed lately that his clothes feel tight. When he steps on the scale, he's shocked to discover that, since starting college 3 months ago, he's gained 7 pounds!

Several popular diets—including the Zone Diet, Sugar Busters, and Dr. Atkins' New Diet Revolution—claim that carbohydrates are bad for your health. They recommend reducing carbohydrate consumption and eating more protein and fat.[1–3] Is this good advice? Are carbohydrates a health menace, and is one type of carbohydrate "better" or "worse" than another?

In this chapter, we'll explore the differences between simple and complex carbohydrates and learn why some carbohydrates really are better than others. We'll also learn how the human body breaks down carbohydrates and uses them to maintain our health and to fuel activity and exercise. In the **In Depth** essay following this chapter, we'll discuss the relationship between carbohydrate intake and diabetes.



Glucose is the preferred source of energy for the brain.

What are carbohydrates?

As noted earlier (in Chapter 1), carbohydrates are one of the three macronutrients. As such, they are an important energy source for the entire body and are the preferred energy source for nerve cells, including those of the brain. We will say more about their functions later in this chapter.

The term **carbohydrate** literally means "hydrated carbon." When something is said to be *hydrated*, it contains water, which is made of hydrogen and oxygen (H_2O). Thus, the chemical abbreviation for carbohydrate (CHO) indicates the atoms it contains: **c**arbon, **h**ydrogen, and **o**xygen.

We obtain carbohydrates predominantly from plant foods, such as fruits, vegetables, and grains. Plants make the most abundant form of carbohydrate, called **glucose**, through a process called **photosynthesis**. During photosynthesis, the green pigment of plants, called *chlorophyll,* absorbs sunlight, which provides the energy needed to fuel the manufacture of glucose. As shown in **Figure 4.1**, water absorbed from the earth by the roots of plants combines with the carbon dioxide present in the leaves to produce the carbohydrate glucose. Plants continually store glucose and use it to support their own growth. Then, when we eat plant foods, our bodies digest, absorb, and use the stored glucose.

Carbohydrates can be classified as *simple* or *complex*. These terms are used to describe carbohydrates based on the number of molecules of sugar present. Simple carbohydrates contain either one or two molecules, whereas complex carbohydrates contain hundreds to thousands of molecules.

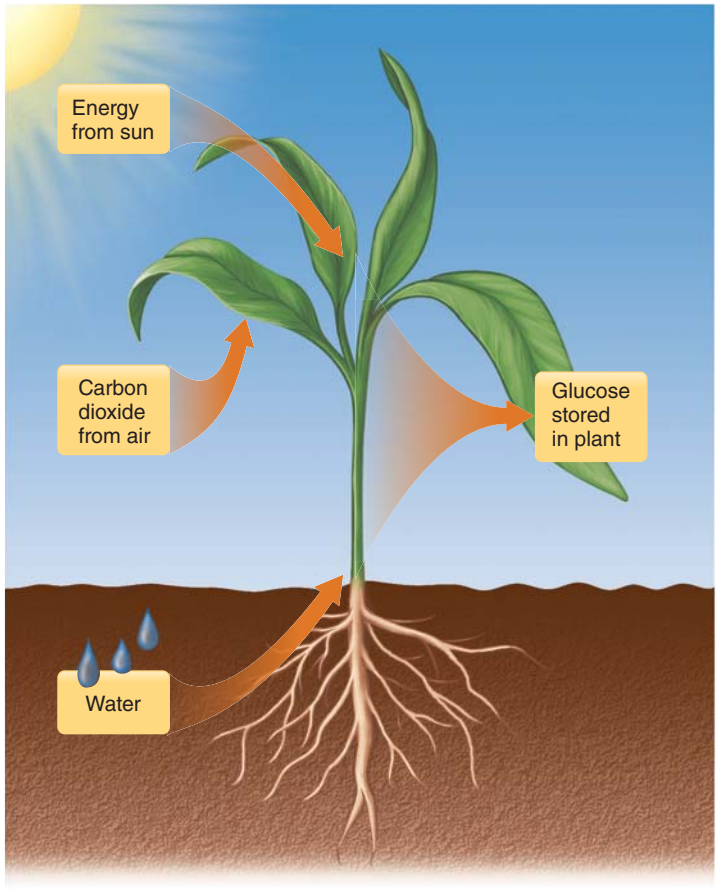


FIGURE 4.1 Plants make carbohydrates through the process of photosynthesis. Water, carbon dioxide, and energy from the sun are combined to produce glucose.

carbohydrate One of the three macronutrients, a compound made up of carbon, hydrogen, and oxygen, that is derived from plants and provides energy.

glucose The most abundant sugar molecule, a monosaccharide generally found in combination with other sugars; it is the preferred source of energy for the brain and an important source of energy for all cells.

photosynthesis The process by which plants use sunlight to fuel a chemical reaction that combines carbon and water into glucose, which is then stored in their cells.

Simple Carbohydrates Include Monosaccharides and Disaccharides

Simple carbohydrates are commonly referred to as *sugars*. Four of these sugars are called **monosaccharides** because they consist of a single sugar molecule (*mono* means "one," and *saccharide* means "sugar"). The other three sugars are **disaccharides**, which consist of two molecules of sugar joined together (*di* means "two").

glucose, Fructose, galactose, and ribose Are Monosaccharides

Glucose, fructose, and *galactose* are the three most common monosaccharides in our diet. Each of these monosaccharides contains six carbon atoms, twelve hydrogen atoms, and six oxygen atoms (FIgure 4.2). Very slight differences in the arrangement of the atoms in these three monosaccharides cause major differences in their levels of sweetness.

Given what you've just learned about how plants manufacture and store carbohydrate in the form of glucose, it probably won't surprise you to discover that glucose is the most abundant sugar molecule in our diets and in our bodies. Glucose does not generally occur by itself in foods, but attaches to other sugars to form disaccharides and complex carbohydrates. In our bodies, glucose is the preferred source of energy for the brain, and it is a very important source of energy for all cells.

Fructose, the sweetest natural sugar, is found in fruits and vegetables. Fructose is also called *levulose*, or *fruit sugar*. In many processed foods, it comes in the form of **high-fructose corn syrup**. This syrup is manufactured from corn and is used to sweeten soft drinks, desserts, candies, and jellies.

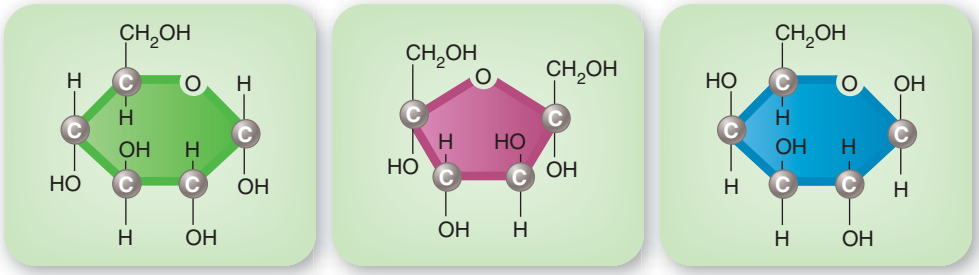
galactose does not occur alone in foods. It joins with glucose to create lactose, one of the three most common disaccharides.

ribose is a five-carbon monosaccharide. Very little ribose is found in our diets; our bodies produce ribose from other carbohydrates we eat, and ribose is contained in the genetic material of our cells: deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).

Lactose, Maltose, and Sucrose Are Disaccharides

The three most common disaccharides found in foods are *lactose, maltose,* and *sucrose* (FIgure 4.3). **Lactose** (also called *milk sugar*) consists of one glucose molecule and one galactose molecule. Interestingly, human breast milk has more lactose than cow's milk, making human breast milk taste sweeter.

Maltose (also called *malt sugar*) consists of two molecules of glucose. It does not generally occur by itself in foods but, rather, is bound together with other molecules. As our bodies break down these larger molecules, maltose results as a by-product. Maltose is also the sugar that is fermented during the production of beer and liquor



Glucose
Most abundant sugar molecule in our diet; good energy source

Fructose
Sweetest natural sugar; found in fruit, high-fructose corn syrup

Galactose
Does not occur alone in foods; binds with glucose to form lactose

FIGURE 4.2 The three most common monosaccharides. Notice that all three monosaccharides contain identical atoms: 6 carbon, 12 hydrogen, and 6 oxygen. It is only the arrangement of these atoms that differs.

simple carbohydrate Commonly called *sugar;* can be either a monosaccharide (such as glucose) or a disaccharide.

monosaccharide The simplest of carbohydrates, consisting of one sugar molecule, the most common form of which is glucose.

disaccharide A carbohydrate compound consisting of two sugar molecules joined together.

fructose The sweetest natural sugar; a monosaccharide that occurs in fruits and vegetables; also called levulose, or fruit sugar.

high-fructose corn syrup A highly sweet syrup that is manufactured from corn and is used to sweeten soft drinks, desserts, candies, and jellies.

galactose A monosaccharide that joins with glucose to create lactose, one of the three most common disaccharides.

ribose A five-carbon monosaccharide that is located in the genetic material of cells.

lactose A disaccharide consisting of one glucose molecule and one galactose molecule. It is found in milk, including human breast milk; also called *milk sugar.*

maltose A disaccharide consisting of two molecules of glucose. It does not generally occur independently in foods but results as a by-product of digestion; also called *malt sugar.*

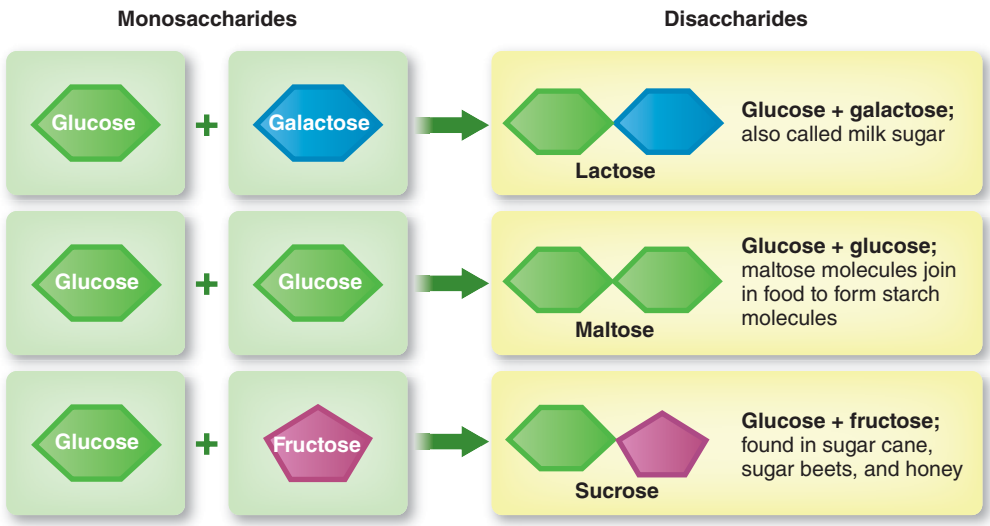


FIGURE 4.3 Galactose, glucose, and fructose join together in different combinations to make the disaccharides lactose, maltose, and sucrose.

Tubers, such as these sweet potatoes, are excellent food sources of starch.

products. **Fermentation** is a process in which an agent, such as yeast, causes an organic substance to break down into simpler substances and results in the production of the energy molecule adenosine triphosphate (ATP). Maltose is formed during the breakdown of sugar in grains and other foods into alcohol. Contrary to popular belief, very little maltose remains in alcoholic beverages after the fermentation process is complete; thus, alcoholic beverages are not good sources of carbohydrate.

Sucrose is composed of one glucose molecule and one fructose molecule. Because sucrose contains fructose, it is sweeter than lactose or maltose. Sucrose provides much of the sweet taste found in honey, maple syrup, fruits, and vegetables. Table sugar, brown sugar, powdered sugar, and many other products are made by refining the sucrose found in sugarcane and sugar beets. Are honey and other naturally occurring forms of sucrose more healthful than manufactured forms? The **Nutrition Myth or Fact?** box investigates this question.

recap Carbohydrates contain carbon, hydrogen, and oxygen. Plants make one type of carbohydrate, glucose, through the process of photosynthesis. Simple carbohydrates include monosaccharides and disaccharides. Glucose, fructose, and galactose are monosaccharides; lactose, maltose, and sucrose are disaccharides.

fermentation A process in which an agent causes an organic substance to break down into simpler substances and results in the production of ATP.

sucrose A disaccharide composed of one glucose molecule and one fructose molecule; sucrose is sweeter than lactose or maltose.

complex carbohydrate A nutrient compound consisting of long chains of glucose molecules, such as starch, glycogen, and fiber.

polysaccharide A complex carbohydrate consisting of long chains of glucose.

starch A polysaccharide stored in plants; the storage form of glucose in plants.

Polysaccharides Are Complex Carbohydrates

Complex carbohydrates, the second major type of carbohydrate, generally consist of long chains of glucose molecules called **polysaccharides** (*poly* means "many"). They include starch, glycogen, and most fibers (Figure 4.4).

Starch Is a Polysaccharide Stored in Plants

Plants store glucose not as single molecules but as polysaccharides in the form of **starch**. The two forms of starch are *amylose* and *amylopectin*. Excellent food sources of starch include grains (wheat, rice, corn, oats, and barley), legumes (peas, beans, and lentils), and tubers (potatoes and yams). Our cells cannot use the complex starch molecules exactly as they occur in plants. Instead, our bodies must break them down into the monosaccharide glucose from which we can then fuel our energy needs.

Our bodies easily digest most starches; however, some starches in plants are not digestible and are called *resistant*. Technically, resistant starch is classified as a type

nutrition myth or fact?

Is Honey More Nutritious Than Table Sugar?

Liz's friend Tiffany is dedicated to eating healthful foods. She advises Liz to avoid sucrose and to eat foods that contain honey, molasses, or raw sugar. Like many people, Tiffany believes these sweeteners are more natural and nutritious than refined table sugar. How can Liz sort sugar fact from fiction?

Remember that sucrose consists of one glucose molecule and one fructose molecule joined together. From a chemical perspective, honey is almost identical to sucrose because honey also contains glucose and fructose molecules in almost equal amounts. However, enzymes in bees' "honey stomachs" separate some of the glucose and fructose molecules; as a result, honey looks and tastes slightly different from sucrose.

As you know, bees store honey in combs, and they fan it with their wings to reduce its moisture content. This also alters the appearance and texture of honey.

Honey does not contain any more nutrients than sucrose, so it is not a more healthful choice than sucrose. In fact, per tablespoon, honey has more Calories (energy) than table sugar. This is because the crystals in table sugar take up more space on a spoon than the liquid form of honey, so a tablespoon contains less sugar. However, some people argue that honey is sweeter, so you use less.

It is important to note that honey commonly contains bacteria that can cause fatal food poisoning in infants. The more mature digestive system of older children and adults is immune to the effects of these bacteria, but babies younger than 12 months should never be given honey.

Are raw sugar and molasses more healthful than table sugar? Actually, the "raw sugar" available in the United States is not really raw. Truly raw sugar is made up of the first crystals obtained when sugar is processed. Sugar in this form contains dirt, parts of insects, and other by-products that make it illegal to sell in the United States. The raw sugar products in American stores have actually gone through more than half of the same steps in the refining process used to make table sugar. Raw sugar has a coarser texture than white sugar and is unbleached; in most markets, it is also significantly more expensive.

Molasses is the syrup that remains when sucrose is made from sugarcane. It is reddish brown in color with a distinctive taste that is less sweet than table sugar. It does contain some iron, but this iron does not occur naturally. It is a contaminant from the machines that process the sugarcane! Incidentally, blackstrap molasses is the residue of a third boiling of the syrup. It contains less sugar than light or dark molasses but more minerals.

TAbLe 4.1 compares the nutrient content of white (or table) sugar, raw sugar, honey, and molasses. As you can see, none of them contains many nutrients that are important for health. This is why highly sweetened products are referred to as "empty Calories."

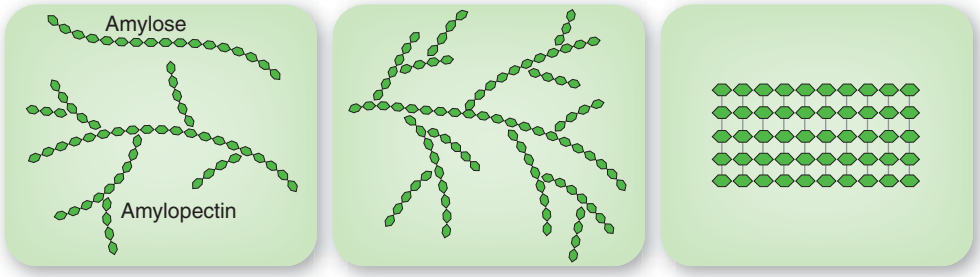
TABLE 4.1 Nutrient Comparison of Four Different Sugars

	Table Sugar	r aw Sugar	Honey	Molasses
Energy (kcal)	49	57	64	58
Carbohydrate (g)	12.6	14.27	17.3	14.95
Fat (g)	0	0	0	0
Protein (g)	0	0	0.06	0
Fiber (grams)	0	0	0	0
Vitamin C (mg)	0	0	0.1	0
Vitamin A (IU)	0	0	0	0
Thiamin (mg)	0	0	0	0.008
Riboflavin (mg)	0.002	0.003	0.008	0
Folate (µg)	0	0	0	0
Calcium (mg)	0	2	1	41
Iron (mg)	0.01	0.05	0.09	0.94
Sodium (mg)	0	0	1	7
Potassium (mg)	0	4	11	293

Note: Nutrient values are identified for 1 tablespoon of each product.

Data from: U.S. Department of Agriculture, Agricultural Research Service. 2012. USDA National Nutrient Database for Standard Reference, Release 25.

of fiber. When our intestinal bacteria ferment resistant starch, a fatty acid called *butyrate* is produced. Consuming resistant starch may be beneficial: some research suggests that butyrate consumption reduces the risk for cancer.[4] Legumes contain more resistant starch than do grains, fruits, or vegetables. This quality, plus their high protein and fiber content, makes legumes a healthful food.



Starch
Storage form of glucose in plants; found in grains, legumes, and tubers

Glycogen
Storage form of glucose in animals; stored in liver and muscles

Fiber
Forms the support structures of leaves, stems, and plants

FIGURE 4.4 Polysaccharides, also referred to as complex carbohydrates, include starch, glycogen, and fiber.

Dissolvable laxatives are examples of soluble fiber.

Glycogen Is a Polysaccharide Stored by Animals

Glycogen is the storage form of glucose for animals, including humans. After an animal is slaughtered, most of the glycogen is broken down by enzymes found in animal tissues. Thus, very little glycogen exists in meat. As plants contain no glycogen, it is not a dietary source of carbohydrate. We store glycogen in our muscles and liver; our bodies can metabolize this stored glycogen to glucose when we need energy. The storage and use of glycogen are discussed in more detail shortly.

Fiber Is a Polysaccharide That Gives Plants Their Structure

Like starch, fiber is composed of long polysaccharide chains; however, our bodies do not easily break down the bonds that connect fiber molecules. This means that most fibers pass through the digestive system without being digested and absorbed, so they contribute no energy to our diet. However, fiber offers many other health benefits, as we will see shortly.

There are currently a number of definitions of fiber. The Food and Nutrition Board of the Institute of Medicine propose three distinctions: *dietary fiber, functional fiber,* and *total fiber*.[5]

- **Dietary fiber** is the nondigestible parts of plants that form the support structures of leaves, stems, and seeds (see Figure 4.4). In a sense, you can think of dietary fiber as a plant's "skeleton."
- **Functional fiber** consists of the nondigestible forms of carbohydrates that are extracted from plants or manufactured in a laboratory and have known health benefits. Functional fiber is added to foods and is the form used in fiber supplements. Examples of functional fiber sources you might see on nutrition labels include cellulose, guar gum, pectin, and psyllium.
- **Total fiber** is the sum of dietary fiber and functional fiber.

Fiber can also be classified according to its chemical and physical properties as soluble or insoluble.

Soluble Fibers **Soluble fibers** dissolve in water. They are also **viscous**, forming a gel when wet, and fermentable; that is, they are easily digested by bacteria in the colon. Soluble fibers are typically found in citrus fruits, berries, oat products, and beans. Research suggests that the regular consumption of soluble fibers reduces the risks for cardiovascular disease and type 2 diabetes by lowering blood cholesterol and blood glucose levels. Soluble fibers include the following:

- *Pectins*, which contain chains of galacturonic acid and other monosaccharides. Pectins are found in the cell walls and intracellular tissues of many fruits and berries. They can be isolated and used to thicken foods, such as jams and yogurts.
- *Gums* contain galactose, glucuronic acid, and other monosaccharides. Gums are a diverse group of polysaccharides that are viscous. They are typically isolated from

glycogen A polysaccharide; the storage form of glucose in animals.

dietary fiber The nondigestible carbohydrate parts of plants that form the support structures of leaves, stems, and seeds.

functional fiber The nondigestible forms of carbohydrates that are extracted from plants or manufactured in a laboratory and have known health benefits.

total fiber The sum of dietary fiber and functional fiber.

soluble fibers Fibers that dissolve in water.

viscous Having a gel-like consistency; viscous fibers form a gel when dissolved in water.

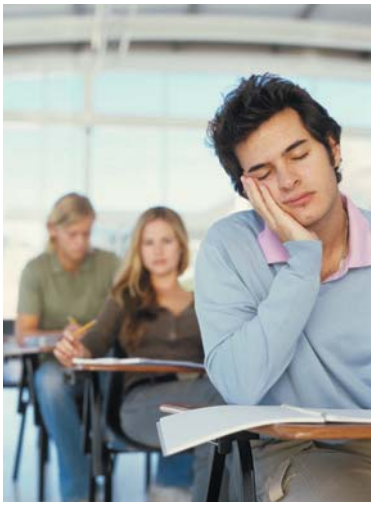
seeds and are used as thickening, gelling, and stabilizing agents. Guar gum and gum arabic are common gums used as food additives.
- *Mucilages* are similar to gums and contain galactose, mannose, and other monosaccharides. Two examples are psyllium and carrageenan. Psyllium is the husk of psyllium seeds, which are also known as plantago or flea seeds. Carrageenan comes from seaweed. Mucilages are used as food stabilizers.

Insoluble Fibers **Insoluble fibers** are those that do not typically dissolve in water. These fibers are usually nonviscous and typically cannot be fermented by bacteria in the colon. Insoluble fibers are generally found in whole grains, such as wheat, rye, and brown rice as well as in many vegetables. These fibers are not associated with reducing cholesterol levels but are known for promoting regular bowel movements, alleviating constipation, and reducing the risk for a bowel disorder called diverticulosis (discussed later in this chapter).

Examples of insoluble fibers include the following:

- *Lignins* are noncarbohydrate forms of fiber. Lignins are found in the woody parts of plant cell walls and in carrots and the seeds of fruits and berries. Lignins are also found in brans (the outer husk of grains such as wheat, oats, and rye) and other whole grains.
- *Cellulose* is the main structural component of plant cell walls. Cellulose is a chain of glucose units similar to amylose but, unlike amylose, cellulose contains bonds that are nondigestible by humans. Cellulose is found in whole grains, fruits, vegetables, and legumes. It can also be extracted from wood pulp or cotton, and it is added to foods as an agent for anticaking, thickening, and texturizing.
- *Hemicelluloses* contain glucose, mannose, galacturonic acid, and other monosaccharides. Hemicelluloses are found in plant cell walls and they surround cellulose. They are the primary component of cereal fibers and are found in whole grains and vegetables. Although many hemicelluloses are insoluble, some are also classified as soluble.

Fiber-r ich Carbohydrates Materials written for the general public usually don't refer to the carbohydrates found in foods as complex or simple; instead, resources such as the Dietary Guidelines for Americans 2010 emphasize eating *fiber-rich carbohydrates*, such as fruits, vegetables, and whole grains.[6] This term is important because fiber-rich carbohydrates are known to contribute to good health, but not all complex carbohydrate foods are fiber-rich. For example, potatoes that have been processed into frozen hash browns retain very little of their original fiber. On the other hand, some foods rich in simple carbohydrates (such as fruits) are also rich in fiber. So when you're reading labels, it pays to check the grams of dietary fiber per serving. And if the food you're considering is fresh produce and there's no label to read, that almost guarantees it's fiber-rich.



Our red blood cells, brain, and nerve cells primarily rely on glucose. This is why we get tired, irritable, and shaky when we have not eaten for a prolonged period.

recap The three types of polysaccharides are starch, glycogen, and fiber. Starch is the storage form of glucose in plants, whereas glycogen is the storage form of glucose in animals. Fiber forms the support structures of plants. Soluble fibers dissolve in water, are viscous, and can be digested by bacteria in the colon, whereas insoluble fibers do not dissolve in water, are not viscous, and cannot be digested. Fiber-rich carbohydrates are known to contribute to good health.

Why do we need carbohydrates?

We have seen that carbohydrates are an important energy source for our bodies. Let's learn more about this and other functions of carbohydrates.

Carbohydrates Provide energy

Carbohydrates, an excellent source of energy for all our cells, provide 4 kilocalories (kcal) of energy per gram. Some of our cells can also use fat and even protein for

insoluble fibers Fibers that do not dissolve in water.

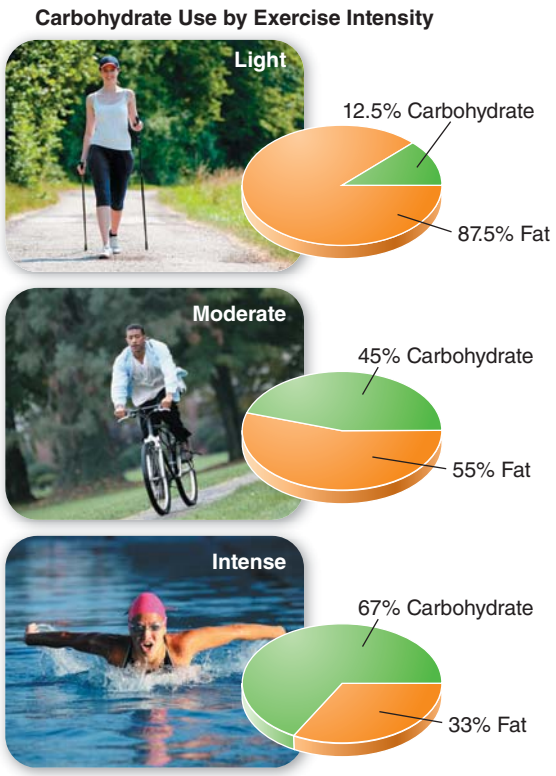


FIGURE 4.5 Amounts of carbohydrate and fat used during light, moderate, and intense exercise.
Data adapted from: "Regulation of endogenous fat and carbohydrate metabolism in relation to exercise intensity and duration" by Romijn et al., from *American Journal of Physiology*, September 1, 1993. Copyright © 1993 by The American Physiological Society. Reprinted with permission.

energy if necessary. However, our red blood cells can use only glucose, and our brain and other nervous tissues rely primarily on glucose. This is why you get tired, irritable, and shaky when you haven't eaten any carbohydrate for a prolonged period.

Carbohydrates Fuel Daily Activity

Many popular diets—such as Dr. Atkins' New Revolution Diet and the Sugar Busters plan—are based on the idea that our bodies actually "prefer" to use fat and/or protein for energy. They claim that current carbohydrate recommendations are much higher than we really need.

In reality, we rely mostly on both carbohydrates and fat for energy. In fact, as shown in **FIgure 4.5**, our bodies always use some combination of carbohydrates and fat to fuel daily activities. Fat is the predominant energy source used at rest and during low-intensity activities, such as sitting, standing, and walking. Even during rest, however, our brain cells and red blood cells rely on glucose.

Carbohydrates Fuel exercise

When we exercise, whether running, briskly walking, bicycling, or performing any other activity that causes us to breathe harder and sweat, we begin to use more glucose than fat. Whereas fat breakdown is a slow process and requires oxygen, we can break down glucose very quickly either with or without oxygen. Even during very intense exercise, when less oxygen is available, we can still break down glucose very quickly for energy. That's why when you are exercising at maximal effort carbohydrates are providing almost 100% of the energy your body requires.

If you are physically active, it is important to eat enough carbohydrates to provide energy for your brain, red blood cells, and muscles. In general, if you do not eat enough carbohydrate to support regular exercise, your body will have to rely on fat and protein as alternative energy sources. One advantage of becoming highly trained for endurance-type events, such as marathons and triathlons, is that our muscles are able to store more glycogen, which provides us with additional glucose we can use during exercise. (See Chapter 12 for more information on how exercise affects our need, use, and storage of carbohydrates.)

Low Carbohydrate Intake Can Lead to Ketoacidosis

When we do not eat enough carbohydrate, our bodies seek an alternative source of fuel for our brain and begins to break down stored fat. This process, called **ketosis**, produces an alternative fuel called **ketones**.

Ketosis is an important mechanism for providing energy to the brain during situations of fasting, low carbohydrate intake, or vigorous exercise. However, ketones also suppress appetite and cause dehydration and acetone breath (the breath smells like nail polish remover). If inadequate carbohydrate intake continues for an extended period, the body will produce excessive amounts of ketones. Because many ketones are acids, high ketone levels cause the blood to become very acidic, leading to a condition called **ketoacidosis**. The high acidity of the blood interferes with basic body functions, causes the loss of lean body mass, and damages many body tissues. People with untreated diabetes are at high risk for ketoacidosis, which can lead to coma and even death (see the **In Depth** on diabetes following this chapter).

Carbohydrates Spare Protein

If the diet does not provide enough carbohydrate, the body will make its own glucose from protein. This involves breaking down the proteins in blood and tissues into amino acids, then converting them to glucose. This process is called **gluconeogenesis** ("generating new glucose").

When our bodies use proteins for energy, the amino acids from these proteins cannot be used to make new cells, repair tissue damage, support our immune system, or

ketosis The process by which the breakdown of fat during fasting states results in the production of ketones.

ketones Substances produced during the breakdown of fat when carbohydrate intake is insufficient to meet energy needs. Ketones provide an alternative energy source for the brain when glucose levels are low.

ketoacidosis A condition in which excessive ketones are present in the blood, causing the blood to become very acidic, which alters basic body functions and damages tissues. Untreated ketoacidosis can be fatal. This condition is found in individuals with untreated diabetes mellitus.

gluconeogenesis The generation of glucose from the breakdown of proteins into amino acids.

perform any other function. During periods of starvation or when eating a diet that is very low in carbohydrate, our bodies will take amino acids from the blood first, and then from other tissues, such as muscles and the heart, liver, and kidneys. Using amino acids in this manner over a prolonged period can cause serious, possibly irreversible, damage to these organs. (See Chapter 6 for more details on using protein for energy.)

When we exercise or perform any activity that causes us to breathe harder and sweat, we begin to use more glucose than fat.

Fiber Helps us Stay Healthy

Although we cannot digest fiber, research indicates that it helps us stay healthy and may prevent many digestive and chronic diseases. The following are potential benefits of fiber consumption:

- May reduce the risk of colon cancer. Although there is some controversy surrounding this claim, many researchers believe that fiber binds cancer-causing substances and speeds their elimination from the colon. However, recent studies of colon cancer and fiber have shown that their relationship is not as strong as previously thought.
- Promotes bowel health by helping to prevent hemorrhoids, constipation, and other intestinal problems by keeping our stools moist and soft. Fiber gives gut muscles "something to push on" and makes it easier to eliminate stools.
- Reduces the risk for *diverticulosis,* a condition that is caused in part by trying to eliminate small, hard stools. A great deal of pressure must be generated in the large intestine to pass hard stools. This increased pressure weakens intestinal walls, causing them to bulge outward and form pockets **(FIgure 4.6)**. Feces and fibrous materials can get trapped in these pockets, which become infected and inflamed. This is a painful condition that must be treated with antibiotics or surgery.
- May reduce the risk of heart disease by delaying or blocking the absorption of dietary cholesterol into the bloodstream, a process depicted in **FIgure 4.7**. In addition, when soluble fibers are digested, bacteria in the colon produce short-chain fatty acids that may reduce the production of low-density lipoprotein (LDL), a blood lipid that is associated with heart disease, to healthful levels.
- May enhance weight loss, as eating a high-fiber diet causes a person to feel more full. Fiber absorbs water, expands in our large intestine, and slows the movement of food through the upper part of the digestive tract. Also, people who eat a fiber-rich diet tend to eat fewer fatty and sugary foods.
- May lower the risk for type 2 diabetes. In slowing digestion and absorption, fiber also slows the release of glucose into the blood. It thereby improves the body's regulation of insulin production and blood glucose levels.

Brown rice is a good food source of dietary fiber.

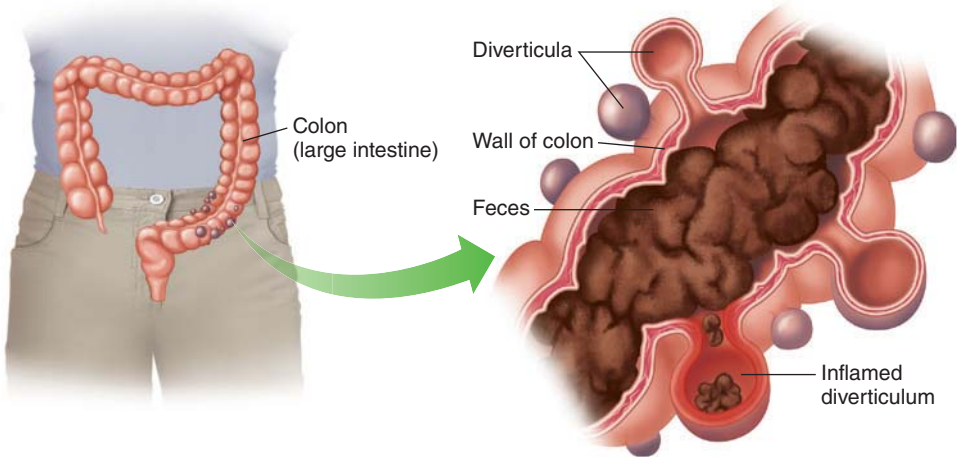


FIGURE 4.6 Diverticulosis occurs when bulging pockets form in the wall of the colon. These pockets become infected and inflamed, demanding proper treatment.

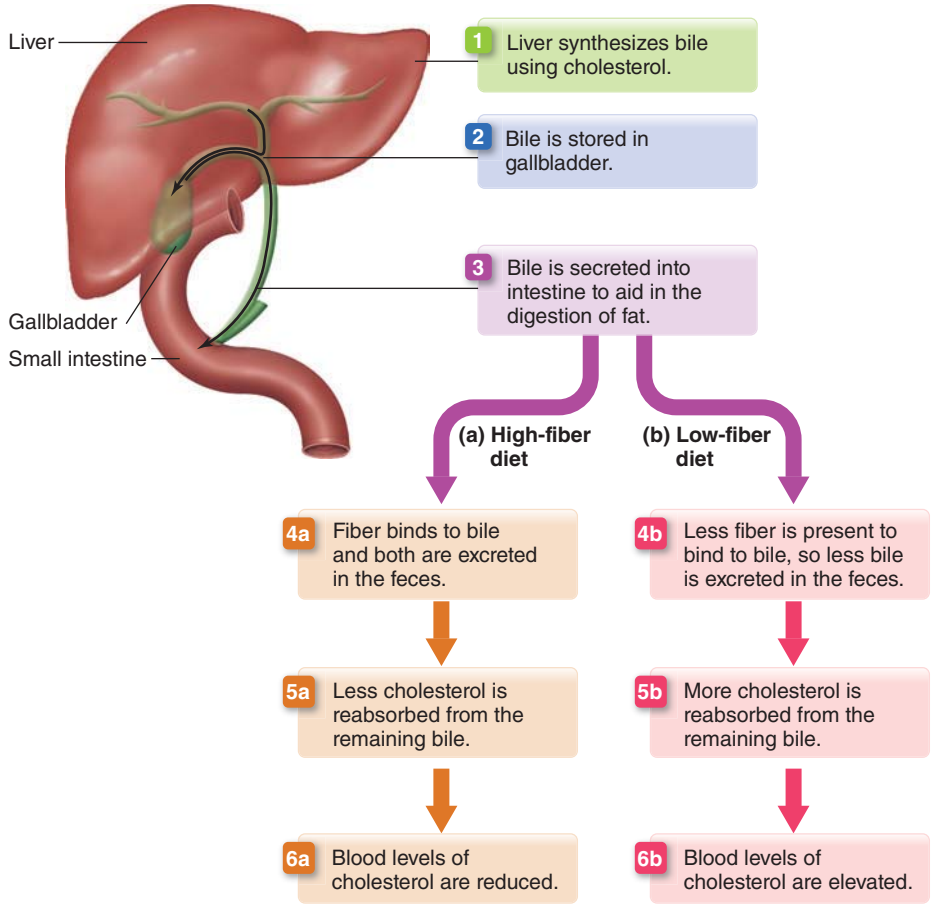


FIGURE 4.7 How fiber may help decrease blood cholesterol levels. **(a)** When eating a high-fiber diet, fiber binds to the bile that is produced from cholesterol, resulting in relatively more cholesterol being excreted in the feces. **(b)** When a lower-fiber diet is consumed, less fiber (and thus less cholesterol) is bound to bile and excreted in the feces.

recap Carbohydrates are an important energy source at rest and during exercise, and they provide 4 kcal of energy per gram. Carbohydrates are necessary in the diet to spare body protein and prevent ketosis. Complex carbohydrates contain fiber and other nutrients that can reduce the risk for obesity, heart disease, and diabetes. Fiber helps prevent hemorrhoids, constipation, and diverticulosis; may reduce the risk for colon cancer and heart disease; and may assist with weight loss.

How do our bodies break down carbohydrates?

Glucose is the form of sugar that our bodies use for energy, and the primary goal of carbohydrate digestion is to break down polysaccharides and disaccharides into monosaccharides, which can then be converted to glucose. **Figure 4.8** provides a visual tour of carbohydrate digestion.

Digestion breaks Down Most Carbohydrates into Monosaccharides

salivary amylase An enzyme in saliva that breaks starch into smaller particles and eventually into the disaccharide maltose.

Carbohydrate digestion begins in the mouth as the starch in the foods you eat mixes with your saliva during chewing (see Figure 4.8). Saliva contains an enzyme called **salivary amylase**, which breaks starch into smaller particles and eventually into the disaccharide maltose. The next time you eat a piece of bread, notice that you can actually taste it becoming sweeter; this indicates the breakdown of starch into maltose. Disaccharides are not digested in the mouth.

focus figure 4.8 | Carbohydrate Digestion Overview

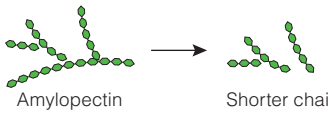
The primary goal of carbohydrate digestion is to break down polysaccharides and disaccharides into monosaccharides that can then be converted to glucose.

ORGANS OF THE GI TRACT

MOUTH

Chewing stimulates secretion of saliva from salivary glands.

Salivary amylase breaks down starch into shorter polysaccharides and maltose.



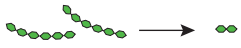
STOMACH

Salivary amylase is destroyed by acids.

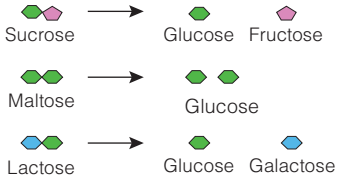
No carbohydrate digestion takes place in the stomach.

SMALL INTESTINE

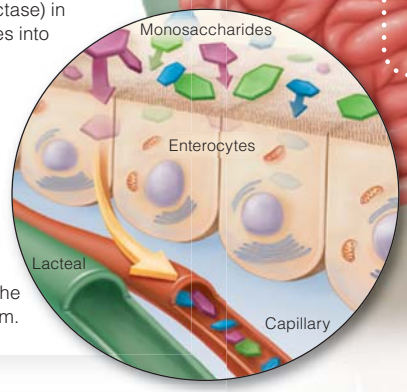
Pancreatic amylase breaks down remaining starch into maltose.



Specific enzymes (maltase, sucrase, lactase) in small intestine break down disaccharides into monosaccharides.



All monosaccharides are absorbed by the small intestine and enter the bloodstream.



LARGE INTESTINE

Some carbohydrates pass into the large intestine undigested.

Bacteria ferment some undigested carbohydrate.

Remaining fiber is excreted in feces.

ACCESSORY ORGANS

SALIVARY GLANDS

Produce salivary amylase.

PANCREAS

Produces digestive enzymes and bicarbonate, which are released into the small intestine via the pancreatic duct.

LIVER

Monosaccharides travel to the liver in the bloodstream via the portal vein, are converted to glucose, and then are transported to body cells to provide energy.

Excess glucose is stored in liver and muscle as glycogen.

pancreatic amylase An enzyme secreted by the pancreas into the small intestine that digests any remaining starch into maltose.

maltase A digestive enzyme that breaks maltose into glucose.

sucrase A digestive enzyme that breaks sucrose into glucose and fructose.

lactase A digestive enzyme that breaks lactose into glucose and galactose.

As the bolus of food leaves the mouth and enters the stomach, all digestion of carbohydrates ceases. This is because the acid in the stomach inactivates the salivary amylase enzyme.

The majority of carbohydrate digestion occurs in the small intestine. As the contents of the stomach enter the small intestine, an enzyme called **pancreatic amylase** is secreted by the pancreas into the small intestine. Pancreatic amylase continues to digest any remaining starch into maltose. Additional enzymes found in the microvilli of the mucosal cells that line the intestinal tract work to break down disaccharides into monosaccharides:

- Maltose is broken down into glucose by the enzyme **maltase**.
- Sucrose is broken down into glucose and fructose by the enzyme **sucrase**.
- Lactose is broken down into glucose and galactose by the enzyme **lactase**.

Once digestion of carbohydrates is complete, all monosaccharides are then absorbed into the mucosal cells lining the small intestine, where they pass through and enter into the bloodstream.

The Liver Converts Most Non-glucose Monosaccharides into glucose

Once the monosaccharides enter the bloodstream, they travel to the liver, where fructose and galactose are converted to glucose. If needed immediately for energy, the glucose is released into the bloodstream, where it can travel to the cells to provide energy. If glucose is not needed immediately for energy, it is stored as glycogen in our liver and muscles. Enzymes in liver and muscle cells combine glucose molecules to form glycogen in an anabolic, or building, process called *glycogenesis*. On average, the liver can store 70 g (280 kcal) and the muscles can store about 120 g (480 kcal) of glycogen. Stored glycogen can then be converted back into glucose in a catabolic, or destructive, process called *glycogenolysis* to supply the body's energy needs. Between meals, for example, our bodies draw on liver glycogen reserves to maintain blood glucose levels and support the needs of our cells, including those of our brain, spinal cord, and red blood cells **(Figure 4.9)**.

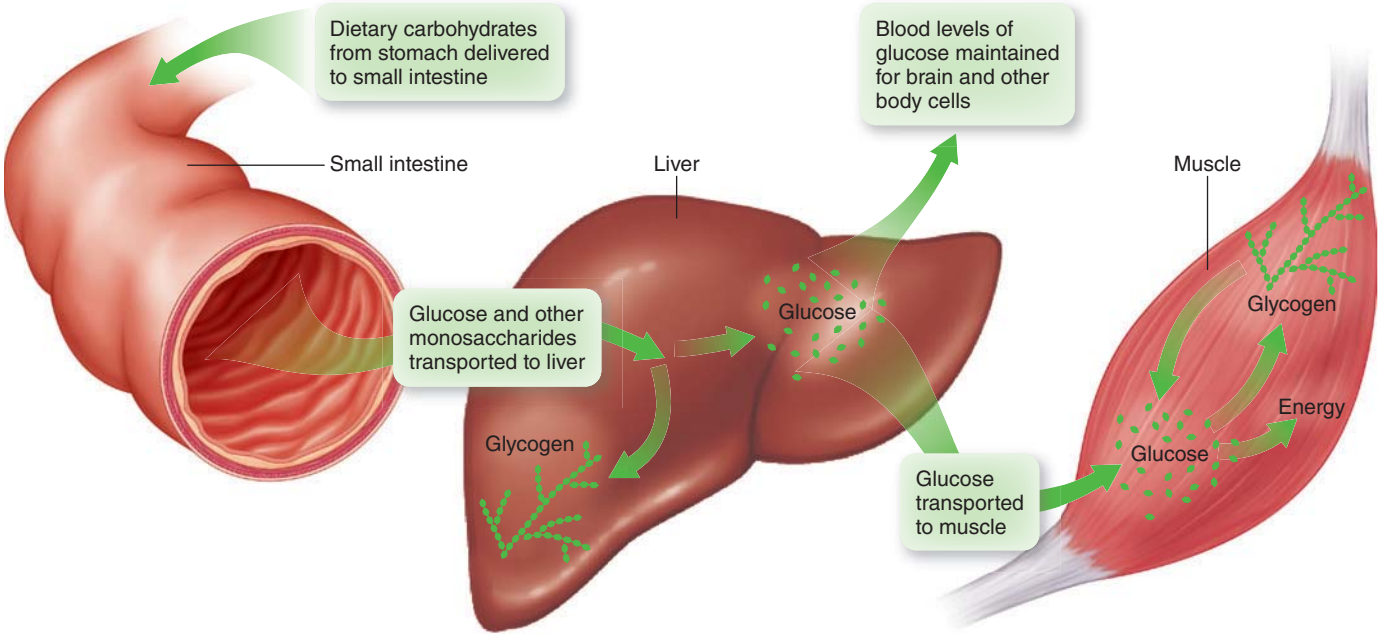


FIGURE 4.9 In the process of glycogenesis, glucose is stored as glycogen in both the liver and muscle. In the process of glycogenolysis, the glycogen stored in the liver is metabolized to maintain blood glucose between meals; muscle glycogen provides immediate energy to the muscle during exercise.

The glycogen stored in our muscles continually provides energy to our muscle cells, particularly during intense exercise. Endurance athletes can increase their storage of muscle glycogen from two to four times the normal amount through a process called *carbohydrate loading* (see Chapter 12). Any excess glucose is stored as glycogen in the liver and muscles and saved for such future energy needs as exercise. Once the storage capacity of the liver and muscles is reached, any excess glucose can be stored as fat in adipose tissue.

Fiber Is excreted from the Large Intestine

As previously mentioned, humans do not possess enzymes in the small intestine that can break down fiber. Thus, fiber passes through the small intestine undigested and enters the large intestine, or colon. There, bacteria ferment some previously undigested carbohydrates, causing the production of gases and a few short-chain fatty acids. The cells of the large intestine use these short-chain fatty acids for energy. The fiber remaining in the colon adds bulk to our stools and is excreted in feces (see Figure 4.8). In this way, fiber assists in maintaining bowel regularity.

recap Carbohydrate digestion starts in the mouth and continues in the small intestine. Glucose and other monosaccharides are absorbed into the bloodstream and travel to the liver, where non-glucose sugars are converted to glucose. Glucose either is used by the cells for energy or is converted to glycogen and stored in the liver and muscle for later use.

A Variety of Hormones r egulate blood g lucose Levels

Our bodies regulate blood glucose levels within a fairly narrow range to provide adequate glucose to the brain and other cells. A number of hormones, including insulin, glucagon, epinephrine, norepinephrine, cortisol, and growth hormone, assist the body with maintaining blood glucose.

When we eat a meal, our blood glucose level rises. But glucose in our blood cannot help our nerves, muscles, and other organs function unless it can cross into their cells. Glucose molecules are too large to cross cell membranes independently. To get in, glucose needs assistance from the hormone **insulin**, which is secreted by the pancreas (**FIgure 4.10** top panel). Insulin is transported in the blood throughout the body, where it stimulates special molecules called glucose transporters, which are located in cells, to travel to the cell membrane and transport glucose into the cell. Insulin can therefore be thought of as a key that opens the gates of the cell membrane, enabling the transport of glucose into the cell interior, where it can be used for energy. Insulin also stimulates the liver and muscles to take up glucose and store it as glycogen.

When you have not eaten for some time, your blood glucose level declines. This decrease in blood glucose stimulates the pancreas to secrete another hormone, **glucagon** (Figure 4.10 bottom panel). Glucagon acts in an opposite way to insulin. It triggers glycogenolysis, in which the liver converts its stored glycogen into glucose, which is then secreted into the bloodstream and transported to the cells for energy. Glucagon also assists in the breakdown of body proteins to amino acids, so that the liver can stimulate gluconeogenesis, the production of new glucose from amino acids.

Epinephrine, norepinephrine, cortisol, and growth hormone are additional hormones that work to increase blood glucose. Epinephrine and norepinephrine are secreted by the adrenal glands and nerve endings when blood glucose levels are low. They trigger glycogen breakdown in the liver, resulting in a subsequent increase in the release of glucose into the bloodstream. They also increase gluconeogenesis. These two hormones are also responsible for our "fight-or-flight" reaction to danger; they are released when we need a burst of energy to respond quickly. Cortisol and growth hormone are secreted by the adrenal glands to act on liver, muscle, and adipose tissue. Cortisol increases gluconeogenesis and decreases the use of glucose by muscles and other body organs. Growth hormone decreases glucose uptake by our muscles,

insulin The hormone secreted by the beta cells of the pancreas in response to increased blood levels of glucose; it facilitates the uptake of glucose by body cells.

glucagon The hormone secreted by the alpha cells of the pancreas in response to decreased blood levels of glucose; it causes the breakdown of liver stores of glycogen into glucose.

focus figure 4.10 | r egulation of blood g lucose

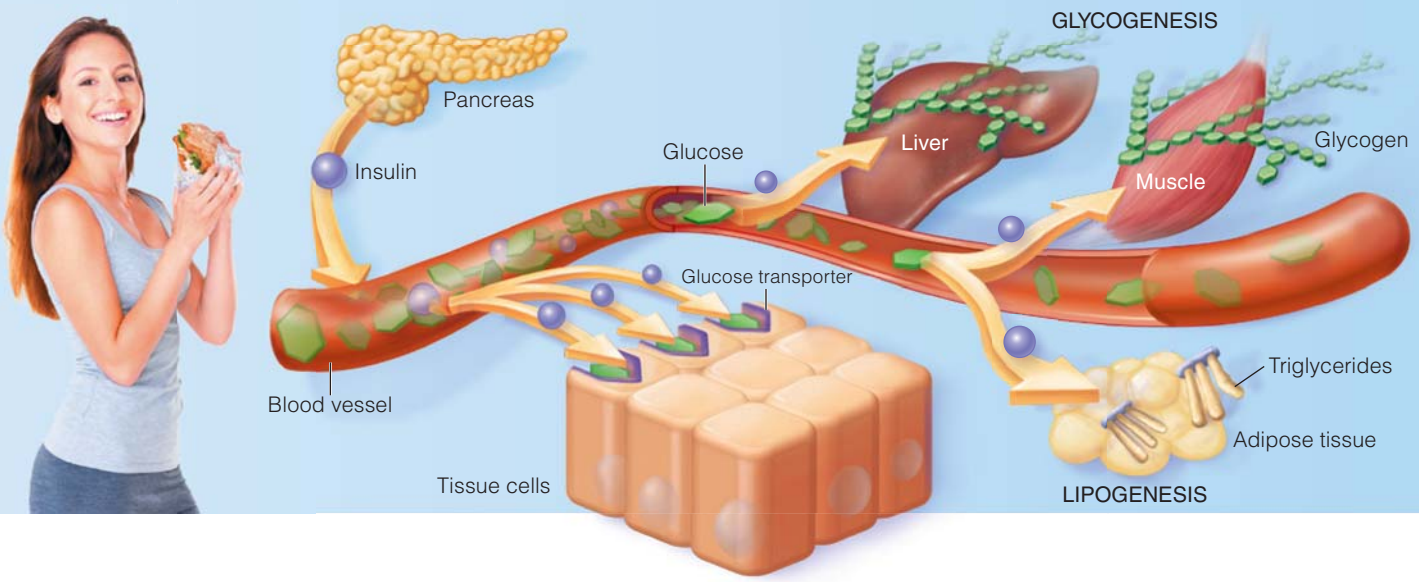
Our bodies regulate blood glucose levels within a fairly narrow range to provide adequate glucose to the brain and other cells. Insulin and glucagon are two hormones that play a key role in regulating blood glucose.

HIGH BLOOD GLUCOSE

1 **Insulin secretion:** When blood glucose levels increase after a meal, the pancreas secretes the hormone insulin from the beta cells into the bloodstream.

2 **Cellular uptake:** Insulin travels to the tissues. There, it stimulates glucose transporters within cells to travel to the cell membrane, where they facilitate glucose transport into the cell to be used for energy.

3 **Glucose storage:** Insulin also stimulates the storage of glucose in body tissues. Glucose is stored as glycogen in the liver and muscles (glycogenesis), and is stored as triglycerides in adipose tissue (lipogenesis).

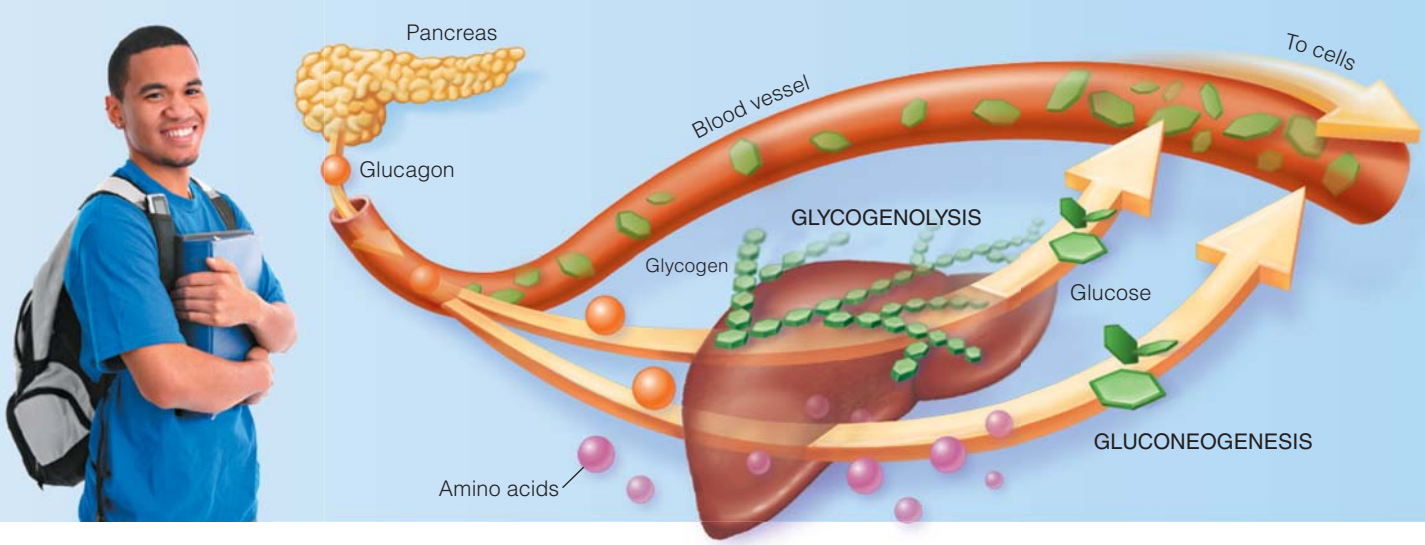


LOW BLOOD GLUCOSE

1 **Glucagon secretion:** When blood glucose levels are low, the pancreas secretes the hormone glucagon from the alpha cells into the bloodstream.

2 **Glycogenolysis:** Glucagon stimulates the liver to convert stored glycogen into glucose, which is released into the blood and transported to the cells for energy.

3 **Gluconeogenesis:** Glucagon also assists in the breakdown of proteins and the uptake of amino acids by the liver, which creates glucose from amino acids.



HOT TOPIC

Is it Hunger—or Hypoglycemia?

After going for several hours without eating, have you ever felt spaced out, shaky, irritable, and weak? And did the symptoms subside once you'd eaten? If so, maybe you wondered if your symptoms were due to hypoglycemia.

In **hypoglycemia**, blood glucose falls to lower-than-normal levels. This commonly occurs in people with diabetes who aren't getting proper treatment, but it can also happen in people who don't have diabetes if their pancreas secretes too much insulin after a high-carbohydrate meal. The characteristic symptoms usually appear about 1 to 4 hours after the meal and occur because the body clears glucose from the blood too quickly. People with this form of hypoglycemia must eat smaller meals more frequently to level out their blood insulin and glucose levels.

The trouble is, ordinary hunger can make you experience symptoms just like those of true hypoglycemia. So which is it—hunger or hypoglycemia? You can only find out for sure by getting a blood test, but unless you have diabetes it's probably not necessary. For most healthy people, eating regular meals and healthy snacks is the only "treatment" needed.

increases our mobilization and use of the fatty acids stored in our adipose tissue, and increases our liver's output of glucose.

Normally, the effects of these hormones balance each other to maintain blood glucose within a healthy range. An alteration in this balance can lead to health conditions such as diabetes (discussed **In Depth** following this chapter) or hypoglycemia.

The glycemic Index Shows How Foods Affect Our blood glucose Level

The term **glycemic index** refers to the potential of foods to raise blood glucose levels. Foods with a high glycemic index cause a sudden surge in blood glucose. This in turn triggers a large increase in insulin, which may be followed by a dramatic drop in blood glucose. Foods with a low glycemic index cause low to moderate fluctuations in blood glucose. When foods are assigned a glycemic index value, they are often compared to the glycemic effect of pure glucose.

An apple has a much lower glycemic index value (38) than a serving of white rice (56).

The glycemic index of a food is not always easy to predict. **Figure 4.11** ranks certain foods according to their glycemic index. Do any of these rankings surprise you? Most people assume that foods containing simple sugars have a higher glycemic index than starches, but this is not always the case. For instance, compare the glycemic index for apples and instant potatoes. Although instant potatoes are a starchy food, they have a glycemic index value of 85, whereas the value for an apple is only 38!

The type of carbohydrate, the way the food is prepared, and its fat and fiber content can all affect how quickly the body absorbs it. It is important to note that we eat most of our foods combined into a meal. In this case, the glycemic index of the total meal becomes more important than the ranking of each food.

For determining the effect of a food on a person's glucose response, some nutrition experts believe that the **glycemic load** is more useful than the glycemic index. A food's glycemic load is the number of grams of carbohydrate it contains multiplied by the glycemic index of that carbohydrate. For instance, carrots are recognized as a vegetable having a relatively high glycemic index of about 68; however, the glycemic load of carrots is only 3.[7] This is because there is very little total carbohydrate in a serving of carrots. The low glycemic load of carrots means that carrot consumption is unlikely to cause a significant rise in glucose and insulin levels.

Why do we care about the glycemic index and glycemic load? Foods and meals with a lower glycemic load are better choices for someone with diabetes because they will not trigger dramatic fluctuations in blood glucose. They may also reduce the risk for heart disease and colon cancer because they generally contain more fiber, and fiber

hypoglycemia A condition marked by blood glucose levels that are below normal fasting levels.

glycemic index The system that assigns ratings (or values) for the potential of foods to raise blood glucose and insulin levels.

glycemic load The amount of carbohydrate in a food multiplied by the glycemic index of the carbohydrate.

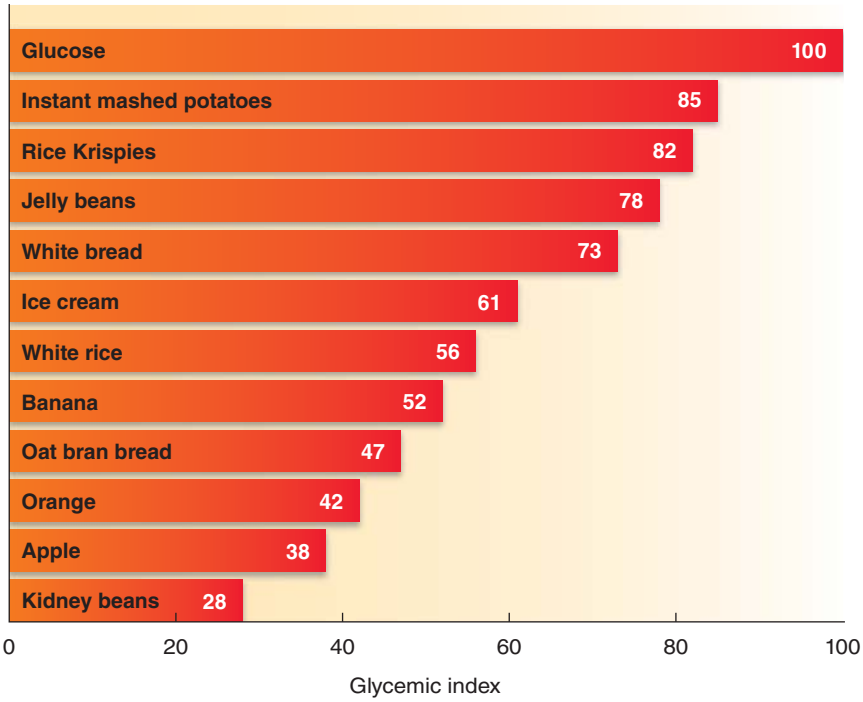


FIGURE 4.11 Glycemic index values for various foods as compared to pure glucose.
Data adapted from: "International Table of Glycemic Index and Glycemic Load Values," by Foster-Powell, K., S. H. A. Holt, and J. C. Brand-Miller from *American Journal of Clinical Nutrition*, 2002.

helps decrease fat levels in the blood. Recent studies have shown that people who eat lower glycemic index diets have higher levels of high-density lipoprotein, or HDL (a healthful blood lipid), and lower levels of low-density lipoprotein, or LDL (a blood lipid associated with increased risk for heart disease), and their blood glucose values are more likely to be normal.[8,9] Diets with a low glycemic index and load are also associated with a reduced risk for prostate cancer.[10]

To find out the glycemic index and glycemic load of over 100 foods, visit www.health.harvard.edu, enter "newsweek" into the search bar, and then click on the link to "glycemic index and glycemic load for 100+ foods."

Despite some encouraging research findings, the glycemic index and glycemic load remain controversial. Many nutrition researchers feel that the evidence supporting their health benefits is weak. In addition, many believe the concepts of the glycemic index/load are too complex for people to apply to their daily lives. Other researchers insist that helping people choose foods with a lower glycemic index/load is critical in the prevention and treatment of many chronic diseases. Until this controversy is resolved, people are encouraged to eat a variety of fiber-rich and less-processed carbohydrates, such as beans and lentils, fresh vegetables, and whole-wheat bread, because these forms of carbohydrates have a lower glycemic load and they contain a multitude of important nutrients.

recap Various hormones are involved in regulating blood glucose. Insulin lowers blood glucose levels by facilitating the entry of glucose into cells. Glucagon, epinephrine, norepinephrine, cortisol, and growth hormone raise blood glucose levels by a variety of mechanisms. The glycemic index is a value that indicates the potential of foods to raise blood glucose and insulin levels. The glycemic load is the amount of carbohydrate in a food multiplied by the glycemic index of the carbohydrate in that food. Foods with a high glycemic index/load cause surges in blood glucose and insulin, whereas foods with a low glycemic index/load cause more moderate fluctuations in blood glucose. Diets with a low glycemic index/load are associated with a reduced risk for chronic diseases.

How much carbohydrate should we eat?

Proponents of low-carbohydrate diets claim that eating carbohydrates makes you gain weight. However, anyone who consumes more Calories than he or she expends will gain weight, whether those Calories are in the form of simple or complex

carbohydrates, protein, or fat. Moreover, fat is twice as "fattening" as carbohydrate: it contains 9 kcal per gram, whereas carbohydrate contains only 4 kcal per gram. In fact, eating carbohydrate sources that are high in fiber and micronutrients has been shown to reduce the overall risk for obesity, heart disease, and diabetes. Thus, all carbohydrates are not bad, and even foods with added sugars—in limited amounts—can be included in a healthful diet.

The Recommended Dietary Allowance (RDA) for carbohydrate is based on the amount of glucose the brain uses.[5] The current RDA for adults 19 years of age and older is 130 g of carbohydrate per day. It is important to emphasize that this RDA does not cover the amount of carbohydrate needed to support daily activities; it covers only the amount of carbohydrate needed to supply adequate glucose to the brain.

Carbohydrates have been assigned an Acceptable Macronutrient Distribution Range (AMDR) of 45% to 65% of total energy intake. This is the range of intake associated with a decreased risk for chronic diseases. TAbLe 4.2 compares the carbohydrate recommendations from the Institute of Medicine with the Dietary Guidelines for Americans related to carbohydrate-containing foods.[5,6] As you can see, the Institute of Medicine provides specific numeric recommendations, whereas the Dietary Guidelines for Americans are general suggestions about foods high in fiber and low in added sugars. Most health agencies agree that most of the carbohydrates you eat each day should be high in fiber, whole-grain, and unprocessed. As recommended in the USDA Food Guide, eating at least half your grains as whole grains and eating the suggested amounts of fruits and vegetables each day will ensure that you get enough fiber-rich carbohydrates in your diet. Although fruits are predominantly composed of simple sugars, they are good sources of vitamins, some minerals, and fiber.

Eating the suggested daily amounts of vegetables and fruit, such as apricots, will ensure that you're getting enough fiber-rich carbohydrate in your diet.

Most Americans eat Too Much Added Sugar

The average carbohydrate intake per person in the United States is approximately 50% of total energy intake. For some people, almost half of this amount consists of sugars. Where does all this sugar come from? Some sugar comes from healthful food sources, such as fruit and milk. Some comes from foods made with refined grains, such as soft white breads, saltine crackers, and pastries. Much of the rest comes from **added sugars**—that is, sugars and syrups that are added to foods during processing or preparation.[5] For example, many processed foods include high-fructose-corn syrup (HFCS).

The most common source of added sugars in the U.S. diet is sweetened soft drinks; we drink an average of 40 gallons per person each year. Consider that one 12-oz cola contains 38.5 g of sugar, or almost 10 teaspoons. If you drink the average amount, you are consuming more than 16,420 g of sugar (about 267 cups) each year! Other common sources of added sugars include cookies, cakes, pies, fruit drinks, fruit

added sugars Sugars and syrups that are added to food during processing or preparation.

TABLE 4.2 Dietary Recommendations for Carbohydrates

Institute of Medicine r ecommendations*	Dietary g uidelines for Americans†
Recommended Dietary Allowance (RDA) for adults 19 years of age and older is 130 g of carbohydrate per day.	Limit the consumption of foods that contain refined grains, especially refined grain foods that contain solid fats, added sugars, and sodium.
The Acceptable Macronutrient Distribution Range (AMDR) for carbohydrate is 45–65% of total daily energy intake.	Reduce the intake of Calories from solid fats and added sugars.
Added sugar intake should be 25% or less of total energy intake each day.	Increase vegetable and fruit intake. Eat a variety of vegetables, especially dark-green and red and orange vegetables and beans and peas. Consume at least half of all grains as whole grains. Increase whole-grain intake by replacing refined grains with whole grains. Choose foods that provide more dietary fiber, as well as potassium, calcium, and vitamin D, which are nutrients of concern in American diets. These foods include vegetables, fruits, whole grains, and milk and milk products.

Data from: *Institute of Medicine, Food and Nutrition Board, 2005. *Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients)*. Washington, DC: The National Academy of Sciences. Reprinted with permission.

Data from: †U.S. Department of Health and Human Services and U.S. Department of Agriculture. 2010. Dietary Guidelines for Americans.

Candy and other foods with added sugars have lower levels of vitamins, minerals, and fiber than foods that naturally contain simple sugars.

punches, and candy. Even many nondessert items, such as peanut butter, yogurt, flavored rice mixes, and even salad dressing, contain added sugars.

If you want a quick way to figure out the amount of sugar in a processed food, check the Nutrition Facts panel on the box for the line that identifies "Sugars." You'll notice that the amount of sugar in a serving is identified in grams. Divide the total grams by 4 to get teaspoons. For instance, one national brand of yogurt contains 21 grams of sugar in a half-cup serving. That's more than 5 teaspoons of sugar! Doing this simple math before you buy may help you choose among different, more healthful versions of the same food.

Added sugars are not chemically different from naturally occurring sugars. However, foods and beverages with added sugars have lower levels of vitamins, minerals, and fiber than foods that naturally contain simple sugars. That's why most healthcare organizations recommend that we limit our consumption of added sugars. The Nutrition Facts panel includes a listing of total sugars, but a distinction is not generally made between added sugars and naturally occurring sugars. Thus, you need to check the ingredients list. Refer to **TAbLe 4.3** for a list of terms indicating added sugars. To maintain a diet low in added sugars, limit foods in which a form of added sugar is listed as one of the first few ingredients on the label.

TABLE 4.3 Forms of Sugar Commonly Added to Foods

Name of Sugar	Definition
brown sugar	A highly refined sweetener made up of approximately 99% sucrose and produced by adding to white table sugar either molasses or burnt table sugar for coloring and flavor.
Cane sugar	Sucrose that has been extracted from sugarcane, a tropical plant naturally rich in sugar.
Concentrated fruit juice sweetener	A form of sweetener made with concentrated fruit juice, commonly pear juice.
Confectioner's sugar	A highly refined, finely ground white sugar; also referred to as powdered sugar.
Corn sweeteners	A general term for any sweetener made with corn starch.
Corn syrup	A syrup produced by the partial hydrolysis of corn starch.
Dextrose	An alternative term for glucose.
Fructose	A monosaccharide that occurs in fruits and vegetables; also called levulose, or fruit sugar.
galactose	A monosaccharide that joins with glucose to create lactose.
granulated sugar	Another term for white sugar, or table sugar.
High-fructose corn syrup	A type of corn syrup in which part of the sucrose is converted to fructose, making it sweeter than sucrose or regular corn syrup; most high-fructose corn syrup contains 42% to 55% fructose.
Honey	A sweet, sticky liquid sweetener made by bees from the nectar of flowers; contains glucose and fructose.
Invert sugar	A sugar created by heating a sucrose syrup with a small amount of acid; inverting sucrose results in its breakdown into glucose and fructose, which reduces the size of the sugar crystals; because of its smooth texture, it is used in making candies and some syrups.
Levulose	Another term for fructose, or fruit sugar.
Mannitol	A type of sugar alcohol.
Maple sugar	A sugar made by boiling maple syrup.
Molasses	A thick, brown syrup that is separated from raw sugar during manufacturing; it is considered the least refined form of sucrose.
Natural sweeteners	A general term used for any naturally occurring sweeteners, such as fructose, honey, and raw sugar.
r aw sugar	The sugar that results from the processing of sugar beets or sugarcane; it is approximately 96% to 98% sucrose; true raw sugar contains impurities and is not stable in storage; the raw sugar available to consumers has been purified to yield an edible sugar.
Sorbitol	A type of sugar alcohol.
Turbinado sugar	The form of raw sugar that is purified and safe for human consumption; sold as "Sugar in the Raw" in the United States.
White sugar	Another name for sucrose, or table sugar.
Xylitol	A type of sugar alcohol.

Sugars Are blamed for Many Health Problems

Why do sugars have such a bad reputation? First, they are known to contribute to tooth decay. Second, many people believe they cause hyperactivity in children. Third, eating a lot of sugar could increase the levels of unhealthful lipids in our blood, increasing our risk for heart disease. High intakes of sugar have also been blamed for causing diabetes and obesity. Let's learn the truth about these accusations.

Sugar Causes Tooth Decay

Sugars do play a role in dental problems, because the bacteria that cause tooth decay thrive on sugar. These bacteria produce acids, which eat away at tooth enamel and can eventually cause cavities and gum disease **(FIgure 4.12)**. Eating sticky foods that adhere to teeth—such as caramels, crackers, sugary cereals, and licorice—and sipping sweetened beverages over time are two behaviors that increase the risk for tooth decay. This means that people shouldn't suck on hard candies or caramels, slowly sip soda or juice, or put babies to bed with a bottle unless it contains water. As we have seen, even breast milk contains sugar, which can slowly drip onto the baby's gums. As a result, infants should not routinely be allowed to fall asleep at the breast.

To reduce your risk for tooth decay, brush your teeth after each meal, after drinking sugary drinks, and after snacking on sweets. Drinking fluoridated water and using a fluoride toothpaste will also help protect your teeth.

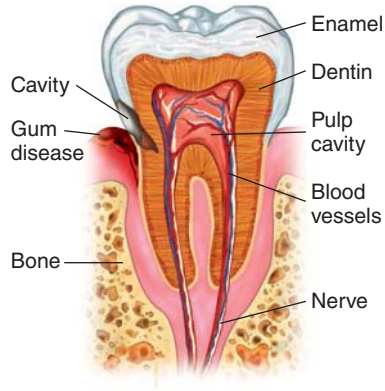


FIGURE 4.12 Eating sugars can cause an increase in cavities and gum disease. This is because bacteria in the mouth consume sugars present on the teeth and gums and produce acids, which eat away at these tissues.

There Is No Link between Sugar and Hyperactivity in Children

Although many people believe that eating sugar causes hyperactivity and other behavioral problems in children, there is little scientific evidence to support this claim. Some children actually become less active shortly after a high-sugar meal! However, it is important to emphasize that most studies of sugar and children's behavior have only looked at the effects of sugar a few hours after ingestion. We know very little about the long-term effects of sugar intake on the behavior of children. Behavioral and learning problems are complex issues, most likely caused by a multitude of factors. Because of this complexity, the Institute of Medicine has stated that, overall, there does not appear to be enough evidence to state that eating too much sugar causes hyperactivity or other behavioral problems in children.[5] Thus, there is no Tolerable Upper Intake Level for sugar.

High Sugar Intake Can Lead to unhealthful Levels of blood Lipids

Research evidence does suggest that consuming a diet high in added sugars is associated with unhealthful changes in blood lipids.[11] For example, higher intakes of added sugars are associated with higher blood levels of low-density lipoproteins (LDL) and lower levels of high-density lipoproteins (HDL). These are risk factors for heart disease. Two recent studies have shown that people who consume sugar-sweetened beverages have an increased risk of heart disease.[12,13] Although these recent findings illustrate a potential link between added sugar intake and heart disease, there is not enough evidence to prove that eating a diet high in sugar directly causes higher levels of heart disease. Still, based on current knowledge, it is prudent to eat a diet low in added sugars. Because added sugars are a component of many processed foods and beverages, careful label reading is advised.

High Sugar Intake Is Associated with Diabetes and Obesity

Recent studies suggest that eating a diet high in added sugars is associated with a higher risk for diabetes; this relationship is particularly strong between higher intakes of sugar-sweetened beverages and diabetes.[14-16] An observational study examined the relationship between diabetes and sugar intake across 175 countries and found that for every 150 kcal per person per day increase in availability of sugar (equivalent to about one can of soft drink per day), the prevalence of diabetes increased by 1.1%.[17] Although the exact mechansims explaining this relationship are not clear, experts have speculated that the dramatic increase in glucose and insulin levels that occur when we consume high amounts of rapidly absorbable carbohydrates (which includes any forms of sugar or high-fructose corn syrup) may stimulate appetite, increase food

QuickTips

Slashing Your Sugar Intake

- When buying fruit, go for fresh, frozen, dried, or canned options packed in water or their own juice. Avoid fruits packed in light or heavy syrup.
- Switch from drinking sweetened soft drinks, juice drinks, and energy drinks to diet drinks, or opt for water or unsweetened tea or coffee.
- Limit the number of specialty coffees flavored with syrup that you drink—have these as an occasional treat.
- Read food labels to increase your awareness of the sugar content of the foods you normally buy.
- Reduce the amount of sugar you put into your coffee, tea, and cereal—try cutting the amount to half, then a quarter. Or consider using an alternative sweetener instead of sugar.
- Choose snacks such as cookies, candies, and cakes less often, and replace more often with snacks with no added sugars, such as nuts, unsweetened yogurts, fresh and dried fruit, and vegetables.

intake, and promote weight gain, which increases our risk for diabetes. High-fructose corn syrup in particular has negative effects on how we metabolize and store body fat; this can lead to us being more resistant to the normal actions of insulin and increase our risk for diabetes.[18]

There is also evidence linking sugar intake with obesity. For example, a recent systematic review of randomized controlled trials and observational studies found that reducing intake of sugars in adults results in weight loss and increasing intake of sugars results in weight gain.[19] This increase in weight is due to the excess Calorie intake and not due to the sugars per se. This same review found that children who consume one or more servings of sugar-sweetened beverages per day had a 1.55 times higher risk of being overweight than those children consuming none or very little.

We know that if you consume more energy than you expend, you will gain weight. It makes intuitive sense that people who consume extra energy from high-sugar foods are at risk for obesity, just like people who consume extra energy from fat or protein. In addition to the increased potential for obesity, another major concern about high-sugar diets is that they tend to be low in nutrient density because the intake of high-sugar foods tends to replace that of more nutritious foods. The relationship between added sugars and obesity is highly controversial and is discussed in more detail in the **Nutrition Debate** (page 136).

If you're concerned about the amount of added sugars you consume, what can you do to cut down? See the **Quick Tips** feature for answers.

Whole-grain foods provide more nutrients and fiber than foods made with enriched flour.

recap The RDA for carbohydrate is 130 g per day; this amount is only sufficient to supply adequate glucose to the brain. The AMDR for carbohydrate is 45% to 65% of total energy intake. Added sugars are sugars and syrups added to foods during processing or preparation. Sugar causes tooth decay but does not appear to cause hyperactivity in children. High intakes of sugars are associated with increases in unhealthful blood lipids and increased risks for heart disease, diabetes, and obesity.

Most Americans eat Too Little Fiber-r ich Carbohydrates

Do you get enough fiber-rich carbohydrate each day? Most people in the United States eat only about two servings of fruits or vegetables each day, and most don't consistently choose whole-grain breads, pastas, and cereals. As explained earlier, fruits, vegetables, and whole-grain foods are rich in micronutrients and fiber. Whole-grains also have a lower glycemic index than refined carbohydrates; thus, they prompt a more gradual release of insulin and result in less severe fluctuations in both insulin and glucose.

TABLE 4.4 Terms Used to Describe Grains and Cereals on Nutrition Labels

Term	Definition
Brown bread	Bread that may or may not be made using whole-grain flour. Many brown breads are made with white flour with brown (caramel) coloring added.
Enriched (or fortified) flour or grain	Enriching or fortifying grains involves adding nutrients back to refined foods. In order to use this term in the United States, a minimum amount of iron, folate, niacin, thiamin, and riboflavin must be added. Other nutrients can also be added.
Refined flour or grain	Refining involves removing the coarse parts of food products; refined wheat flour is flour in which all but the internal part of the kernel has been removed.
Stone ground	This term refers to a milling process in which limestone is used to grind any grain. Stone ground does not mean that bread is made with whole grain because refined flour can be stone ground.
Unbleached flour	Unbleached flour has been refined but not bleached; it is very similar to refined white flour in texture and nutritional value.
Wheat flour	This term refers to any flour made from wheat; it includes white flour, unbleached flour, and whole-wheat flour.
White flour	White flour has been bleached and refined. All-purpose flour, cake flour, and enriched baking flour are all types of white flour.
Whole-grain flour	This flour is made from grain that is not refined; whole grains are milled in their complete form with only the husk removed.
Whole-wheat flour	Whole-wheat flour is an unrefined, whole-grain flour made from whole-wheat kernels.

TAbLe 4.4 defines the terms commonly used on nutrition labels for breads and cereals. Read the label for the bread you eat—does it list *whole-wheat* flour or just *wheat* flour? Although most labels for breads and cereals list wheat flour as the first ingredient, this term actually refers to enriched white flour, which is made when flour is processed. So check the ingredients label closely to make sure the first ingredient has the word "whole" in it. To gain a better understanding of the difference between a whole grain and processed grain products, it's important to learn about what makes a whole grain whole, and how whole grains are processed to reduce their fiber content.

What Makes a Whole grain Whole?

Grains are grasses that produce edible kernels. A kernel of grain is the seed of the grass. If you were to plant a kernel of barley, a blade of grass would soon shoot up. Kernels of different grains all share a similar design. As shown in FIgure 4.13, they consist of three parts:

- The outermost covering, called the *bran*, is very high in fiber and contains most of the grain's vitamins and minerals.
- The *endosperm* is the grain's midsection and contains most of the grain's carbohydrates and protein.
- The *germ* sits deep in the base of the kernel, surrounded by the endosperm, and is rich in healthful fats and some vitamins.

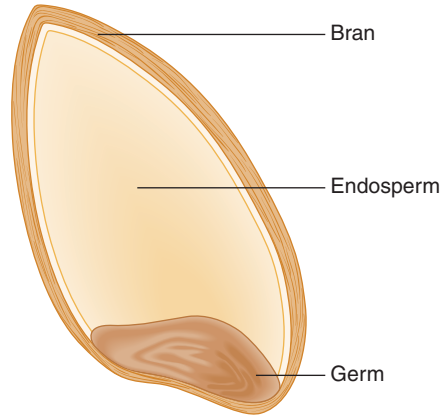


FIGURE 4.13 A whole grain includes the bran, endosperm, and germ.

Whole grains are kernels that retain all three of these parts.

The kernels of some grains also have a *husk* (hull): a thin, dry coat that is inedible. Removing the husk is always the first step in milling (grinding) these grains for human consumption.

People worldwide have milled grains for centuries, usually using heavy stones. A little milling removes only a small amount of the bran, leaving a crunchy grain suitable for cooked cereals. For example, cracked wheat and hulled barley retain much of the kernel's bran. Whole-grain flours are produced when whole grains are ground and then recombined. Because these hearty flours retain a portion of the bran, endosperm, and germ, foods such as breads made with them are rich in fiber and a wide array of vitamins and minerals.

With the advent of modern technology, processes for milling grains became more sophisticated, with seeds being repeatedly ground and sifted into increasingly finer flours, retaining little or no bran and therefore little fiber and few vitamins and minerals. For instance, white wheat flour, which consists almost entirely of endosperm, is high in carbohydrate but retains only about 25% of the wheat's fiber, vitamins, and minerals. In the United States, manufacturers of breads and other baked goods made with white flour are required by law to enrich their products with vitamins and minerals to replace some of those lost in processing. **enriched foods** are foods in which nutrients that were lost during processing have been added back, so the food meets

enriched foods Foods in which nutrients that were lost during processing have been added back, so that the food meets a specified standard.

nutrition label activity

Recognizing Carbohydrates on the Label

Figure 4.14 shows labels for two breakfast cereals. The cereal on the left (a) is processed and sweetened, whereas the one on the right (b) is a whole-grain product with no added sugar. Which is the better breakfast choice? Fill in the label data below to find out!

- Check the center of each label to locate the amount of total carbohydrate.
  1. For the sweetened cereal, the total carbohydrate is _____ g.
  2. For the whole-grain cereal, the total carbohydrate is _____ g for a smaller serving size.
- Look at the information listed as subgroups under Total Carbohydrate. The label for the sweetened cereal lists all types of carbohydrates in the cereal: dietary fiber, sugars, and other carbohydrate (which refers to starches). Notice that this cereal contains 13 g of sugar—half of its total carbohydrates.
  3. How many grams of dietary fiber doees the sweetened cereal contain? _____
- The label for the whole-grain cereal lists only 1 g of sugar, which is 4% of its total carbohydrates.
  4. How many grams of dietary fiber does the whole-grain cereal contain?
- To calculate the percentage of Calories that comes from carbohydrate, do the following:
  - **a.** Calculate the *Calories* in the cereal that come from carbohydrate. Multiply the total grams of carbohydrate per serving by the energy value of carbohydrate:

    26 g of carbohydrate × 4 kcal/g =
    104 kcal from carbohydrate
  - **b.** Calculate the *percentage of Calories* in the cereal that come from carbohydrate. Divide the Calories from carbohydrate by the total Calories for each serving:

    (104 kcal ÷ 120 kcal) × 100 =
    87% Calories from carbohydrate

Which cereal should you choose to increase your fiber intake? Check the ingredients for the sweetened cereal. Remember that they are listed in order from highest to lowest amount. The second and third ingredients listed are sugar and brown sugar, and the corn and oat flours are not whole grain. Now look at the ingredients for the other cereal—it contains whole-grain oats. Although the sweetened product is enriched with more B-vitamins, iron, and zinc, the whole-grain cereal packs 4 g of fiber per serving, not to mention 5 g of protein, and it contains no added sugars. Overall, it is a more healthful choice.

Nutrition Facts

Serving Size: 3/4 cup (30g)
Servings Per Package: About 14

Amount Per Serving	Cereal	Cereal With 1/2 Cup Skim Milk
Calories	120	160
Calories from Fat	15	15
	% Daily Value**	
Total Fat 1.5g*	2%	2%
Saturated Fat 0g	0%	0%
Trans Fat 0g		
Polyunsaturated Fat 0g		
Monounsaturated Fat 0.5g		
Cholesterol 0mg	0%	1%
Sodium 220mg	9%	12%
Potassium 40mg	1%	7%
Total Carbohydrate 26g	9%	11%
Dietary Fiber 1g	3%	3%
Sugars 13g		
Other Carbohydrate 12g		
Protein 1g		

INGREDIENTS: Corn Flour, Sugar, Brown Sugar, Partially Hydrogenated Vegetable Oil (Soybean and Cottonseed), Oat Flour, Salt, Sodium Citrate (a flavoring agent), Flavor added [Natural & Artificial Flavor, Strawberry Juice Concentrate, Malic Acid (a flavoring agent)], Niacinamide (Niacin), Zinc Oxide, Reduced Iron, Red 40, Yellow 5, Red 3, Yellow 6, Pyridoxine Hydrochloride (Vitamin B6), Riboflavin (Vitamin B2), Thiamin Mononitrate (Vitamin B1), Folic Acid (Folate) and Blue 1.

(a)

Nutrition Facts

Serving Size: 1/2 cup dry (40g)
Servings Per Container: 13

Amount Per Serving	
Calories	150
Calories from Fat	25
	% Daily Value*
Total Fat 3g	5%
Saturated Fat 0.5g	2%
Trans Fat 0g	
Polyunsaturated Fat 1g	
Monounsaturated Fat 1g	
Cholesterol 0mg	0%
Sodium 0mg	0%
Total Carbohydrate 27g	9%
Dietary Fiber 4g	15%
Soluble Fiber 2g	
Insoluble Fiber 2g	
Sugars 1g	
Protein 5g	

INGREDIENTS: 100% Natural Whole Grain Rolled Oats.

(b)

FIGURE 4.14 Labels for two breakfast cereals: **(a)** processed and sweetened cereal; **(b)** whole-grain cereal with no sugar added.

a specified standard. However, enrichment replaces only a handful of nutrients and leaves the product low in fiber. Notice that the terms *enriched* and *fortified* are not synonymous: **fortified foods** have nutrients added that did not originally exist in the food (or existed in insignificant amounts). For example, some breakfast cereals have been fortified with iron, a mineral that is not present in cereals naturally.

When choosing cereals, breads, and crackers and other baked goods, look for whole wheat, whole oats, or similar whole grains on the ingredient list. This ensures that the product contains the fiber and micronutrients that nature packed into the plant's seed. Try the nearby **Nutrition Label Activity** to learn how to recognize various carbohydrates on food labels.

We Need at Least 25 grams of Fiber Daily

How much fiber do we need? The Adequate Intake for fiber is 25 g per day for women and 38 g per day for men, or 14 g of fiber for every 1,000 kcal per day that a person eats.[5] Most people in the United States eat only 12 to 18 g of fiber each day, getting only half of the fiber they need. Although fiber supplements are available, it is best to get fiber from food because foods contain additional nutrients, such as vitamins and minerals.

It's important to drink plenty of fluid as you increase your fiber intake because fiber binds with water to soften stools. Inadequate fluid intake with a high-fiber diet can actually result in hard, dry stools that are difficult to pass through the colon. At least eight 8-oz glasses of fluid each day are commonly recommended.

Can you eat too much fiber? Excessive fiber consumption can lead to problems such as intestinal gas, bloating, and constipation. Also, because fiber causes the body to eliminate more water in the feces, a very-high-fiber diet could result in dehydration. Fiber also binds many vitamins and minerals; thus, a diet with too much fiber can reduce our absorption of iron, zinc, calcium, and vitamin D. In children, some elderly, the chronically ill, and other at-risk populations, extreme fiber intake can even lead to malnutrition—they feel full before they have eaten enough to provide adequate energy and nutrients. So, although some societies are accustomed to a very-high-fiber diet, most people in the United States find it difficult to tolerate more than 50 g of fiber per day.

To see a vast menu of high-fiber choices for each meal of the day, and find out how much fiber the foods you eat provide, visit the Fiber-o-Meter at www.webmd.com. Enter "fiber-o-meter" into the search bar to get to the page with a direct link.

Food Sources of Fiber

Eating the amounts of whole grains, legumes and other vegetables, fruits, and nuts recommended in the USDA Food Guide will ensure that you eat enough fiber. **Figure 4.15** shows some common foods and their fiber content. You can use this information to design a diet that includes adequate fiber.

To help you eat right all day, see the menu choices high in fiber. Each of these choices is also packed with vitamins, minerals, and phytochemicals. For instance, a sweet potato is loaded with beta-carotene, a phytochemical the body converts to vitamin A.

See the **Quick Tips** feature (p. 133) for suggestions on selecting carbohydrate sources rich in fiber.

fortified foods Foods in which nutrients are added that did not originally exist in the food, or which existed in insignificant amounts.

eating right all day

breakfast
Oatmeal instead of sugary cereal!

Lunch
Bean soup instead of pizza!

Dinner
Sweet potato instead of french fries!

Snack
Fresh fruit instead of a candy bar!

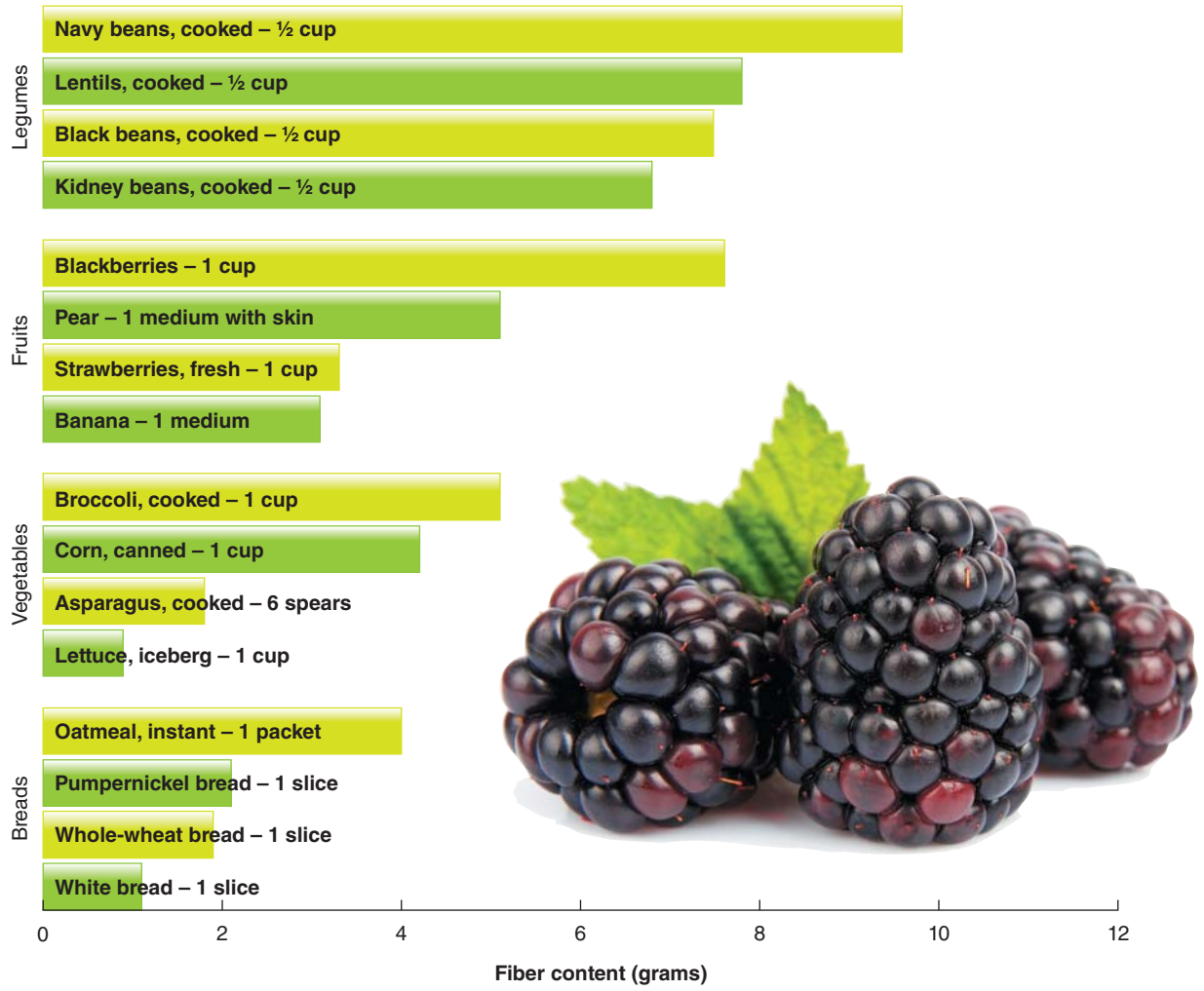


FIGURE 4.15 Fiber content of common foods. *Note:* The Adequate Intake for fiber is 25 g per day for women and 38 g per day for men.
Data from: U.S. Department of Agriculture, Agricultural Research Service. 2012. USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory Home Page.

recap The Adequate Intake for fiber is 25 g per day for women and 38 g per day for men. Most Americans eat only half of the fiber they need each day. Foods high in fiber and nutrient density include whole grains and cereals, legumes and other vegetables, fruits, and nuts. The more processed the food, the fewer fiber-rich carbohydrates it contains.

What's the story on alternative sweeteners?

Most of us love sweets but want to avoid the extra Calories and tooth decay that go along with them. Remember that all carbohydrates, whether simple or complex, contain 4 kcal of energy per gram. Because sweeteners such as sucrose, fructose, honey, and brown sugar contribute energy, they are called **nutritive sweeteners**.

Other nutritive sweeteners include the *sugar alcohols* such as mannitol, sorbitol, isomalt, and xylitol. Popular in sugar-free gums, mints, and diabetic candies, sugar alcohols are less sweet than sucrose. Foods with sugar alcohols have health benefits that foods made with sugars do not have, such as a reduced glycemic response and decreased risk of dental caries. Also, because sugar alcohols are absorbed slowly and incompletely from the intestine, they provide less energy than sugar, usually 2 to 3 kcal of energy per gram. However, because they are not completely absorbed from the intestine, they can attract water into the large intestine and cause diarrhea.

A number of other products have been developed to sweeten foods without promoting tooth decay and weight gain. Because these products provide little or no energy, they are called **non-nutritive**, or *alternative*, **sweeteners.**

nutritive sweeteners Sweeteners, such as sucrose, fructose, honey, and brown sugar, that contribute Calories (energy).

non-nutritive sweeteners Manufactured sweeteners that provide little or no energy; also called *alternative sweeteners.*

QuickTips

Hunting for Fiber

- Select breads made with *whole* grains, such as wheat, oats, barley, and rye. Two slices of whole-grain bread provide 4–6 grams of fiber.
- Switch from a low-fiber breakfast cereal to one that has at least 4 grams of fiber per serving.
- For a mid-morning snack, stir 1–2 tablespoons of whole ground flaxseed meal (4 grams of fiber) into a cup of low-fat or nonfat yogurt. Or choose an apple or a pear, with the skin left on (approximately 5 grams of fiber).
- Instead of potato chips with your lunchtime sandwich, have a side of carrot sticks or celery sticks (approximately 2 grams of fiber per serving).
- Eat legumes every day, if possible (approximately 6 grams of fiber per serving). Have them as your main dish, as a side, or in soups, chili, and other dishes.
- Don't forget the vegetables! A cup of cooked leafy greens provides about 4 grams of fiber, and a salad is rich in fiber.
- Snack on a handful of almonds (about 4 grams of fiber) mixed with dried fruit.
- For dessert, try fresh, frozen, or dried fruit or a high-fiber granola with sweetened soy milk.
- When shopping, choose fresh fruits and vegetables whenever possible. Buy frozen vegetables and fruits when fresh produce is not available. Check frozen selections to make sure there is no sugar or salt added.
- Be careful when buying canned fruits, vegetables, and legumes because they may be high in added sugar or sodium. Select versions without added sugar or salt, or rinse before serving.

Limited use of Alternative Sweeteners Is Not Harmful

Research has shown alternative sweeteners to be safe for adults, children, and individuals with diabetes. Women who are pregnant should discuss the use of alternative sweeteners with their healthcare provider. In general, it appears safe for pregnant women to consume alternative sweeteners in amounts within the Food and Drug Administration (FDA) guidelines.[20] These amounts, known as the **Acceptable Daily Intake (ADI)**, are estimates of the amount of a sweetener that someone can consume each day over a lifetime without adverse effects. The estimates are based on studies conducted on laboratory animals, and they include a 100-fold safety factor. It is important to emphasize that actual intake by humans is typically well below the ADI.

Saccharin

Discovered in the late 1800s, *saccharin* is about 300 times sweeter than sucrose. Concerns arose in the 1970s that saccharin could cause cancer; however, more than 20 years of subsequent research failed to link saccharin to cancer in humans. Based on this evidence, in May 2000 the National Toxicology Program of the U.S. government removed saccharin from its list of products that may cause cancer. No ADI has been set for saccharin, and it is used in foods and beverages and as a tabletop sweetener. It is sold as Sweet n' Low (also known as "the pink packet") in the United States.

Acesulfame-K

Acesulfame-K (acesulfame potassium) is marketed under the names Sunette and Sweet One. It is a Calorie-free sweetener that is 200 times sweeter than sugar. It is used to sweeten gums, candies, beverages, instant tea, coffee, gelatins, and puddings. The taste of acesulfame-K does not change when it is heated, so it can be used in cooking. The body does not metabolize acesulfame-K, so it is excreted unchanged by the kidneys. The ADI for acesulfame-K is 15 mg per kg body weight per day. For example, the ADI in an adult weighing 150 pounds (or 68 kg) would be 1,020 mg.

Acceptable Daily Intake (ADI) An FDA estimate of the amount of a nonnutritive sweetener that someone can consume each day over a lifetime without adverse effects.

Contrary to media reports claiming severe health consequences related to the consumption of alternative sweeteners, major health agencies have determined that these products are safe for us to consume.

Aspartame

Aspartame, also called Equal ("the blue packet") and NutraSweet, is one of the most popular alternative sweeteners currently in use. Aspartame is composed of two amino acids: phenylalanine and aspartic acid. When these amino acids are separate, one is bitter and the other has no flavor—but joined together, they make a substance that is 180 times sweeter than sucrose. Although aspartame contains 4 kcal of energy per gram, it is so sweet that only small amounts are used, thus it ends up contributing little or no energy. Heat destroys the bonds that bind the two amino acids in aspartame. Thus, it cannot be used in cooking because it loses its sweetness.

Although there are numerous claims that aspartame causes headaches and dizziness, and can increase a person's risk for cancer and nerve disorders, studies do not support these claims.[21] A significant amount of research has been done to test the safety of aspartame.

The ADI for aspartame is 50 mg per kg body weight per day. For an adult weighing 150 pounds (or 68 kg), the ADI would be 3,400 mg. **TAbLe 4.5** shows how many servings of aspartame-sweetened foods would have to be consumed to exceed the ADI. Because the ADI is a very conservative estimate, it would be difficult for adults or children to exceed this amount of aspartame intake. However, drinks sweetened with aspartame, which are extremely popular among children and teenagers, are very low in nutritional value. They should not replace more healthful beverages such as milk, water, and 100% fruit juice.

There are some people who should not consume aspartame at all: those with the disease *phenylketonuria (PKU).* This is a genetic disorder that prevents the breakdown of the amino acid phenylalanine. Because the person with PKU cannot metabolize phenylalanine, it builds up to toxic levels in the tissues of the body and causes irreversible brain damage. In the United States, all newborn babies are tested for PKU; those who have it are placed on a phenylalanine-limited diet. Some foods that are common sources of protein and other nutrients for many growing children, such as meats and milk, contain phenylalanine. Thus, it is critical that children with PKU not waste what little phenylalanine they can consume on nutrient-poor products sweetened with aspartame.

Sucralose

Sucralose is marketed under the brand name Splenda and is known as "the yellow packet." It is made from sucrose, but chlorine atoms are substituted for the hydrogen and oxygen normally found in sucrose, and it passes through the digestive tract unchanged, without contributing any energy. It is 600 times sweeter than sucrose and is stable when heated, so it can be used in cooking. It has been approved for use in many foods, including chewing gum, salad dressings, beverages, gelatin and pudding products, canned fruits, frozen dairy desserts, and baked goods. Studies have shown sucralose to be safe. The ADI for sucralose is 5 mg per kg body weight per day. For example, the ADI of sucralose in an adult weighing 150 pounds (or 68 kg) would be 340 mg.

Neotame and Stevia

Neotame is an alternative sweetener that is 7,000 times sweeter than sugar. Manufacturers use it to sweeten a variety of products, such as beverages, dairy products, frozen desserts, and chewing gums.

Stevia was approved as an alternative sweetener by the FDA in 2008. It is produced from a purified extract of the stevia plant, native to South America. Stevia is 200 times sweeter than sugar. It is currently used commercially to sweeten beverages and is available in powder and liquid for tabletop use. Stevia is also called Rebiana, Reb-A, Truvia, and Purevia.

TABLE 4.5 Foods and Beverages That a Child and an Adult Would Have to Consume Daily to Exceed the ADI for Aspartame

Foods and beverages	50-lb Child	150-lb Adult
12 fl. oz carbonated soft drink OR	7	20
8 fl. oz powdered soft drink OR	11	34
4 fl. oz gelatin dessert OR	14	42
Packets of tabletop sweetener	32	97

Data from: "Aspartame" from the Calorie Control Council website, 2013.

using Artificial Sweeteners Does Not Necessarily Prevent Weight gain

Remember that to prevent weight gain, you need to balance the total number of Calories you consume against

nutri-case | HANNAH

"Last night, my mom called and said she'd be late getting home from work, so I made dinner. I made vegetarian quesadillas with flour tortillas, canned green chilies, cheese, and sour cream, plus a few baby carrots on the side. Later on while I was studying, I got really hungry, so I had some sugar-free cookies. They're sweetened with sorbitol and taste just like regular cookies! I ate maybe three or four, but I didn't think it was a big deal because they're sugar-free. When I checked the package label this morning, I found out that each cookie has 90 Calories! I'm so mad at myself for blowing my diet!"

Without knowing the exact ingredients in Hannah's dinner and snack, would you agree that, prior to the cookies, she'd been making healthy choices? Why or why not? How might she have changed the ingredients in her quesadillas to increase their fiber content? And, if the cookies were sugar-free, how can you explain the fact that each cookie still contained 90 Calories?

the number you expend. If you're expending an average of 2,000 kcal a day and you consume about 2,000 kcal per day, then you'll neither gain nor lose weight. But if, in addition to your normal diet, you regularly indulge in "treats," you're bound to gain weight, whether they are sugar free or not. Consider the Calorie count of these artificially sweetened foods:

- One cup of nonfat chocolate frozen yogurt with artificial sweetener = 199 Calories
- One sugar-free chocolate cookie = 100 Calories
- One serving of no-sugar-added hot cocoa = 55 Calories

Does the number of Calories in these foods surprise you? *Remember, sugar-free doesn't mean Calorie-free*. Make it a habit to check the Nutrition Facts panel to find out how much energy is really in your food!

recap Alternative sweeteners can be used in place of sugar to sweeten foods. Most of these products do not promote tooth decay and contribute little or no energy. The alternative sweeteners approved for use in the United States are considered safe when consumed in amounts less than the Acceptable Daily Intake.

*behavior change . . . getting started!

Now that you've read this chapter, try making these changes:

For yourself:

- Eat more high-fiber foods with each meal – including fruits, legumes and other vegetables, and whole-grain cereals and breads.
- Drink more water or other non-caloric beverages with every meal to reduce your energy intake and help you digest the higher amount of fiber you are eating.
- Brush your teeth more often throughout the day, particularly after eating sweet foods or sticky, starchy foods. This will reduce your risk for dental caries.

For your community:

- Write a blog for your school's website highlighting strategies to help people increase their fiber intake.
- Identify who on campus makes the decisions about the beverage and food content of vending machines, and inquire about his or her willingness to provide sugar-free and higher fiber options.

nutrition debate

Are Added Sugars the Cause of the Obesity Epidemic?

Over the past 30 years, obesity rates have increased dramatically for adults and children. Obesity has become public health enemy number one because many chronic diseases, such as type 2 diabetes, heart disease, high blood pressure, and arthritis, go hand in hand with obesity.

Genetics cannot be held solely responsible for the rapid rise in obesity that has occurred. Our genetic makeup takes thousands of years to change; humans who lived 100 years ago had essentially the same genetic makeup as we do. We need to look at the effect of our lifestyle changes over the same period.

It is estimated that the rate of overweight in children has doubled since the mid-1970s.

One lifestyle factor that has come to the forefront of nutrition research is the contribution of added sugars to overweight and obesity. Consuming more energy than we expend causes weight gain. Consuming higher amounts of added sugars is a factor in weight gain for many people because they do not compensate for these increased Calories by increasing their energy expenditure through exercise or by reducing their energy intake from other foods.

The role of sugar-sweetened beverages in increasing our risk for obesity has received a great deal of attention in recent years. These beverages include soft drinks, fruit drinks, energy drinks, and vitamin water drinks. It is estimated that U.S. children's intake of sugar-sweetened beverages has increased threefold since the late 1970s, with approximately 10% of children's energy intake coming from these beverages.[19]

High-fructose corn syrup (HFCS), in particular, has garnered a great deal of attention because researchers have emphasized that HFCS is the sole caloric sweetener in sugared soft drinks and represents more than 40% of caloric sweeteners added to other foods and beverages in the United States.[22] These researchers have linked the increased use and consumption of HFCS with the rising rates of obesity since the 1970s, when HFCS first appeared. HFCS is made by converting the starch in corn to glucose and then converting some of the glucose to fructose, which is sweeter. Unfortunately, fructose is metabolized differently than glucose because it is absorbed farther down in the small intestine, and, unlike glucose, it does not stimulate insulin release from the pancreas. Because insulin inhibits food intake in people, this failure to stimulate insulin release could increase energy intake. In addition, fructose enters body cells via a transport protein not present in brain cells; thus, unlike glucose, fructose cannot enter brain cells and stimulate satiety signals. If we don't feel full, we are likely to continue eating or drinking.

The growing evidence linking the consumption of sugar-sweetened beverages with overweight and obesity in children has led to dramatic changes in soft drink availability in schools and at school-sponsored events. In 2006, the soft drink industry agreed to a voluntary ban on sales of all sweetened soft drinks in elementary and high schools. Despite these positive changes, there is still ample availability of foods and beverages containing added sugars in the marketplace.

Although the evidence pinpointing added sugars and HFCS as major contributors to the obesity epidemic may appear strong, other nutrition professionals disagree. It has been proposed that soft drinks would have contributed to the obesity epidemic whether the sweetener was sucrose or fructose, and that their contribution to obesity is due to increased consumption as a result of advertising, increases in serving sizes, and virtually unlimited access to soft drinks.[23] It is possible that the obesity epidemic has resulted from increased consumption of energy (from sweetened soft drinks and other high-energy foods) *and* a reduction in physical activity levels, and added sugars themselves are not to blame.

This issue is extremely complex, and more research needs to be done in humans before we can fully understand how added sugars contribute to our diet and our health.

Critical Thinking Questions

1. After reading this, do you think added sugars should be banned from our food supply? Why or why not?
2. Should reducing sugar-sweetened beverages be up to individuals, or should it be mandatory for those at high risk for obesity? Why or why not?
3. Should families, schools, and our government play a central role in controlling the types of foods and beverages offered to young people throughout their day?

chapter **review**

test yourself | answers

1. **False.** At 4 kcal/g, carbohydrates have less than half the energy of a gram of fat. Eating a high-carbohydrate diet will not cause people to gain body fat unless their total diet contains more energy (kcal) than they expend. In fact, eating a diet high in complex, fiber-rich carbohydrates is associated with a lower risk for obesity.
2. **False.** There is no evidence that diets high in sugar cause hyperactivity in children.
3. **True.** Contrary to recent reports claiming harmful consequences related to the consumption of alternative sweeteners, major health agencies have determined that these products are safe for most of us to consume in limited quantities.

MasteringNutrition™

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- Hear It: MP3s
- Study It: Get Ready for Nutrition Math and Chemistry review
- Do It: NutriTools and "Find the Quack" feature
- Review It: Quizzes, flashcards, and glossary

review questions

1. Glucose, fructose, and galactose are
   a. monosaccharides.
   b. disaccharides.
   c. polysaccharides.
   d. complex carbohydrates.
2. Which of the following statements about carbohydrates is true?
   a. Carbohydrates are our main energy source during light activity and while we are at rest.
   b. Simple carbohydrates are higher in energy (kcals per gram) than complex carbohydrates.
   c. Excessive intake of carbohydrates can lead to ketoacidosis.
   d. Consuming a diet high in fiber-rich carbohydrates may reduce the level of cholesterol in the blood.
3. Glucose not immediately needed by the body
   a. is converted to cholesterol and stored in abdominal fat.
   b. is converted to glycogen and stored in the liver and muscles.
   c. passes into the large intestine and is fermented by bacteria.
   d. All of the above are possible fates of excess glucose.
4. The glycemic index rates
   a. the acceptable amount of alternative sweeteners to consume in 1 day.
   b. the potential of foods to raise blood glucose and insulin levels.
   c. the risk of a given food for causing diabetes.
   d. the ratio of soluble to insoluble fiber in a complex carbohydrate.
5. The Institute of Medicine recommends that adults consume
   a. up to 14 grams of fiber a day.
   b. at least 25% of our daily energy intake as added sugars.
   c. up to 65% of our daily energy intake as carbohydrate.
   d. at least half of all grains as whole grains.
6. The most common source of added sugar in the American diet is
   a. table sugar.
   b. white flour.
   c. alcohol.
   d. sweetened soft drinks.

7. Which of the following is a reliable source of fiber-rich carbohydrate?
   a. wheat bread
   b. unbleached flour
   c. whole-oat cereal
   d. enriched grains
8. Aspartame should not be consumed by people who have
   a. phenylketonuria.
   b. type 1 diabetes.
   c. lactose intolerance.
   d. diverticulosis.
9. **True or false?** In the process of photosynthesis, plants produce carbohydrate and store it as fiber.
10. **True or false?** Both insulin and glucagon are pancreatic hormones.

math review

11. Simon is trying to determine the minimum amount of carbohydrate he should consume in his diet to meet the AMDR for health. His total energy intake needed to maintain his current weight is 3,500 kcal per day. How many a) kcal, and b) grams, of carbohydrate should Simon consume each day?

Answers to Review Questions and Math Review are located at the back of this text and in the MasteringNutrition Study Area.

web resources

www.foodinsight.org
Food Insight—International Food Information Council Foundation

Search this site to find out more about sugars and low-Calorie sweeteners.

www.ada.org
American Dental Association

Go to this site to learn more about tooth decay as well as other oral health topics.

www.nidcr.nih.gov
National Institute of Dental and Craniofacial Research

Find out more about recent oral and dental health discoveries, and obtain statistics and data on the status of dental health in the United States.

www.caloriecontrol.org
Calorie Control Council

This site provides information about reducing energy and fat in the diet, achieving and maintaining a healthy weight, and eating various low-Calorie, reduced-fat foods and beverages.