“No one who can rise before dawn three hundred sixty days a year fails to make his family rich.” Malcolm Gladwell cites this proverb as a principle of the connection between the stereotypical Asian work ethic and the millennia-old tradition of rice cultivation in China. The production of rice is a far more demanding endeavor than the growing of other grains: Working in a rice field is 10 to 20 times more labor intensive than working on an equivalent-size corn or wheat field.

Every culture relies on carbohydrate-rich grains as a readily available, inexpensive source of calories, and grains occupy a prominent place in everyday life. The Chinese word for rice also means food, and the Japanese word for cooked rice means meal; bread is the “staff of life,” and “breaking bread together” is a universal sign of friendship.

Westerners have a love-hate relationship with carbohydrates. We’re told to “carbo-load” before serious

Carbohydrates: Sugars, Starches, and Fibers
exercise, like a marathon, yet we’re admonished by health and fitness authorities to moderate our intake of carbohydrate-rich foods. Many of us fear carbohydrates as a cause of unwanted weight gain and other health problems. Should we manage our carbs as wisely—and diligently—as a rice farmer tends a paddy?
Carbohydrates in Our Food

LEARNING OBJECTIVES

1. Distinguish refined carbohydrates from unre- fined carbohydrates.
2. Compare whole grains to enriched grains.
3. Explain how added refined sugars and naturally occurring sugars differ from each other.

Our hunter-gatherer ancestors ate very dif- ferently from the way we eat. Their diet consisted almost entirely of unrefined foods—foods eaten either just as they are found in nature or with only minimal processing, such as cooking. Today we still consume some unrefined sources of carbohydrate, but many of the foods we consume are made with refined grains and contain added refined sugar (Figure 4.1).

The increased consumption of refined carbohydrates that has occurred around the world over the past few decades has been implicated as one of the causes of the current obesity epidemic and the rising incidence of chronic diseases. Recommendations for a healthy diet suggest that we select more unrefined sources of carbohydrates, including whole grains, vegetables, and fruits, and that we limit foods high in refined carbohydrates, such as candies, cookies, and sweetened beverages.

What Is a Whole Grain?

When you eat a bowl of oatmeal or a slice of whole-wheat toast, you are consuming a whole-grain product. Whole-grain products include the entire kernel of the grain: the germ, the bran, and the endosperm (Figure 4.2a). Refined grain products, such as white bread, include just the endosperm. The bran and germ are discarded during refining, and along with them the fiber and some vitamins and minerals are lost. To make up some of these losses, refined grains sold in the United States are required to be enriched. Enrichment, which is a type of fortification, adds back some, but not all, of the nutrients lost in processing (Figure 4.2b). For example, thiamin and iron are lost when grains are milled, and they are later added back to even higher levels through enrichment. Vitamin E and vitamin B₆ are also removed by milling, but they are not added back. Therefore, foods made with refined grains contain more of some nutrients and less of others than foods made from whole grains.

Unrefined and refined foods • Figure 4.1

Corn is an unrefined source of carbohydrate, but it can be refined through grinding, cooking, extruding, and drying to eventually end up as cornflakes in your cereal bowl. The sugar you sprinkle on cornflakes is also a refined carbohydrate; it has been refined from sugar cane or sugar beets.

refined Refers to foods that have undergone processing to remove the coarse parts of the original food.

enrichment The addition of specific amounts of thiamin, riboflavin, niacin, and iron to refined grains. Since 1998, folic acid has also been added to enriched grains.

fortification The addition of nutrients to foods.
What Is Added Refined Sugar?

Refined sugars added to food during processing or at the table account for about 16% of the calories consumed in the typical American diet. Refined sugars are nutritionally and chemically identical to sugars that occur naturally in foods. When separated from their plant sources, however, refined sugars no longer contain the fiber, vitamins, minerals, and other substances found in the original plant. Therefore, added refined sugars contribute empty calories to the diet. Foods that naturally contain sugars, such as fruits and milk, provide vitamins, minerals, and phytochemicals, along with the calories from the sugar, making them higher in nutrient density (Figure 4.3).

CONCEPT CHECK

1. What is the difference between a whole-grain product and a product made with a refined grain?
2. How do the nutrients in enriched grains compare to those in whole grains?
3. Why are foods high in added refined sugars said to contribute empty calories?

A 12-ounce can of soda contains about 140 Calories from sugar but almost no other nutrients. Three medium kiwis also provide about 140 Calories, along with plenty of other nutrients, including vitamin C, folate, and calcium, making the kiwis more nutrient dense than the soda.
Chemically, carbohydrates are a group of compounds made up of one or more sugar units that contain carbon (carbon) as well as hydrogen and oxygen in the same two-to-one proportion found in water (hydrate, H₂O). Carbohydrates made up of only one sugar unit are called monosaccharides, those made up of two sugar units are called disaccharides, and those made up of more than two sugar units are called polysaccharides.

**monosaccharide** A carbohydrate made up of a single sugar unit.

**disaccharide** A carbohydrate made up of two sugar units.

**polysaccharide** A carbohydrate made up of many sugar units linked together.

**sugar unit** A sugar molecule that cannot be broken down to yield other sugars.

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**LEARNING OBJECTIVES**

1. **Name** the basic unit of carbohydrate.
2. **Classify** carbohydrates as simple or complex.
3. **Describe** the types of complex carbohydrates.
4. **Distinguish** soluble fiber from insoluble fiber.
Complex Carbohydrates

Complex carbohydrates are polysaccharides; they are generally not sweet tasting the way simple carbohydrates are. They include glycogen in animals and starches and fibers in plants (Figure 4.4c). Glycogen is the storage form of glucose in humans and other animals. It is found in the liver and muscles, but we don’t consume it in our diet because the glycogen in animal muscles is broken down soon after the animal is slaughtered.

Starch is made up of glucose molecules linked together in either straight or branched chains (see Figure 4.4c). It is the storage form of carbohydrate in plants and provides energy for plant growth.

Simple Carbohydrates

Monosaccharides and disaccharides are classified as simple carbohydrates. The three most common monosaccharides in the diet are glucose, fructose, and galactose. Each contains 6 carbon, 12 hydrogen, and 6 oxygen atoms (C₆H₁₂O₆), but these three sugars differ in the arrangement of these atoms (Figure 4.4a). Glucose, often called blood sugar, is the most important carbohydrate fuel for the human body.

The most common disaccharides in our diet are maltose, sucrose, and lactose (Figure 4.4b).

Think Critically

How do the bonds that link the glucose units in a molecule of starch differ from those in a molecule of cellulose fiber?
substances, some of which are soluble in water. Soluble fiber, found around and inside plant cells, dissolves in water to form viscous solutions. Although human enzymes can’t digest soluble fiber, bacteria in the large intestine can break it down. Foods that contain soluble fiber include oats, apples, beans, and seaweed (Figure 4.6).

Fiber that does not dissolve in water is called insoluble fiber. Insoluble fiber comes primarily from structural parts of plants, such as cell walls. This type of fiber adds bulk to fecal matter because it passes, unchanged, through the gastrointestinal tract. Food sources of insoluble fiber include wheat and rye bran, broccoli, and celery.

and reproduction. When we eat plants, we consume the energy stored in the starch (Figure 4.5).

Fiber is a type of complex carbohydrate that cannot be broken down by human digestive enzymes. Thus fiber cannot be absorbed in the human small intestine, and it passes into the large intestine. Fiber includes several chemical substances, some of which are soluble in water. Soluble fiber, found around and inside plant cells, dissolves in water to form viscous solutions. Although human enzymes can’t digest soluble fiber, bacteria in the large intestine can break it down. Foods that contain soluble fiber include oats, apples, beans, and seaweed (Figure 4.6).

Fiber that does not dissolve in water is called insoluble fiber. Insoluble fiber comes primarily from structural parts of plants, such as cell walls. This type of fiber adds bulk to fecal matter because it passes, unchanged, through the gastrointestinal tract. Food sources of insoluble fiber include wheat and rye bran, broccoli, and celery.

1. What molecules make up starch?
2. Why is sucrose classified as a simple carbohydrate?
3. What is glycogen?
4. Which type of fiber is plentiful in beans?

Soluble fiber • Figure 4.6

a. Jams and jellies are thickened with pectin, which is a soluble fiber found in fruits and vegetables. Gums are also used as thickeners because they combine with water to keep solutions from separating. Gums you might see in an ingredient list include gum arabic, gum karaya, guar gum, locust bean gum, xanthan gum, and gum tragacanth, which are extracted from shrubs, trees, and seedpods, and agar, carrageenan, and alginates, which are gums derived from seaweed.

b. Beans contain soluble fiber and small polysaccharides that cannot be broken down by human digestive enzymes. Both of these pass into the large intestine, where they are digested by bacteria creating gas.
Carbohydrate Digestion and Absorption

LEARNING OBJECTIVES

1. Describe the steps of carbohydrate digestion.
2. Explain what is meant by lactose intolerance.
3. Discuss how indigestible carbohydrates affect the colon and feces.
4. Draw a graph that compares blood glucose levels after eating soda and after eating beans.

Disaccharides and complex carbohydrates must be digested to monosaccharides before they can be absorbed into the body. Carbohydrates that cannot be completely digested cannot be absorbed but still have an impact on the gastrointestinal tract and overall health. Once absorbed, carbohydrates travel in the blood to the liver.

Carbohydrate Digestion

Carbohydrate digestion begins in the mouth, but most digestion occurs in the small intestine (Figure 4.7). Carbohydrate that cannot be digested passes into the colon. Some of this is broken down by bacteria. Material that cannot be absorbed is excreted in the feces.

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**Carbohydrate digestion • Figure 4.7**

1. In the mouth, the enzyme salivary amylase starts breaking starch into shorter polysaccharides.
2. In the stomach, salivary amylase is inactivated by acid so no carbohydrate digestion occurs.
3. In the small intestine, most starch digestion and breakdown of disaccharides occur. Here pancreatic amylase completes the job of breaking down starch into disaccharides and short chains of sugar units called oligosaccharides.
4. At the villi of the small intestine, enzymes attached to the microvilli complete the digestion of carbohydrates. Here, disaccharides and oligosaccharides are broken down into monosaccharides.
5. In the large intestine, fiber and other indigestible carbohydrates are partially broken down by bacteria to form fatty acids and gas. Some fiber is excreted in the feces.
Lactose intolerance • Figure 4.8

Lactose intolerance The disaccharide lactose is broken down by the enzyme lactase in the small intestine.

We are all born with adequate levels of lactase, but in many people, levels decline so much with age that lactose cannot be completely digested, a condition called lactose intolerance. When these individuals consume milk and other dairy products, the lactose passes into the large intestine, where it draws in water and is metabolized by bacteria, producing gas and causing abdominal distension, cramping, and diarrhea. The incidence of lactose intolerance varies among populations (Figure 4.8).

Because milk is the primary source of calcium in the U.S. diet, lactose-intolerant individuals may have difficulty meeting calcium needs. Many people who are lactose intolerant can handle small amounts of lactose and therefore can meet their calcium needs by consuming small portions of milk throughout the day and eating cheese and yogurt, which contain less lactose than milk. Those who cannot tolerate any lactose can get their calcium from nondairy sources, such as tofu, legumes, dark green vegetables, and canned salmon and sardines, which are consumed with the bones, as well as from calcium-fortified foods, calcium supplements, and lactase-treated milk (such as Lactaid). Another option is to take lactase tablets with or before consuming milk products to digest the lactose before it passes into the large intestine.

Indigestible carbohydrates Some carbohydrates are not digested and therefore not readily absorbed. Fiber and some oligosaccharides are not digested because they cannot be broken down by human enzymes. Resistant starch is not digested either because the natural structure of the grain protects the starch molecules or because cooking and processing alter their digestibility. Legumes, unripe bananas, and cold cooked potatoes, rice, and pasta are high in resistant starch.

As indigestible carbohydrates pass through the gastrointestinal tract, they slow the rate at which nutrients, such as glucose, are absorbed (Figure 4.9a). Fiber can also bind to certain minerals, preventing their absorption. For instance, wheat bran fiber binds zinc, calcium, magnesium, and iron. Indigestible carbohydrates also speed transit through the intestine by increasing the amount of water and the volume of material in the intestine. This stimulates peristalsis, causing the muscles of the large intestine to work more and function better, helping to prevent constipation (Figure 4.9b).

Some carbohydrates that are not digested by human enzymes are digested by intestinal bacteria when they reach the large intestine, producing fatty acids and gas. The fatty acids can be used as a fuel source for cells in the colon and other body tissues; they may play a role in regulating cellular processes and preventing disease (Figure 4.9c).
a. The bulk and volume of a fiber-rich meal dilutes the gastrointestinal contents. This dilution slows the digestion of food and absorption of nutrients (green dots), causing a delay and a blunting of the rise in blood glucose that occurs after a meal (see graph). With a low-fiber meal, nutrients are more concentrated; digestion and absorption occur more rapidly, causing a quicker, sharper rise in blood glucose.

b. Ugandan villagers consume a diet high in fiber, but British subjects living in Uganda consume a more refined, low-fiber diet. Stool weights are greater and transit times shorter for Ugandan villagers, than for British subjects.

c. Indigestible carbohydrates are a food source for the bacteria in the colon. When bacteria break down these carbohydrates, fatty acids are formed. The acidic conditions inhibit the growth of undesirable bacteria and favor the growth of healthy ones, such as the *Bifidobacteria* shown here. These bacteria and their metabolic by-products may help prevent and treat diarrhea due to inflammation in the bowel and protect against colon cancer.
Carbohydrate Absorption

After a meal, the monosaccharides from carbohydrate digestion enter the portal circulation and travel to the liver. Glucose can be used to provide energy, stored as liver glycogen, or delivered via the general blood circulation to other body tissues, causing blood glucose levels to rise.

Glycemic response is a measure of how quickly and how high blood glucose levels rise after carbohydrate is consumed. Glycemic response is affected by how long it takes a food to leave

Glycemic Index

Potatoes are a source of unrefined carbohydrate, but scientists know that the effect potatoes have on blood glucose is very different from the effect beans have. Beans are also a source of unrefined carbohydrate, but they are much higher in fiber and protein, both of which slow digestion and absorption and therefore reduce the glycemic response.

The glycemic response of beans versus potatoes is shown here graphically, but it can also be expressed using the glycemic index, which is a ranking of how a food affects blood glucose relative to the effect of an equivalent amount of carbohydrate from a reference food, such as white bread or pure glucose. For example, on a glycemic index scale on which white bread is 100, potatoes are 90 and kidney beans are about 25. This means that blood glucose levels do not increase as much after eating beans as they do after eating white bread or potatoes.

A shortcoming of the glycemic index is that it is measured using a set amount of carbohydrate in a food (usually 50 grams), not the typical serving of food that we eat. For example, it takes over 4 cups of strawberries to supply 50 g of carbohydrate, but people typically eat only about 1 cup. Glycemic load compares the effect of typical portions of food on blood glucose so it is a more practical way to assess the effect of a food on blood glucose levels.

A shortcoming of both the glycemic index and glycemic load is that they are determined for individual foods rather than for meals, which contain mixtures of foods. We typically eat meals, so knowing the glycemic index or load of a single food doesn’t tell us much about the rise in blood glucose that will occur after eating a meal.

Think Critically: How would the graph of blood glucose levels after eating meat and potatoes differ from the graph that would result after eating potatoes alone?
the stomach and by how fast it is digested and the glucose absorbed.

Refined sugars and starches generally cause a greater glycemic response than unrefined carbohydrates because sugars and starches consumed alone leave the stomach quickly and are rapidly digested and absorbed. For example, when you drink a bottle of sugary soda, your blood glucose increases within minutes. Because fiber takes longer to leave the stomach and slows absorption in the small intestine, a fiber-containing food such as oatmeal would take longer to leave your stomach and therefore cause a lower glycemic response (see *What a Scientist Sees*). When carbohydrate, fat, and protein are consumed together, stomach emptying is slowed, delaying both digestion and absorption of carbohydrate, so blood glucose rises more slowly than when carbohydrate is consumed alone. For instance, after a meal of chicken, brown rice, and green beans, which contains carbohydrate, fat, protein, and fiber, blood glucose doesn’t begin to rise for 30 to 60 minutes.

**CONCEPT CHECK**

1. What steps are involved in starch digestion?
2. How does lactose in the colon cause gas and diarrhea?
3. Why do indigestible carbohydrates affect the type of bacteria in the colon?
4. How does fiber affect the rate at which blood glucose rises after a meal?

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**Carbohydrate Functions**

**LEARNING OBJECTIVES**

1. Name the main function of carbohydrate in the body.
2. Contrast the roles of insulin and glucagon in blood glucose regulation.
3. Compare anaerobic and aerobic metabolism.
4. Discuss what happens to protein and fat metabolism when dietary carbohydrate is insufficient.

The main function of carbohydrates is to provide energy, but carbohydrates also play other roles in the body. For example, nerve tissue needs the sugar galactose, and in breast-feeding women, galactose combines with glucose to produce the milk sugar lactose. The monosaccharides ribose and deoxyribose play nonenergy roles as components of RNA and DNA, respectively, the two molecules that contain a cell’s genetic information. Ribose is also a component of the B vitamin riboflavin. Oligosaccharides are associated with cell membranes, where they help signal information about cells, and large polysaccharides found in connective tissue provide cushioning and lubrication.

**Getting Enough Glucose to Cells**

Glucose is an important fuel for body cells. Many body cells can use energy sources other than glucose, but brain cells, red blood cells, and a few others must have glucose to stay alive. In order to provide a steady supply of glucose, the concentration of glucose in the blood is regulated by the liver and by hormones secreted by the pancreas. The rise in blood glucose levels after eating stimulates the pancreas to secrete the hormone insulin, which allows glucose to be taken into body cells, causing blood glucose levels to drop. Once inside cells, glucose can be used immediately to provide energy or converted into energy-storage molecules for future use. In both muscle cells and liver cells, insulin promotes the conversion of glucose into glycogen for storage. In the
liver and in fat-storing cells, it promotes the conversion of glucose to fat for storage (Figure 4.10).

A few hours after eating, blood glucose levels—and consequently the amount of glucose available to the cells—begin to decrease. This triggers the pancreas to secrete the hormone glucagon (see Figure 4.10). Glucagon raises blood glucose by signaling liver cells to break down glycogen into glucose, which is released into the blood. At the same time, glucagon signals the liver to synthesize new glucose molecules, which are also released into the blood, bringing blood glucose levels back to normal.

**Blood glucose regulation • Figure 4.10**

Immediately after a meal, the blood glucose level increases. Insulin is released, stimulating the uptake and storage of glucose.

The dashed line represents fasting blood glucose. It is measured after an 8- to 12-hour overnight fast and is normally maintained between 70 and 100 mg of glucose per 100 ml of blood.

Several hours after a meal, the blood glucose level drops. Glucagon is released from the pancreas, stimulating the breakdown of glycogen into glucose and the synthesis of new glucose molecules.

**Think Critically** What would happen to blood glucose levels if insulin were not available?

*glucagon* A hormone made in the pancreas that raises blood glucose levels by stimulating the breakdown of liver glycogen and the synthesis of glucose.
Inside body cells, the reactions of cellular respiration split the bonds between carbon atoms in glucose, releasing energy that is used to synthesize ATP. ATP is used to power the energy-requiring processes in the body.

1. Glycolysis, which takes place in the cell fluid, splits glucose, a six-carbon molecule, into two three-carbon molecules (pyruvate). This step releases high-energy electrons (purple balls) and produces a small amount of ATP. Pyruvate is then either broken down to produce more ATP or used to remake glucose.

2. Pyruvate can be used to produce more ATP when oxygen is available. In the mitochondria, pyruvate is broken down, releasing carbon dioxide and high-energy electrons and forming acetyl-CoA (2 carbons), which continues through aerobic metabolism.

3. Acetyl-CoA enters the citric acid cycle, where carbon dioxide and high-energy electrons are released and where a small amount of ATP is produced.

4. Most ATP is produced in the final step of aerobic metabolism. Here the energy in the high-energy electrons released in previous steps is transferred to ATP, and the electrons are combined with oxygen and hydrogen to form water.

**Glucose as a Source of Energy**

Glycolysis is an anaerobic metabolic pathway that splits glucose into two three-carbon pyruvate molecules; the energy released from one glucose molecule is used to make two molecules of ATP.

Cells use glucose to provide energy via cellular respiration (see Chapter 3). Cellular respiration uses oxygen to convert glucose to carbon dioxide and water and provide energy in the form of ATP (Figure 4.11).

The first step in cellular respiration is glycolysis (glyco = “glucose,” lysis = “to break down”). Glycolysis can rapidly produce two molecules of ATP from each glucose molecule. Because oxygen isn’t needed for this pathway reaction, glycolysis is sometimes called anaerobic glycolysis, or anaerobic metabolism. When oxygen is available, the complete breakdown of glucose can proceed. This aerobic metabolism produces about 36 molecules of ATP for each glucose molecule, 18 times more ATP than is generated by anaerobic glycolysis.
**Ketone formation • Figure 4.12**

Fatty acids are broken down into two-carbon units that form acetyl-CoA. To proceed through aerobic metabolism, acetyl-CoA must combine with a molecule derived primarily from carbohydrate. When carbohydrate is in short supply, acetyl-CoA molecules cannot proceed through aerobic metabolism and instead react with each other to form ketones. When carbohydrate is adequate, acetyl-CoA can proceed through aerobic metabolism, allowing the fatty acids to be completely broken down to yield ATP.

**Carbohydrate and protein breakdown** Glucose is an essential fuel for brain cells and red blood cells. If adequate amounts of glucose are not available, it can be synthesized from three-carbon molecules (see Figure 4.11, step 1 on previous page). Fatty acids cannot be used to make glucose because the reactions that break them down produce two-carbon, rather than three-carbon, molecules. Amino acids from protein breakdown can supply the three-carbon molecules. However, because protein is not stored in the body, this use of amino acids takes away functioning body proteins. Body proteins that are broken down to make glucose are no longer available to do their job, whether that job is to speed up a chemical reaction or contract a muscle. Sufficient dietary carbohydrate ensures that protein is not utilized in this way; carbohydrate is therefore said to spare protein.

**Carbohydrate and fat breakdown** Most of the energy stored in the body is stored as fat. In order to fully access the energy from fatty acids, carbohydrate is required. If carbohydrate is not available, such as during starvation or when consuming a low-carbohydrate diet, molecules called ketones or ketone bodies are formed (Figure 4.12). The heart, muscle, and kidney can use ketones for energy. After about three days of fasting, even the brain adapts and can obtain about half of its energy from ketones. The use of ketones for energy helps spare glucose and decreases the amount of protein that must be broken down to synthesize glucose.

Ketones not used for energy can be excreted in the urine. However, when high levels of ketones build up in the blood, a condition known as ketosis, they can increase the blood’s acidity so much that normal body processes are disrupted. Mild ketosis can occur during starvation or when consuming a low-carbohydrate weight-loss diet and can cause symptoms such as reduced appetite, headaches, dry mouth, and odd-smelling breath. Severe ketosis can occur with untreated diabetes and can cause coma and even death.

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**CONCEPT CHECK**

1. Why is it important to keep blood glucose levels in the normal range?
2. How does insulin affect blood glucose levels?
3. What process breaks down glucose in the presence of oxygen to yield ATP?
4. Why is carbohydrate said to spare protein?
Carbohydrates in Health and Disease

LEARNING OBJECTIVES

1. Define diabetes and explain its health consequences.
2. Describe how carbohydrates contribute to the development of dental caries.
3. Discuss the role of carbohydrates in weight control.
4. Explain how fiber may help protect health.

Are carbohydrates good for you or bad for you? On the one hand, they have been blamed for everything from diabetes to obesity. On the other hand, U.S. guidelines for a healthy diet recommend that people base their diet on carbohydrate-rich foods in order to reduce disease risk. This incongruity relates to the health effects of different types of dietary carbohydrates: Diets high in unrefined carbohydrates from whole grains, fruits, and vegetables are associated with a lower incidence of a variety of chronic diseases, whereas diets high in refined carbohydrates, such as refined grains and foods high in added sugars, may increase chronic disease risk.

Diabetes

Diabetes mellitus, commonly referred to simply as diabetes, is a disease characterized by high blood glucose levels (Figure 4.13). Uncontrolled diabetes damages the heart, blood vessels, kidneys, eyes, and nerves. It is the leading cause of adult blindness and accounts for over 40% of new cases of kidney failure and more than 60% of nontraumatic lower-limb amputations. In the United States, nearly 26 million people have diabetes, and 7 million of these people have not been diagnosed.6

Blood glucose levels in diabetes • Figure 4.13

Normal blood glucose is less than 100 mg/100 ml blood after an 8-hour fast; a fasting blood level from 100 to 125 mg/100 ml is defined as prediabetes; a fasting level of 126 mg/100 ml or above is defined as diabetes. Two hours after consuming 75 g of glucose, normal blood levels are less than 140 mg/100 ml; prediabetes levels are from 140 to 199 mg/100 ml; diabetes levels are 200 mg/100 ml or greater.
CHAPTER 4 Carbohydrates: Sugars, Starches, and Fibers

Type 1 and type 2 diabetes in adolescents • Figure 4.14

This graph compares the number of cases of type 1 and type 2 diabetes diagnosed per year in adolescents (ages 10 to 19) by race/ethnicity. Twenty years ago, type 2 diabetes was rare in this age group, but as in adults, the incidence is rising, especially in certain minority groups. Reducing type 2 diabetes in minority groups will require culturally sensitive strategies to modify diet and lifestyle.

Types of diabetes

- **Type 1 diabetes** is an autoimmune disease in which the insulin-secreting pancreatic cells are destroyed by the body’s immune system. This form of diabetes accounts for only 5 to 10% of diagnosed cases and is usually diagnosed before age 30. Because no insulin is produced, people with type 1 diabetes must inject insulin in order to keep blood glucose levels in the normal range. When insulin levels are low, the lack of glucose inside cells leads to ketone formation. In uncontrolled type 1 diabetes, ketone levels can get high enough to increase the acidity of the blood. This condition, called ketoacidosis, can lead to coma and death.

- **Type 2 diabetes** is the more common form of diabetes, which accounts for 90 to 95% of all cases. It occurs when the body does not produce enough insulin to keep blood glucose in the normal range. This can occur because body cells lose their sensitivity to insulin, a condition called insulin resistance, or when the amount of insulin secreted is reduced. Type 2 diabetes is believed to be due to both genetic and lifestyle factors. Type 2 diabetes is more commonly diagnosed in adulthood, but we now know that people can develop this disease at any age (Figure 4.14). A progressive disease, it usually begins with prediabetes, a condition in which glucose levels are above normal but not high enough to be diagnosed as diabetes (see Figure 4.13 on previous page). In many cases, adjustments in diet and lifestyle can keep prediabetes from progressing to type 2 diabetes.

- **Gestational diabetes** is an elevation of blood sugar that is first recognized during pregnancy. The high levels of glucose in the mother’s blood are passed to the fetus, frequently resulting in a baby that is large for gestational age and at increased risk of complications. Gestational diabetes usually resolves after the pregnancy, but women with gestational diabetes are at increased risk of developing type 2 diabetes later in life.
Symptoms and complications of diabetes The symptoms and complications of all types of diabetes result from the inability to use glucose normally and from high glucose levels in the blood. Cells that require insulin in order to take up glucose are starved for glucose, and cells that can use glucose without insulin are exposed to damaging high levels.

Early symptoms of diabetes include frequent urination, excessive thirst, blurred vision, and weight loss. Frequent urination and excessive thirst occur because as blood glucose levels rise, the kidneys excrete the extra glucose and as a result must also excrete extra water, increasing the volume of urine. The additional loss of water from the body makes the individual thirsty. Blurred vision occurs when excess glucose enters the lens of the eye, drawing in water and causing the lens to swell.

Weight loss occurs because cells are unable to use glucose for energy, and so the body must break down fat to obtain the energy it needs.

The long-term complications of diabetes include damage to the heart, blood vessels, kidneys, eyes, and nerves (Figure 4.15). These complications are believed to be due to prolonged exposure to high glucose levels.

Managing blood glucose The goal in treating diabetes is to maintain blood glucose levels within the normal range. This requires a program of diet, exercise, and, in many cases, medication, along with frequent monitoring of blood glucose levels. Carbohydrate intake must be coordinated with exercise and medication schedules so that glucose and insulin are available in the right proportions.
Dietary management of diabetes involves limiting the amount of carbohydrate consumed at each meal to prevent a rapid or prolonged rise in blood glucose. A diet providing unrefined carbohydrates is recommended because these carbohydrate sources cause a slower rise in blood glucose than refined carbohydrates. Diets for individuals with diabetes should also be limited in saturated fat, *trans* fat, and cholesterol in order to reduce the risk for cardiovascular disease. Weight management is an important component of diabetes care because excess body fat increases the resistance of body cells to insulin. Exercise is important not only because it helps to achieve and maintain a healthy body weight but also because it increases the sensitivity of body cells to insulin.

Individuals with type 1 diabetes require insulin injections because they no longer make insulin. Insulin must be given by injection because it is a protein and would therefore be digested in the gastrointestinal tract if taken orally. Individuals with type 2 and gestational diabetes are often able to manage blood glucose levels with diet and exercise but may also require oral medications and/or insulin injections.

**Carbohydrate intake and the risk of diabetes**

Evidence is accumulating that carbohydrate consumption may play a role in the development of type 2 diabetes in susceptible individuals. In populations in which the diet is high in whole grains, the risk of developing type 2 diabetes is lower than in populations in which the diet is high in refined starches and added sugars. The reason for this is not fully understood. However, it has been proposed that because insulin needs are increased when the diet is high in refined carbohydrates, the insulin-producing cells in the pancreas may wear out over time.

**Hypoglycemia**

Another condition that involves blood glucose is *hypoglycemia*. Symptoms of hypoglycemia include low blood sugar (below 70 mg glucose/100 ml blood), irritability, sweating, shakiness, anxiety, rapid heartbeat, headache, hunger, weakness, and sometimes seizures and coma. Hypoglycemia occurs most frequently in people who have diabetes as a result of overmedication. It can also be caused by abnormalities in insulin production or by abnormalities in the way the body responds to insulin or to other hormones.

**Fasting hypoglycemia**, which occurs when an individual has not eaten, is often related to some underlying condition, such as excess alcohol consumption, hormonal deficiencies, or tumors. Treatment involves identifying and treating the underlying disease.
occurs in response to the consumption of high-carbohydrate foods. The rise in blood glucose from the carbohydrate meal stimulates insulin release. However, too much insulin is secreted, resulting in a rapid fall in blood glucose to abnormally low levels. To prevent the rapid changes in blood glucose that occur with reactive hypoglycemia, the diet should consist of small, frequent meals that are low in carbohydrate and high in protein and fiber.

**Dental Caries**

Dental caries, or cavities, are the best-documented health problem associated with carbohydrate intake. Eighty-five percent of people 18 years and older have had caries. They occur when bacteria on the teeth metabolize carbohydrates, producing acids. These acids can dissolve tooth enamel and the underlying tooth structure, forming dental caries. Simple carbohydrates, especially sucrose, are easiest for the bacteria to metabolize into acids, but starchy foods also promote tooth decay. The longer teeth are exposed to carbohydrates—for example, through frequent snacking, consuming foods that stick to the teeth, sucking hard candy, and slowly sipping soda—the greater the risk of caries. Limiting intake of sweet or sticky foods and proper dental hygiene can help prevent dental caries.

**Weight Management**

As low-carbohydrate diets have gained popularity, carbohydrates have gotten a reputation for being fattening. In reality, carbohydrates are no more fattening than other nutrients, and there is no evidence that the proportion of total carbohydrate in the diet affects energy intake. Weight gain is caused by excess intake of calories, no matter whether the excess is from carbohydrate, fat, or protein. Carbohydrates provide only 4 Calories/gram, less than half the 9 Calories/gram provided by fat (Figure 4.16).

**Carbohydrates and weight loss** The type of carbohydrates you consume can affect how hungry you feel and whether you lose or gain weight (Figure 4.17). A diet high in unrefined carbohydrates is high in fiber, which increases the sense of fullness by adding bulk and slowing digestion, allowing you to feel satisfied with less food. This can help promote weight loss. However, diets high in fiber may be problematic for children, who have a small stomach capacity, because they may become satiated before meeting their nutrient requirements.

Foods high in refined carbohydrates cause a rapid rise in blood glucose and therefore stimulate release of insulin. Insulin promotes fat storage. Therefore, a diet high in refined carbohydrate, which causes more insulin release, may shift
Debate

Should You Avoid High-Fructose Corn Syrup?

The Issue: High-fructose corn syrup is the most common added sweetener in the American diet. Based on the media hype, you might think it is poison. But is high-fructose corn syrup really worse than other sweeteners?

A host of processed foods are sweetened with high-fructose corn syrup (HFCS). Magazine articles and Internet blogs tell you that HFCS is unhealthy because it’s not a natural sweetener. They accuse it of causing the obesity epidemic and implicate it in heart disease and diabetes. They even point out that the overuse of corn, particularly genetically modified (GM) corn, is a threat to the environment. That’s a lot of blame for a simple sweetener!

To understand the pros and cons of HFCS, you have to know what it is. HFCS is made by extracting starch from corn and treating it to break the bonds between the glucose molecules. The resulting corn syrup is then treated to convert about half the glucose to fructose, hence high-fructose corn syrup. This obviously is not a natural food, but neither is sucrose, which starts as sugar beets or sugar cane and undergoes processing to extract, purify, and crystallize the sucrose. In 1970, the most common sweetener in the American diet was sucrose (see graph). Over the next four decades, HFCS use increased dramatically, and it almost completely replaced sucrose in soft drinks. Manufacturers prefer HFCS because it is cheaper and more stable during storage than other sweeteners.17

HFCS has been implicated as a cause of obesity because the increase in its use parallels the increase in obesity (see graph), which in turn increases the risk of diabetes and heart disease. A study of fructose metabolism provides good evidence that this sugar may promote weight gain. Fructose is converted to fat more readily than glucose. Fructose is also not as effective as glucose at stimulating the release of hormones that suppress appetite and promote weight loss or at inhibiting the release of hormones that stimulate appetite.18 So, when compared to glucose, fructose contributes more to fat synthesis and less to appetite suppression, leading to overeating and weight gain. This would incriminate HFCS if it provided more fructose than sucrose. In fact, both sucrose and HFCS are about half fructose and half glucose, and once digested and absorbed, the fructose from sucrose is no different than that in HFCS.18 Eliminating HFCS will help fight obesity and other health problems only if people do not replace it with other added sweeteners.

Is concern about the environment a reason to avoid this corn sweetener? The agricultural methods used to grow corn in the United States deplete soil nutrients and introduce pesticides and fertilizers into the environment. About half of the corn grown in the United States are GM varieties that have been designed to reduce the use of pesticides. Advocates and opponents of GM crops argue about whether they are harmful for people and the environment (see Chapter 13).19 Regardless of the answer, only about 6% of the corn crop is used to produce HFCS,20 so eliminating it without changing agricultural practices will have a relatively minor environmental impact.

Is HFCS worse than other sweeteners? When consumed in large amounts, HFCS has the potential to increase body fat. In addition, the production of HFCS may have an impact on the environment. But will eliminating HFCS from our food supply necessarily make our diets healthier or protect the environment?

Think critically: Compare the relationship between the percentage of adults who are obese and the intake of HFCS from 1970 to 2000 and from 2000 to 2005. Do they correlate with each other over both these time periods? What do these relationships tell you about the role of HFCS in obesity?

Since 1970, HFCS intake has increased dramatically, while sucrose use has declined. Over this same time period, the incidence of obesity has more than doubled.
Pros and cons of nonnutritive sweetners. One way to reduce the amount of refined sugar in the diet is to replace sugar with nonnutritive sweeteners (also called artificial sweeteners). The FDA has approved saccharin, aspartame, sucralose, acesulfame K, neotame, and rebiana as nonnutritive sweeteners and defined acceptable daily intakes (ADIs)—levels that should not be exceeded when using these products (Table 4.1).21

<table>
<thead>
<tr>
<th>Sweetener</th>
<th>Brand names</th>
<th>What is it?</th>
<th>ADI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saccharin</td>
<td>Sweet’N Low, SugarTwin</td>
<td>The oldest of the nonnutritive sweeteners, developed in 1879. It was once considered a carcinogen but was taken off the government’s list of cancer-causing substances in 2000. It is 300 times sweeter than sucrose and has a bitter aftertaste.</td>
<td>5 mg/kg of body weight/day; One packet contains 36 mg of saccharin. A 154-lb (70-kg) person would exceed the ADI by consuming 10 packets or about three 12-oz saccharin-sweetened beverages.</td>
</tr>
<tr>
<td>Aspartame</td>
<td>Equal, NutraSweet</td>
<td>Made of two amino acids (phenylalanine and aspartic acid; see What a Scientist Sees: Phenylketonuria, in Chapter 6). Because it breaks down when heated, it is typically used in cold products or added after cooking. It is 200 times sweeter than sucrose.</td>
<td>50 mg/kg of body weight/day; One packet contains 37 mg of aspartame. To exceed the ADI, a 154-lb (70-kg) person would have to consume 95 packets or 16 12-oz aspartame-sweetened beverages. It must be limited in the diets of people with phenylketonuria (see Chapter 6).</td>
</tr>
<tr>
<td>Acesulfame K</td>
<td>Sunett, Sweet One</td>
<td>A heat-stable sweetener that is often used in combination with other sweeteners. It is 200 times sweeter than sucrose.</td>
<td>15 mg/kg of body weight/ day; A 154-lb (70-kg) person could consume 2 gallons of beverages containing acesulfame K without exceeding the ADI.</td>
</tr>
<tr>
<td>Neotame</td>
<td>No brand name. Neotame is not sold as a tabletop sweetener.</td>
<td>Made from the same two amino acids as aspartame, but because the bond between them is harder to break than the bond in aspartame, it is heat stable and can be used in baking. It is used in soft drinks, dairy products, and gum but is not sold as a tabletop sweetener. It is 8000 times sweeter than sucrose.</td>
<td>18 mg/kg of body weight/day.</td>
</tr>
<tr>
<td>Sucralose</td>
<td>Splenda</td>
<td>Made from sucrose molecules that have been modified so that they cannot be digested or absorbed. It is heat stable so it can be used in cooking. It is 600 times sweeter than sucrose.</td>
<td>5 mg/kg of body weight/ day; One packet contains about 12 mg of sucralose. A 154-lb (70-kg) person could consume 29 packets without exceeding the ADI.</td>
</tr>
<tr>
<td>Rebiana</td>
<td>Truvia, Pure Via</td>
<td>A natural sweetener made from the leaf of the stevia plant.22 It is the newest sweetener on the market and is about 300 times sweeter than sucrose.</td>
<td>12 mg/kilogram of body weight/day; To exceed the ADI, a 154-lb (70-kg) person would have to consume more than 30 packets of a rebiana sweetener or drink about six 12-oz cans of a rebiana-sweetened soda.</td>
</tr>
</tbody>
</table>
When nonnutritive sweeteners are used to replace added sugars in the diet, they can help reduce the incidence of dental caries and manage blood sugar levels. Whether use of these products promotes weight loss, however, depends on whether the calories they spare are added back from other food sources. When the effect of nonnutritive sweeteners on body weight was examined, their use was actually associated with weight gain, not weight loss. One hypothesis to explain this is that the sweet taste increases appetite, causing users to actually increase their food intake.23

If you think switching to nonnutritive sweeteners will make your diet healthier, think again. Foods that are high in added sugar tend to be nutrient poor. Replacing them with artificially sweetened alternatives does not necessarily increase the nutrient density of the diet or improve overall diet quality.

Heart Disease

The impact of carbohydrates on heart disease risk depends on the type of carbohydrate. There is evidence that diets high in sugar can raise blood lipid levels and thereby increase the risk of heart disease,24 whereas diets high in fiber have been found to reduce the risk of heart disease.15, 25

Foods containing soluble fiber, such as legumes, oats, flaxseed, and brown rice, may reduce the risk of heart disease by lowering blood cholesterol levels. In the digestive tract, soluble fiber binds dietary cholesterol and bile acids, which are made from cholesterol, preventing them from being absorbed (Figure 4.18).26 Soluble fiber may also help lower blood cholesterol because the by-products of the bacterial breakdown of the fiber may inhibit cholesterol synthesis in the liver or increase its removal from the blood.26

Cholesterol and soluble fiber • Figure 4.18

a. When the diet is low in soluble fiber, dietary cholesterol and bile, which contains cholesterol and bile acids made from cholesterol, are absorbed into the blood and transported to the liver, where they are reused.

![Without soluble fiber](image)

b. When soluble fiber is present in the digestive tract, the fiber binds cholesterol and bile acids so that they are excreted rather than absorbed. This helps reduce the amount of cholesterol in the body.

![With soluble fiber](image)
Insoluble fibers, such as wheat bran and cellulose, do not lower blood cholesterol, but a diet high in any type of fiber may help lower blood pressure, normalize blood glucose levels, prevent obesity, and affect a number of other parameters that help reduce the risk of heart disease.\(^{27}\)

**Bowel Health**

Fiber and other indigestible carbohydrates add bulk and absorb water in the gastrointestinal tract, making the feces larger and softer and reducing the pressure needed for defecation. This helps reduce the incidence of constipation and hemorrhoids, the swelling of veins in the rectal or anal area. It also reduces the risk of developing outpouches in the wall of the colon called **diverticula** (the singular is **diverticulum**) (Figure 4.19). Fecal matter can accumulate in these pouches, causing irritation, pain, and inflammation—a condition known as **diverticulitis**. Diverticulitis may lead to infection. Treatment usually includes antibiotics to eliminate the infection and a low-fiber diet to prevent irritation of inflamed tissues. Once the inflammation is resolved, a high-fiber diet is recommended to ease stool elimination and reduce future attacks of diverticulitis.

Although fiber speeds movement of the intestinal contents, when the diet is low in fluid, fiber can contribute to constipation. The more fiber in the diet, the more water is needed to keep the stool soft. When too little fluid is consumed, the stool becomes hard and difficult to eliminate. In severe cases of excessive fiber intake and low fluid intake, intestinal blockage can occur.

A diet high in fiber, particularly from whole grains, may reduce the risk of colon cancer, although not all studies support this finding.\(^{15,28,29}\) Fiber reduces contact between the cells lining the colon and potentially cancer-causing substances in the feces. Fiber in the colon also affects the intestinal microflora and their by-products. These by-products may directly affect colon cells or may change the environment of the colon in a way that can affect the development of colon cancer. Some of the protective effect may also be due to antioxidant vitamins and phytochemicals present in fiber-rich whole grains.

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**CONCEPT CHECK**

1. **What** health problems are common in people who have uncontrolled diabetes?
2. **Why** does frequent snacking on high-carbohydrate foods promote dental caries?
3. **When** does a low-carbohydrate diet promote weight loss?
4. **How** does fiber benefit colon health?

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Meeting Carbohydrate Needs

LEARNING OBJECTIVES

1. Discuss how the carbohydrate intake of Americans compares with recommendations.
2. Calculate the percentage of calories from carbohydrate in a food or in a diet.
3. Use food labels to identify foods that are high in fiber and low in added sugar.

Recommendations for carbohydrate intake focus on two main points: getting enough carbohydrate to meet the need for glucose and choosing the types that promote health and prevent disease.

Carbohydrate Recommendations

The RDA for carbohydrate is 130 g/day, based on the average minimum amount of glucose used by the brain.\(^{30}\) In a diet that meets energy needs, this amount provides adequate glucose and prevents ketosis. Additional carbohydrate provides an important source of energy in the diet, and carbohydrate-containing foods can add vitamins, minerals, fiber, and phytochemicals. Therefore, the Acceptable Macronutrient Distribution Range for carbohydrate is 45 to 65% of total calorie intake. A diet within this range meets energy needs without excessive amounts of protein or fat (Figure 4.20).

The typical U.S. diet meets the recommendation for the amount of carbohydrate, but most of this comes from refined sources, making the diet lower in fiber and higher in added sugar than recommended (see Thinking It Through). The Adequate Intake for fiber is 38 g/day for men and 25 g/day for women; the typical intake is only about 15 g/day.

There is no RDA or Daily Value for added sugars, but the 2010 Dietary Guidelines recommend reducing the consumption of added sugars, which add calories without contributing to the overall nutrient adequacy of the diet. Reducing added sugars reduces calorie intake without reducing essential nutrients.\(^{31}\)

Because no specific toxicity is associated with high intake of any type of carbohydrate, no UL has been established for total carbohydrate intake, for fiber intake, or for added sugar intake.

How much carbohydrate do you eat? • Figure 4.20

To calculate the percentage of calories from carbohydrate in a diet, first determine the number of grams of carbohydrate and multiply this value by 4 Calories/gram. For example, the vegetarian food shown here, which represents a day’s intake, provides about 300 g of carbohydrate:

\[300 \text{ g} \times 4 \text{ Calories/g} = 1200 \text{ Calories from carbohydrate}\]

Next divide the number of Calories from carbohydrate by the total number of Calories in the diet and multiply by 100 to convert it to a percentage. In this example, the diet contains 2000 total Calories, and so it provides:

\[
\frac{1200 \text{ Calories from carbohydrate}}{2000 \text{ Calories total}} \times 100 = 60\% \text{ of Calories from carbohydrate}
\]

Ask Yourself

What is the percentage of calories from carbohydrate in a diet that provides 240 g of carbohydrate and 2400 Calories?\(^{a}\)

\begin{itemize}
  \item a. 10
  \item b. 40
  \item c. 50
  \item d. 60
\end{itemize}
Trina is busy and tends to grab whatever is quick and easy to eat. She just read an article that says Americans eat the wrong kinds of carbohydrates. To see how she is doing, Trina analyzes a typical day’s intake using iProfile. For breakfast she has a bowl of presweetened cereal and a piece of fruit, lunch is chips and a soda, and dinner is a burrito. She always drinks milk with dinner. She has another soda at night while studying. Her iProfile analysis shows that she eats 2199 Calories, 70 g protein, 71 g fat, 320 g carbohydrate, and 12 g fiber per day.

How does her intake compare with the recommended amounts of carbohydrate and fiber?

By calculating the percentage of calories from carbohydrate (320 g carbohydrate x 4 Calories/gram ÷ 2199 Calories x 100 = 58%), Trina is surprised to see that despite her poor choices, her carbohydrate intake is in the recommended range of 45 to 65% of calories. However, she consumes only 12 g of fiber, 13 g less than the 25 g recommended for women her age.

Compared to her MyPlate Daily Food Plan, Trina is not consuming enough fruits, vegetables, or whole grains. Boosting her intake of these will help increase her fiber intake. She decides to switch to whole-grain bread and cereal and increase her servings of high-fiber fruits and vegetables.

Use iProfile to look up the fiber content of the fruits and vegetables listed below and choose a combination of these that will add at least 13 g of fiber to Trina’s diet.

### Vegetables
- Black beans, 1/2 cup
- Green beans, 1/2 cup
- Iceberg lettuce, 1 cup
- Broccoli, 1/2 cup
- Asparagus, 1/2 cup
- Raw spinach, 1 cup

### Fruits
- Pear, 1 medium
- Kiwi, 2 small
- Apple, 1 medium
- Banana, 1 medium
- Watermelon, 1 cup
- Orange, 1 medium

If Trina replaces the two 20-oz sodas she drinks per day with water, how many calories and how much sugar will this eliminate from her diet?

Your answer:

To reduce the sugar and increase the fiber in her breakfast, Trina plans to choose between these two healthy-sounding breakfast cereals.

<table>
<thead>
<tr>
<th>Raisin and Bran Cereal</th>
<th>Multigrain Cereal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nutrition Facts</strong></td>
<td><strong>Nutrition Facts</strong></td>
</tr>
<tr>
<td>Serving Size 1 Cup</td>
<td>Serving Size 1 cup</td>
</tr>
<tr>
<td>(59g/2.1 oz.)</td>
<td>(29g)</td>
</tr>
<tr>
<td>Servings Per Container</td>
<td></td>
</tr>
<tr>
<td>about 8</td>
<td></td>
</tr>
<tr>
<td><strong>Amount Per Serving</strong></td>
<td><strong>Amount Per Serving</strong></td>
</tr>
<tr>
<td>Cereal with % Daily</td>
<td>Cereal with % Daily</td>
</tr>
<tr>
<td>% Daily Value**</td>
<td>% Daily Value**</td>
</tr>
<tr>
<td>Calories</td>
<td>Calories</td>
</tr>
<tr>
<td>190</td>
<td>110</td>
</tr>
<tr>
<td>230</td>
<td>150</td>
</tr>
<tr>
<td>Calories from Fat</td>
<td>Calories from Fat</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Saturated Fat 0g</td>
<td>Saturated Fat 0g</td>
</tr>
<tr>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Trans Fat 0g</td>
<td>Trans Fat 0g</td>
</tr>
<tr>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Cholesterol 0mg</td>
<td>Cholesterol 0mg</td>
</tr>
<tr>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Sodium 250mg</td>
<td>Sodium 160mg</td>
</tr>
<tr>
<td>10%</td>
<td>7%</td>
</tr>
<tr>
<td>Potassium 320mg</td>
<td>Potassium 65mg</td>
</tr>
<tr>
<td>9%</td>
<td>2%</td>
</tr>
<tr>
<td>Total Carbohydrate 46g</td>
<td>Total Carbohydrate 23g</td>
</tr>
<tr>
<td>15%</td>
<td>8%</td>
</tr>
<tr>
<td>Dietary Fiber 5g</td>
<td>Dietary Fiber 4g</td>
</tr>
<tr>
<td>20%</td>
<td>16%</td>
</tr>
<tr>
<td>Sugars 17g</td>
<td>Sugars 6g</td>
</tr>
<tr>
<td>Other Carbohydrate 24g</td>
<td>Other Carbohydrate 13g</td>
</tr>
<tr>
<td>20%</td>
<td>16%</td>
</tr>
<tr>
<td>Protein 5g</td>
<td>Protein 2g</td>
</tr>
</tbody>
</table>

Use the ingredient list to identify the sources of whole grains and added sugars in these two products.

Your answer:

Looking at her typical choices, Trina can see that much of her carbohydrate intake is from added sugars in her beverages and breakfast cereal.

Based on the amounts of sugars and fiber in each, which one would you recommend?

Your answer:

(Check your answers in Appendix J.)
Using MyPlate to make healthy choices

For a 2000-Calorie diet, MyPlate recommends 6 oz of grains (half of which should be whole grains), 2 cups of fruit, and 2½ cups of vegetables. As Figure 4.21 suggests, refined carbohydrates can be replaced with unrefined ones to make the diet healthier. For example, an apple provides about 80 Calories and 3.7 g of fiber, making it a better choice than 1 cup of apple juice, which has the same amount of energy but almost no fiber (0.2 g).

Interpreting food labels

Food labels can help in choosing the right mix of carbohydrates (Figure 4.22).
Choosing carbohydrates from the label • Figure 4.22

The Nutrition Facts panel of a food label lists the number of grams of total carbohydrate, fiber, and sugars. The total carbohydrate and fiber values are also given as a percentage of the Daily Value.

The Daily Value for total carbohydrate is 60% of the diet’s energy content, or 300 g for a 2000-Calorie diet. The Daily Value for fiber in a 2000-Calorie diet is 25 g.

To identify products made mostly from whole grains, look for the word “whole” before the name of the grain. If this is the first ingredient listed, the product is made from mostly whole grain. “Wheat flour” simply means it was made with wheat, not whole wheat. Note that foods labeled with the words “multigrain,” “stone-ground,” “100% wheat,” “cracked wheat,” “seven-grain,” or “bran” are not necessarily 100% whole-grain products and may not contain any whole grains.

Foods labeled “high fiber” contain 20% or more of the Daily Value per serving.

Foods labeled “good source of fiber” contain between 10 and 19% of the Daily Value per serving.

Foods labeled “low” or “reduced” sugar contain 25% less sugar than the regular, or reference, product.

Products labeled “reduced sugar” contain 25% less sugar per serving.

The ingredient list helps identify added sugars. Many products have more than one added sweetener. The closer the name of each sweetener appears to the beginning of the list, the more of it has been added.

In the ingredient list, all these mean added sugar: Brown sugar, corn sweetener, corn syrup, dextrose, fructose, fruit juice, glucose, high fructose corn syrup, honey, invert sugar, lactose, maltose, malt syrup, molasses, raw sugar, sucrose, and sugar syrup concentrates.

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WHAT SHOULD I EAT?

Carbohydrates

Make half your grains whole
• Have your sandwich on whole-wheat, oat bran, rye, or pumpernickel bread.
• Switch to whole-wheat pasta and brown rice.
• Fill your cereal bowl with plain oatmeal and add a few raisins for sweetness.
• Check the ingredient list for the words whole or whole grain before the grain ingredient's name.

Increase your fruits and veggies
• Don’t forget beans. Kidney beans, chickpeas, black beans, and others have more fiber and resistant starch than any other vegetables.
• Add berries, bananas, and oats to cereal and desserts.
• Pile the veggies on your sandwich.
• Have more than one vegetable at dinner.

Limit added sugars
• Switch to a 12-oz can instead of a 20-oz bottle when you grab a soft drink or, better yet, have a glass of water or low-fat milk.
• Use one-quarter less sugar in your recipe next time you bake.
• Snack on a piece of fruit instead of a candy bar.
• Swap your sugary breakfast cereal for an unsweetened whole-grain variety.

The Nutrition Facts panel helps consumers find foods that are good sources of fiber and low in sugar. The ingredient list helps identify whole-grain products and the sources of added sugars. Nutrient content claims such as “high in fiber” or “no sugar added” and health claims such as those highlighting the relationship between fiber intake and the risk of heart disease and cancer help identify foods that meet the recommendations for fiber and added sugar intake (see What Should I Eat? and Appendix F).

CONCEPT CHECK

1. How does the U.S. diet compare with recommendations for fiber and added sugar?
2. What is the percentage of calories from carbohydrate in your breakfast cereal?
3. Where on a food label can you find information about added sugars?

Summary

1 Carbohydrates in Our Food 100

• Unrefined whole grains, fruits, and vegetables are good sources of fiber and micronutrients. When these foods are refined, nutrients and fiber are lost. Whole grains contain the entire kernel, as shown here, which includes the endosperm, bran, and germ; refined grains include only the endosperm. Enrichment, one type of fortification, adds back some but not all of the nutrients lost in refining.

• Refined sugars contain calories but few nutrients; for this reason, foods high in added refined sugar are low in nutrient density.
2 Types of Carbohydrates  102

- Carbohydrates contain carbon as well as hydrogen and oxygen, in the same proportion as water. **Simple carbohydrates** include monosaccharides and disaccharides and are found in foods such as table sugar, honey, milk, and fruit. **Complex carbohydrates** are polysaccharides; they include glycogen in animals and starches, illustrated here, and fiber in plants.

**Structures and sources of carbohydrates:**
Complex carbohydrates • Figure 4.4c

- Fiber cannot be digested in the stomach or small intestine and therefore is not absorbed into the body. **Soluble fiber** dissolves in water to form a viscous solution and is digested by bacteria in the colon; **insoluble fiber** is not digested by bacteria and adds bulk to fecal matter.

3 Carbohydrate Digestion and Absorption  105

- Disaccharides and starches must be digested to monosaccharides, as shown here, before they can be absorbed. In individuals with lactose intolerance, lactose passes into the colon undigested, causing cramps, gas, and diarrhea. Indigestible complex carbohydrates, including fiber, some oligosaccharides, and resistant starch, can increase intestinal gas, but they benefit health by increasing bulk in the stool, promoting growth of healthy microflora, and slowing nutrient absorption.

**Carbohydrate digestion** • Figure 4.7

- After a meal, blood glucose levels rise. The rate, magnitude, and duration of this rise are referred to as the glycemic response. Glycemic response is affected by the amount and type of carbohydrate consumed and by other nutrients ingested with the carbohydrate.

4 Carbohydrate Functions  109

- Carbohydrate, primarily as glucose, provides energy to the body. Blood glucose levels are maintained by the hormones **insulin** and **glucagon**. As depicted here, when blood glucose levels rise insulin from the pancreas allows cells to take up glucose from the blood and promotes the synthesis of glycogen, fat, and protein. When blood glucose levels fall, glucagon increases them by causing glycogen breakdown and glucose synthesis.

**Blood glucose regulation** Figure • 4.10

- Glucose is metabolized through cellular respiration. It begins with **glycolysis**, which breaks each six-carbon glucose molecule into two three-carbon pyruvate molecules, producing ATP even when oxygen is unavailable. The complete breakdown of glucose through **aerobic metabolism** requires oxygen and produces carbon dioxide, water, and more ATP than glycolysis.

- When carbohydrate intake is limited, amino acids from the breakdown of body proteins can be used to synthesize glucose. Therefore, an adequate carbohydrate intake is said to spare protein. Limited carbohydrate intake also results in the formation of ketones (**ketone bodies**) by the liver. These can be used as an energy source by other tissues. Ketones that accumulate in the blood can cause symptoms that range from headache and lack of appetite to coma and even death if levels are extremely high.

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• Gram for gram, carbohydrates provide less energy than fat. High-fiber diets can prevent weight gain by making you feel full longer so that you eat less. Low-carbohydrate diets promote weight loss by causing a spontaneous reduction in food intake. Nonnutritive sweeteners aid weight loss if the sugar calories they replace are not added back from other food sources.

• Diets high in unrefined carbohydrates from whole grains, vegetables, fruits, and legumes may reduce the risk of heart disease, bowel disorders, and colon cancer. Soluble fiber helps prevent heart disease because it can lower blood cholesterol.

Blood glucose levels in diabetes • Figure 4.13

- Hypoglycemia, or low blood glucose, causes symptoms such as sweating, headaches, and rapid heartbeat.

- Diets high in carbohydrate, particularly refined sugars, increase the risk of dental caries. Bacteria on the teeth use carbohydrate as a food supply, producing acids that damage the teeth.

Key Terms

- acceptable daily intake (ADI) 119
- aerobic metabolism 111
- anaerobic metabolism 111
- autoimmune disease 114
- bran 100
- cellulose 103
- complex carbohydrate 103
- diabetes mellitus 113
- disaccharide 102
- diverticulitis 121
- diverticulosis 121
- diverticula 121
- endosperm 100
- enrichment 100
- fasting hypoglycemia 116
- fiber 104
- fortification 100
- fructose 103
- galactose 103
- germ 100
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- glucagon 110
- glucose 103
- glycemic index 108
- glycemic load 108
- glycemic response 108
- glycogen 103
- glycolysis 111
- hemorrhoid 121
- hypoglycemia 116
- insulin 109
- insulin resistance 114
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- lactose intolerance 106
- maltose 103
- monosaccharide 102
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- oligosaccharide 106
- photosynthesis 104
- polysaccharide 102
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- soluble fiber 104
- starch 103
- sucrose 103
- sugar unit 102
- type 1 diabetes 114
- type 2 diabetes 114
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- whole-grain product 100

Meeting Carbohydrate Needs 122

- Guidelines for a healthy diet recommend 45 to 65% of energy from carbohydrates. Most of this should come from whole grains, legumes, fruits, and vegetables, such as those in this photo. Foods high in added sugar should be consumed in moderation.

How much carbohydrate do you eat? Figure 4.20

- The recommendations of MyPlate and the information on food labels can be used to select healthy amounts and sources of carbohydrate.
Online Resources

- For more information on diabetes, go to http://diabetes.niddk.nih.gov.
- For more information on how beverages affect our calorie intake, go to www.cdc.gov/healthyweight/healthy_eating/drinks.html.
- For more information on choosing whole grains, go to www.mayoclinic.com/health/whole-grains/NU00204.
- For more information on the 2010 Dietary Guidelines, go to www.health.gov/dietaryguidelines/.
- Visit your WileyPLUS site for videos, animations, podcasts, self-study, and other media that will aid you in studying and understanding this chapter.

Critical and Creative Thinking Questions

1. Record everything you eat for three days. Use iProfile to calculate your fiber intake. How does it compare with the recommendations? How could you increase your fiber intake?

2. For each high-carbohydrate food on your food record, indicate whether it is refined or unrefined. Suggest some changes that would increase your intake of unrefined carbohydrates. List some foods in your diet that are high in added sugars. Suggest some changes that would reduce your intake of these sugars.

3. Adam is 19 and plays basketball. Recently, he has been thirsty all the time, and he needs to get up several times a night to urinate. He has lost 10 pounds and is so tired that he has been missing basketball practice. What type of diabetes is most likely affecting Adam? How does it need to be managed? Why is it important to keep blood sugar levels within the normal range in both type 1 and type 2 diabetes?

4. Are carbohydrates good for you? Explain why or why not.

5. Imagine that you have gained 20 pounds over the past 5 years, and you decide to use a low-carbohydrate diet to return to a healthy weight. You are happy with your initial weight loss but begin to have headaches and bad breath. What is causing these symptoms, and why?

6. This is the label from a hot breakfast cereal. How much fiber and sugars does it provide? Is it a whole-grain product? What does this label tell you about the amount of added sugar it contains? Would you recommend this product to a friend? Why or why not?

Nutrition Facts

<table>
<thead>
<tr>
<th>Serving Size</th>
<th>Amount Per Serving</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 packet (43g)</td>
<td>Cereal</td>
</tr>
<tr>
<td></td>
<td>Calories: 160</td>
</tr>
<tr>
<td></td>
<td>Calories from Fat: 15</td>
</tr>
<tr>
<td></td>
<td>% Daily Value:</td>
</tr>
<tr>
<td></td>
<td>Total Fat: 1.5g</td>
</tr>
<tr>
<td></td>
<td>Saturated Fat 0g</td>
</tr>
<tr>
<td></td>
<td>Trans Fat 0g</td>
</tr>
<tr>
<td></td>
<td>Cholesterol: 0mg</td>
</tr>
<tr>
<td></td>
<td>Sodium: 230mg</td>
</tr>
<tr>
<td></td>
<td>Total Carbohydrate: 33g</td>
</tr>
<tr>
<td></td>
<td>Dietary Fiber: 3g</td>
</tr>
<tr>
<td></td>
<td>Soluble Fiber: 1g</td>
</tr>
<tr>
<td></td>
<td>Sugars: 13g</td>
</tr>
<tr>
<td></td>
<td>Protein: 4g</td>
</tr>
</tbody>
</table>

INGREDIENTS: WHOLE GRAIN ROLLED OATS (WITH OAT BRAN), SUGAR, SALT, NATURAL AND ARTIFICIAL FLAVORS, CALCIUM CARBONATE (A SOURCE OF CALCIUM), GUAR GUM, CARAMEL COLOR, VITAMIN A PALMITATE, NIACINAMIDE*, REDUCED IRON, PYRIDOXINE HYDROCHLORIDE*, RIBOFLAVIN*, THIAMIN MONONITRATE*, FOLIC ACID*.

*ONE OF THE B VITAMINS.

What is happening in this picture?

These students are choosing fruit drinks, sports drinks, and iced tea because they believe these beverages are healthier choices than soda.

Think Critically

1. How does the amount of added sugar in these products compare to the amount in soft drinks?
2. Do these beverages provide significant amounts of any essential nutrients?
3. Suggest beverage alternatives that would be lower in added sugar.
Self-Test

(Check your answers in Appendix K.)

1. Which of the following is a source of unrefined carbohydrate?
   a. white bread  
   b. white rice  
   c. corn on the cob  
   d. donut

2. Which of these molecules is a disaccharide?
   a. A  
   b. B  
   c. C  
   d. D

3. Which of the following is most likely to occur soon after you eat a large carbohydrate-rich meal?
   a. You break down body fat stores.  
   b. Your pancreas releases insulin.  
   c. Your pancreas releases glucagon.  
   d. Your liver breaks down glycogen.  
   e. You produce ketones.

4. Which of the following is contributing to the increase in type 2 diabetes?
   a. the increase in obesity  
   b. consuming more fiber  
   c. changes in our genes  
   d. more sensitive immune systems

5. The Daily Value for fiber is 25 g. If a product label indicates that it provides 20% of the Daily Value, how much fiber does a serving contain?
   a. 2 g  
   b. 3 g  
   c. 4 g  
   d. 5 g

6. Which part of this whole-wheat kernel contains most of the grain’s fiber as well as many vitamins?
   a. A  
   b. B  
   c. C

7. Foods high in added sugar provide ____________.
   a. many vitamins in each calorie  
   b. empty calories  
   c. soluble fiber  
   d. insoluble fiber

8. Which statement about simple carbohydrates is false?
   a. Fructose is found in fruit.  
   b. Lactose is milk sugar.  
   c. Glucose is blood sugar.  
   d. Maltose is table sugar.

9. The digestive enzymes that break disaccharides into monosaccharides are located in the ____________.
   a. stomach  
   b. saliva  
   c. microvilli  
   d. colon

10. When blood glucose levels drop, all except which of the following may occur?
    a. Glucagon is released.  
    b. Glycogen is broken down.  
    c. Fatty acids are used to make glucose.  
    d. Amino acids from protein are used to make glucose.

11. Which one of the following statements about insoluble fiber is true?
    a. It holds water in the gastrointestinal tract.  
    b. It is digested by bacteria in the colon.  
    c. It dissolves in water and forms a viscous solution.  
    d. It adds bulk to the intestinal contents.
12. People who are lactose intolerant do not produce enough of the enzyme __________.
   a. lactase         c. galactose
   b. lactose         d. amylase

13. This graph shows an individual's glycemic response after consuming a sugar-sweetened beverage. Which of the following individuals does this graph represent?
   a. a person who has a normal glycemic response
   b. a person who has hypoglycemia
   c. a person who has prediabetes
   d. a person who has diabetes

14. A high-fiber diet may help protect against which of the following?
   a. heart disease     c. large swings in blood glucose
   b. diverticulosis    d. all of the above

15. Which steps in the diagram proceed in the absence of oxygen?
   a. only step 1
   b. steps 1, 2, and 3
   c. only step 4
   d. steps 1 and 3

**THE PLANNER**
Review your Chapter Planner on the chapter opener and check off your completed work.