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Chapter 4

Carbohydrates: Sugars, Starches, and Fiber

AS THE LOW-CARBOHYDRATE DIET CRAZE FADED, THE 15 POUNDS SHAMARA HAD LOST WHILE CONSUMING THIS DIET SLOWLY CREEPT BACK ONTO HER 5'6" FRAME. She has always



been heavier than she liked, and was delighted to lose 15 pounds. Now she has regained 10 pounds to bring her weight up to 153 pounds. Since this weight is still in the healthy range, she decided to forget the weight-loss diet and try to just focus on eating healthy foods. To do this, Shamara looked up her MyPyramid recommendations. She was surprised to find that not all carbs are bad—MyPyramid recommended that she eat the equivalent of about six servings of grain products and that at least half of these be whole grains. She also saw that she needed to increase her intake of fruits and vegetables. These foods contain carbohydrate but are also high in fiber.

The first step Shamara took to improve her diet was to boost her fruit and vegetable intake by keeping a bag of cut-up raw vegetables and a bowl of fruit salad in her refrigerator, ready to be snacked on or added to a meal. To increase her intake of whole grains she started by making smarter choices at the grocery store. She switched from white rice to brown rice and chose multi-grain breads and healthy sounding

LEARNING OBJECTIVES *After reading this chapter, students should be able to:*

- 1 Discuss the difference between refined and unrefined carbohydrates.
- 2 Compare the structures of simple and complex carbohydrates.
- 3 Distinguish between soluble and insoluble fiber and name food sources of each.
- 4 Define lactose intolerance and explain why it causes gas and bloating when milk is consumed.
- 5 Discuss the effects of dietary fiber and other indigestible carbohydrates on gastrointestinal function and health.
- 6 Describe the steps involved in metabolizing glucose to produce energy.
- 7 Explain how insulin and glucagon are involved in regulating blood glucose.
- 8 Compare the causes and consequences of type 1 and type 2 diabetes.
- 9 Discuss the health risks and benefits of diets high in unrefined carbohydrates and diets high in refined carbohydrates.
- 10 Modify a diet so it meets current recommendations for the types and amounts of carbohydrate.
- 11 Discuss the role of artificial sweeteners in a weight-loss plan.



cereals. A few weeks later, she had her diet analyzed at a health fair. She was surprised to see that her fiber intake was still below the recommended 25 grams per day. She started reading the labels on the foods in her cupboard and found that her seven-grain bread didn't contain any whole grains. Her breakfast cereal did contain whole wheat but only provided 2 grams of fiber in a cup—it also contained 18 grams of sugars. Choosing healthy carbohydrates was turning out to be almost as difficult as eliminating them from her diet had been when she was consuming the low-carb diet.

CARBOHYDRATES IN THE MODERN DIET

REFINED Refers to foods that have undergone processes that change or remove various components of the original food.

Carbohydrates are the basis of our diet. They are found in foods as diverse as whole-wheat bread, chocolate cake, fresh fruit, milk, and carbonated soft drinks. The carbohydrates in these foods are a readily available source of energy; they supply 4 kcalories per gram. However, the additional nutritional impact they deliver varies depending on whether the carbohydrate is **refined** or in its natural state. The carbohydrates in the whole-wheat bread, the fresh fruit, and the milk are considered whole food sources of carbohydrate because they have not been altered from their natural state. These foods contain vitamins, minerals, and other health-promoting substances as well as carbohydrates. The cake and the soda provide carbohydrates that have been refined. Refining separates carbohydrates from essential nutrients and other food components present in the whole food (Table 4.1).

TABLE 4.1 *More and Less Refined Food Choices*

	LESS REFINED	MORE REFINED	HIGH IN ADDED SUGARS
Cereals	Oatmeal, shredded wheat, Kashi	Corn flakes, Rice Puffs, Cheerios	Lucky Charms, Frosted Shredded Wheat
Breads	Whole-wheat bread, whole-wheat bagel	White bread, English muffin, white bagel	Doughnut, Danish pastry
Grains	Whole-wheat pasta, brown rice, bulgur wheat, barley, quinoa	White pasta, white rice, rice cakes	Rice pudding, Rice Krispie treats, sweetened rice cakes
Fruit	Raspberries, apple, orange	Canned fruit, dried fruit, orange juice	Canned fruit in heavy syrup, fruit pies, sweetened dried fruit, candied fruit, fruit punch
Vegetables	Baked potato, zucchini	French fries, fried zucchini	Candied yams, sweet potato pie, pumpkin cake

Over the last century the amounts and sources of carbohydrates in the American diet have changed. Our total carbohydrate intake decreased between 1909 and 1963. Most of this drop was due to a decrease in the consumption of whole grains, and with it came a 40% drop in the amount of fiber consumed.¹ Since the 1960s our total carbohydrate intake has increased, but our fiber intake did not rise with it, suggesting an increase in the intake of refined carbohydrates. Much of the carbohydrates added back to our diet between 1960 and 2000 came from sugars; over this time period per capita sugar consumption rose by 33%.²



FIGURE 4.1 Recommendations for a healthy diet tell us to choose more whole sources of carbohydrates such as whole grains, legumes, vegetables, and fruits and limit foods high in refined carbohydrates, such as white bread and white rice, and added refined sugars, such as candies, cookies, and sweetened beverages. (Andy Washnik)

Whole-grain breads, dried peas and beans, and bulgur had been replaced by white bread, snack foods, and sugared soft drinks. The type of sweetener also changed. In the 1960s we sweetened food with cane and beet sugar, but today most of the foods we buy are sweetened with corn sweeteners.

The carbohydrates in today's diet are more refined than they were earlier in the century. Recommendations for a healthy diet tell us to choose more of the carbohydrates we used to eat: more whole sources such as whole grains, vegetables, legumes, and fruits, and fewer foods high in refined carbohydrates and **added sugars** such as baked goods and soft drinks (Figure 4.1).

REFINED CARBOHYDRATES

Whole food sources of carbohydrate such as grains, legumes, vegetables, fruit, and milk contain a variety of nutrients in addition to carbohydrates. Grains, legumes, and vegetables provide B vitamins, some minerals, and fiber. Fruits provide vitamins A and C along with fiber. Milk is a good source of the B vitamin riboflavin and the mineral calcium. In contrast, refined sources of carbohydrate such as the corn flakes you may have had for breakfast, are made from corn that has been ground, sieved, washed, cooked, extruded, and dried. During these refining steps, many of the nutrients and other healthful components of the corn kernel are lost. When we eat the entire kernel or seed of a grain, such as corn or wheat, we are eating an unrefined or **whole-grain** product. The whole-grain kernel includes three parts (Figure 4.2). The **outermost bran** layers contain most of the fiber and are a good source of vitamins. The **germ**, which lies at the base of the kernel, is the plant embryo where sprouting occurs. It is the source of vegetable oils such as corn or safflower oil, and is rich in vitamin E. It also contains

ADDED SUGARS Sugars and syrups that have been added to foods during processing or preparation.

WHOLE GRAIN The entire kernel of grain including the bran layers, the germ, and the endosperm.

BRAN The protective outer layers of whole grains. It is a concentrated source of dietary fiber.

GERM The embryo or sprouting portion of a kernel of grain. It contains vegetable oil, protein, fiber, and vitamins.

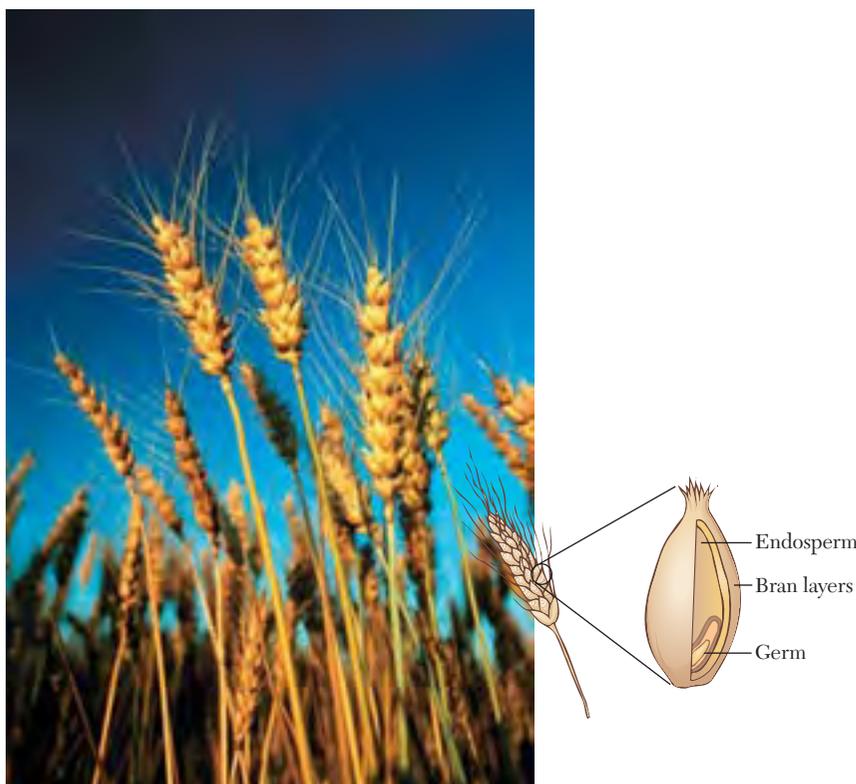


FIGURE 4.2 A kernel of wheat contains outer layers of bran, the plant embryo or germ, and a carbohydrate-rich endosperm. (Kevin Morris/Stone/Getty Images)

ENDOSPERM The largest portion of a kernel of grain. It is primarily starch and serves as a food supply for the sprouting seed.

ENRICHED GRAINS Grains to which some of the nutrients lost in processing have been added to a level equal to or higher than that originally present.

100 grams of whole-wheat flour (about three-quarters of a cup) contains about 12 grams of fiber, whereas 100 grams of enriched, bleached, all-purpose flour contains less than 3 grams of fiber.

protein, fiber, and the B vitamins riboflavin, thiamin, and vitamin B₆. The remainder of the kernel is the **endosperm**, which is primarily starch but also contains most of the protein and some vitamins and minerals. During the milling of grain into flour, the grinding detaches the germ and bran from the endosperm. Whole-grain flours such as whole-wheat flour include most of the bran, germ, and endosperm (see Off the Shelf: Choosing Whole Grains: Not as Easy as It Sounds). White flour however is produced from just the endosperm. Fiber and some vitamins, minerals, and phytochemicals naturally found in the whole grain are therefore lost. In order to restore some of the lost nutrients, refined grains sold in the United States are fortified with some, but not all, of the nutrients lost in processing. **Enriched grains** contain added thiamin, riboflavin, niacin, and iron and are fortified with folate. However, they do not contain added vitamin E, magnesium, vitamin B₆, or a number of other nutrients that are also removed by milling (see Chapter 8).

ADDED SUGARS

If you sprinkle some sugar on your corn flakes you are adding another refined source of carbohydrate. This added sugar was most likely extracted from a sugar beet, boiled, bleached, and purified. It adds calories without adding any nutrients thereby reducing the nutrient density of your breakfast. But the sugar you add isn't the only source of added sugars in the diet—much of the added sugar we consume comes from desserts, beverages, and snacks that we purchase already prepared. Refined added sugars make up about 16% of the calories in the American diet.³ Added sugars are not nutritionally or chemically different from sugars occurring naturally in foods. The only difference is that they have been separated from their plant sources and therefore are not consumed with the fiber, vitamins, minerals, and other substances found in the original plant.



OFF THE SHELF

CHOOSING WHOLE GRAINS: NOT AS EASY AS IT SOUNDS

Eat more whole-grain products. They are rich in dietary fiber, B vitamins, vitamin E, selenium, zinc, copper, magnesium, and phytochemicals that may play important roles in disease prevention.¹ Doesn't this mean picking brown bread instead of white? Unfortunately, the color of a product may have little to do with whether it is a whole grain—the dark color of breads may be due to whole grains, but it could also be due to other ingredients such as molasses. How about choosing a multi-grain product? Again this may not help you meet your whole grain quota. Terms like “multi-grain”, “five grain”, and “seven grain” sound healthy but these descriptors simply mean the product contains more than one type of grain, not that these grains are necessarily whole. Other terms may be equally misleading. “Wheat” refers to the type of grain, not how refined

it is; “stone ground” refers to the way the grain is processed, not whether the bran and germ are included; and terms like “bran” and “oat” may refer to things added to the product, not whether the product is made predominantly from a whole grain.

So what is a whole grain? The American Association of Cereal Chemists has proposed the following consumer friendly definition for whole grains:

Whole cereal grains and foods made from them consist of the entire grain seed usually referred to as the kernel. The kernel is made of three components the bran, the germ and the endosperm. If the kernel has been cracked, crushed or flaked, then in order to be called whole grain, it must retain nearly the same relative proportions of bran, germ, and endosperm as the original grain.²

(continued)

Whole Grain Crackers

Nutrition Facts	
Serving Size 7 Crackers (29g)	
Servings Per Container About 12	
Amount Per Serving	
Calories 120	Calories from Fat 25
%Daily Value*	
Total Fat 3g	5%
Saturated Fat 0g	0%
Trans Fat 0g	
Polyunsaturated Fat 1.5g	
Monounsaturated Fat 0.5g	
Cholesterol 0mg	0%
Sodium 160mg	6%
Total Carbohydrate 21g	7%
Dietary Fiber 3g	13%
Sugars 0g	
Protein 3g	

INGREDIENTS: WHOLE WHEAT, SOYBEAN OIL, SALT, MONOGLYCERIDES



Multigrain, but not Whole grain crackers

Nutrition Facts	
Serving Size 13 Crackers (31g)	
Servings Per Container About 7	
Amount Per Serving	
Calories 140	Calories from Fat 35
%Daily Value*	
Total Fat 3.5g	6%
Saturated Fat 0.5g	3%
Trans Fat 0g	
Polyunsaturated Fat 0g	
Monounsaturated Fat 1g	
Cholesterol 0mg	0%
Sodium 240mg	10%
Total Carbohydrate 23g	8%
Dietary Fiber 1g	5%
Sugars 4g	
Protein 3g	

INGREDIENTS: ENRICHED UNBLEACHED AND BLEACHED FLOUR (WHEAT FLOUR, NIACIN, REDUCED IRON, THIAMINE MONONITRATE (VITAMIN B1), RIBOFLAVIN (VITAMIN B2), FOLIC ACID), PARTIALLY HYDROGENATED SOYBEAN OIL, SUGAR, RICE, OATMEAL DEGERMED YELLOW CORNMEAL, WHOLE WHEAT, WHOLE WHEAT FLOUR, BARLEY FLAKES, OAT BRAN, HIGH FRUCTOSE CORN SYRUP, SALT, LEAVENING (BAKING SODA, YEAST, CALCIUM PHOSPHATE), CRACKED WHEAT, MODIFIED CORNSTARCH, ONION POWDER, MALTSYRUP, SOYLECITHIN (EMULSIFIER), CORNSTARCH, MALTED BARLEY FLOUR.



These whole grain stamps developed by the Whole Grains Council can help consumers choose three servings of whole grains per day. (Whole Grain Stamps™ are a trademark of Oldways Preservation Trust and the Whole Grains Council. www.wholegrainscouncil.org)



To see if the breads, cereals, pastas, crackers, and other grain products you are pulling off the shelf are whole-grain products take a look at the ingredient list. When a whole grain is the first ingredient, as it is in the whole-grain crackers, the product is made with mostly whole grain. If the first ingredient is wheat flour, enriched flour, or degerminated cornmeal the product is not made mostly from a whole grain. The ingredient list will also identify products to which fibers, such as wheat bran or oat bran, have been added. These additions increase the fiber content of the food, but don't mean that it is a whole-grain product. In fact, a cereal made from refined grain with added bran may provide more fiber than one made from a whole grain without the added bran.

Another tool that can help you make half your grains whole is the whole-grain stamp, developed by the Whole Grains Council. This stamp provides an easy way to identify three levels of whole-grain products, depending on how much whole grain they provide (see above). Foods with the "good source" stamp provide a half serving of whole grains, whereas those with the "excellent source" or "100%/excellent source" provide a full serving. Eating three servings of whole-grain food products labeled "Excellent Source" or "100%/Excellent" or six servings of products labeled "good source" will meet the whole-grain goals of the Dietary Guidelines. The presence of the whole-grain health claim on food product labels also indicates that your choice is a whole-grain product. The claim states that: "Diets rich in whole grain foods and other plant foods and low in total fat, saturated fat, and cholesterol may

help reduce the risk of heart disease and certain cancers." This claim can only be used on a product label when the food contains at least 51% whole grains by weight and is also low in fat.³

The table below provides a list of whole grains found on the shelves of U.S. grocery stores. Look for these on the labels to increase your whole grain consumption. But don't forget to look at the rest of the label as well. For example, Lucky Charms cereal is made with whole grains but it also has lots of added sugars—marshmallows are the second ingredient on the list. This choice may increase your consumption of whole grains but it also increases your intake of added sugars. So, when you are standing in the bread or cereal aisle, look at more than the color and name of the product to see if you are getting the benefits you seek.

Whole Grains to Look For

Whole wheat	Whole-grain barley
Whole oats	Wild rice
Oatmeal	Buckwheat
Rolled Oats	Triticale
Whole-grain corn	Bulgur (cracked wheat)
Popcorn	Millet
Brown rice	Quinoa
Whole rye	Sorghum

Source: Dietary Guidelines, 2005

¹Slavin, J. L., Jacobs, D., Marquart, L., and Wiemer, K. The role of whole grains in disease prevention. *J. Am. Diet. Assoc.* 101:780–785, 2001.

²AACC International press release. Available online at www.aaccnet.org/news/CFWholeGrain.asp. Accessed January 23, 2006.

³US Dept. of Health and Human Services, US Dept. of Agriculture. *Dietary Guidelines for Americans*, 6th ed., Washington, DC, 2005.

EMPTY KALORIES Refers to foods that contribute energy but few other nutrients.

Because added sugars provide few nutrients for the number of calories they contain they have a low nutrient density and are therefore thought of as **empty calories**. Unrefined or whole food sources of sugar such as fruit provide vitamins, minerals, and phytochemicals as well as calories. For example, a 12-ounce soda contains about 140 calories but almost no nutrients other than sugar. Three kiwis also have about 140 calories but contribute vitamin C, folate, potassium, and some calcium as well as fiber (Figure 4.3).



NUTRIENT	SODA (12 FLUID OZ)	KIWI (3 MEDIUM)
Vitamin A (μg)	0	7
Vitamin C (mg)	0	223
Folate (μg DFE)	0	87
Potassium (mg)	4	757
Calcium (mg)	7	60
Protein (g)	0	2
Fiber (g)	0	8
Carbohydrate (g)	37	34
Sugars (g)	37	26
Energy (kcal)	141	139

About one-third of the added sugars in our diet come from soft drinks; another third come from candy, cakes, cookies, and pies.

Blackstrap molasses is a by-product of the refining of sucrose from sugar cane. It is a thick, brown syrup that remains after the sucrose has crystallized. Unlike sucrose, it contains some essential minerals; a tablespoon of molasses has over 100 mg of calcium and 2.4 mg of iron.

FIGURE 4.3 *Kiwis and soda in the portions shown here provide about the same amount of energy and carbohydrate, but the kiwis are also a good source of fiber and nutrients such as vitamin C and folate. (© George Semple)*

SIMPLE AND COMPLEX CARBOHYDRATES

Chemically, carbohydrates are compounds that contain carbon (carbo), as well as hydrogen and oxygen in the same proportion as in water (hydrate). They are typically divided into **simple carbohydrates**, also known as sugars, and **complex carbohydrates**, which include starches and fibers. Both can provide a source of energy to fuel the body.

SIMPLE CARBOHYDRATES

The basic unit of carbohydrate is a single sugar molecule, a **monosaccharide** (*mono* means one). When two sugar molecules combine, they form a **disaccharide** (*di* means two). Monosaccharides and disaccharides are known as simple sugars or simple carbohydrates. Fruits, vegetables, and milk are sources of simple carbohydrates. The sugars we add to food such as white table sugar, brown sugar, molasses, and confectioner's sugar are also simple carbohydrates. These are produced by refining the sugar from plants such as sugar cane and sugar beets.

MONOSACCHARIDES The three most common monosaccharides in the diet are glucose, galactose, and fructose. Each contains 6 carbon, 12 hydrogen, and 6 oxygen atoms but differ in their arrangement (Figure 4.4). **Glucose**, commonly referred to as blood sugar, is the most important carbohydrate fuel for the body. It is produced in plants by the process of photosynthesis, which uses energy from the

SIMPLE CARBOHYDRATES

Carbohydrates known as sugars that include monosaccharides and disaccharides.

COMPLEX CARBOHYDRATES

Carbohydrates composed of sugar molecules linked together in straight or branching chains. They include glycogen, starches, and fibers.

MONOSACCHARIDE *A single sugar molecule, such as glucose.*

DISACCHARIDE *A sugar formed by linking two monosaccharides.*

GLUCOSE *A monosaccharide that is the primary form of carbohydrate used to produce energy in the body. It is the sugar referred to as blood sugar.*

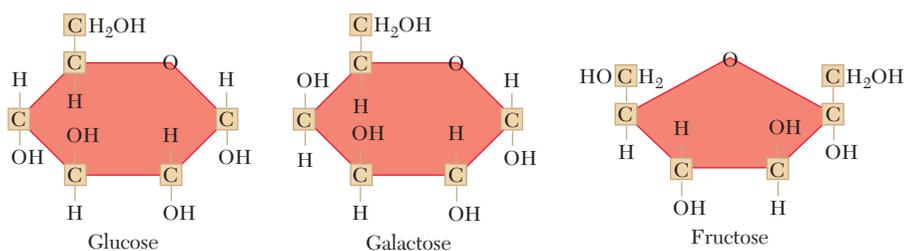


FIGURE 4.4 *The structure of some common monosaccharides.*

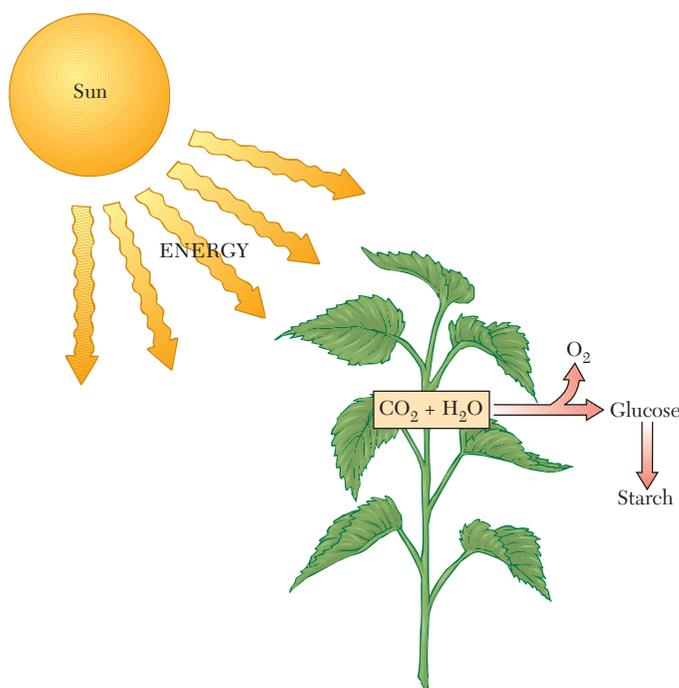


FIGURE 4.5 The process of photosynthesis uses energy from the sun to synthesize glucose from carbon dioxide and water. Glucose can then be stored as starch.

GALACTOSE A monosaccharide that combines with glucose to form lactose or milk sugar.

FRUCTOSE A monosaccharide that is the primary form of carbohydrate found in fruit.

High concentrations of sugar hold water and prevent the growth of microorganisms. For this reason sugar serves as a preservative in foods like jams and jellies.

SUCROSE A disaccharide that is formed by linking fructose and glucose. It is commonly known as table sugar or white sugar.

LACTOSE A disaccharide that is formed by linking galactose and glucose. It is commonly known as milk sugar.

MALTOSE A disaccharide made up of 2 molecules of glucose. It is formed in the intestines during starch digestion.

Honey is derived from the nectar of flowering plants. Bees collect the nectar and convert some of the sucrose into fructose and glucose. The color, flavor, and proportions of the sugars in honey vary with the source of the nectar.

sun to combine carbon dioxide and water (Figure 4.5). Glucose rarely occurs as a monosaccharide in food. It is most often found as part of a disaccharide or starch. **Galactose** is also rarely present as a monosaccharide in the food supply. It occurs most often as a part of lactose, the disaccharide in milk.

Fructose is a monosaccharide that tastes sweeter than glucose. It is found in fruits and vegetables and makes up more than half the sugar in honey. Because fructose does not cause as great a rise in blood glucose as other sugars, it is sometimes used in products for people with diabetes. However, because fructose causes an increase in blood lipids, its use should be limited. Fructose consumed in fruits or juices can also cause diarrhea in children. Most of the fructose in our diet comes from high-fructose corn syrup. This sweetener is produced by modifying starch extracted from corn to produce a syrup that is approximately half glucose and half fructose. High-fructose corn syrup is sweeter and less expensive than table sugar. It is now the most common caloric sweetener added to foods and beverages and is the caloric sweetener used in most soft drinks in the United States.⁴ The dramatic increase in the use of high-fructose corn sweeteners that has occurred in the last few decades has been suggested to be related to the increased incidence of diabetes and obesity.⁴

DISACCHARIDES Disaccharides are simple carbohydrates made up of two monosaccharides linked together (Figure 4.6). **Sucrose**, or common white table sugar, is the disaccharide formed by linking glucose to fructose. It is found in sugar cane, sugar beets, honey, and maple syrup. Sucrose is the only sweetener that can be called “sugar” in the ingredient list on food labels in the United States. **Lactose**, or milk sugar, is glucose linked to galactose. Lactose is the only sugar found naturally in animal foods. It contributes about 30% of the energy in whole cow’s milk and about 40% of the energy in human milk. **Maltose** is a disaccharide consisting of two molecules of glucose. This sugar is made whenever starch is broken down. For example, it is responsible for the slightly sweet taste experienced when bread is held in the mouth for a few minutes. As salivary amylase begins digesting the starch, some sweeter-tasting maltose is formed.

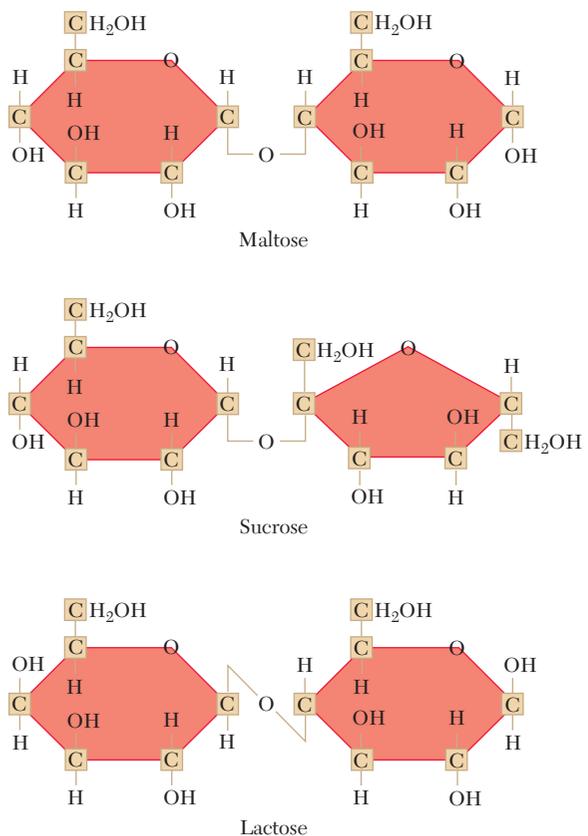


FIGURE 4.6 The structure of some common disaccharides.

MAKING AND BREAKING SUGAR CHAINS The chemical reaction that breaks the bonds between sugar molecules is called a **hydrolysis reaction** (Figure 4.7). Hydrolysis reactions use water to add a hydroxyl group (OH) to one sugar and a hydrogen atom (H) to the other. The reaction that links two sugars together is called a **condensation reaction**. Condensation reactions release a molecule of water by taking a hydroxyl group from one sugar and a hydrogen atom from the other.

HYDROLYSIS REACTION A type of chemical reaction in which a large molecule is broken into two smaller molecules by the addition of water.

CONDENSATION REACTION A type of chemical reaction in which two molecules are joined to form a larger molecule and water is released.

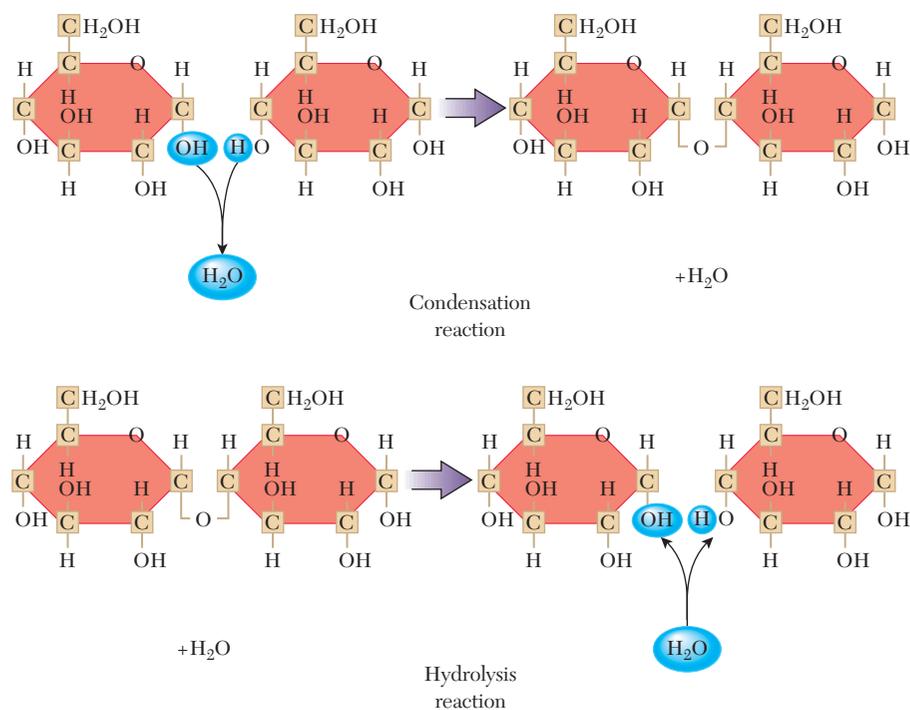


FIGURE 4.7 When two glucose molecules are joined in a condensation reaction, a molecule of water is lost and the disaccharide maltose is formed. A hydrolysis reaction breaks a bond by adding a molecule of water, as is shown here by the hydrolysis of maltose into its component monosaccharides.



OLIGOSACCHARIDES *Short chain carbohydrates containing 3 to 10 sugar units.*

POLYSACCHARIDES *Carbohydrates containing many sugar units linked together.*

GLYCOGEN *A carbohydrate made of many glucose molecules linked together in a highly branched structure. It is the storage form of carbohydrate in animals.*

STARCH *A carbohydrate made of many glucose molecules linked in straight or branching chains. The bonds that hold the glucose molecules together can be broken by human digestive enzymes.*

COMPLEX CARBOHYDRATES

Complex carbohydrates are made up of many monosaccharides linked together in chains. They are generally not sweet to the taste like simple carbohydrates. Short chains of three to ten monosaccharides are called **oligosaccharides**, and longer chains are called **polysaccharides** (*poly* means many). The polysaccharides include **glycogen** in animals and **starch** and fiber in plants (Figure 4.8).

OLIGOSACCHARIDES Some oligosaccharides are formed in the gut during the breakdown of polysaccharides. These are then further digested to simple sugars. Other oligosaccharides are found naturally in foods such as beans and other legumes, onions, bananas, garlic, and artichokes. Many of these are not digested by human enzymes in the digestive tract and pass into the colon where they are broken down by the intestinal microflora. Therefore they can affect the types of bacteria that grow in the colon and have beneficial effects on gastrointestinal (GI) health.

GLYCOGEN Glycogen is the storage form of carbohydrate in animals. It is a polysaccharide made up of highly branched chains of glucose molecules (see Figure 4.8). The branched structure allows it to be broken down quickly when glucose is needed. In humans, glycogen is stored in the muscles and in the liver. Muscle glycogen provides glucose to the muscle as a source of energy during activity; liver glycogen releases glucose into the bloodstream for delivery to cells throughout the body. We consume only minimal amounts of glycogen in our food because glycogen present in animal muscles is broken down soon after slaughter so is not present when the meat is consumed.

The amount of glycogen in the body is relatively small—about 200 to 500 grams. The amount of glycogen stored in muscle can be temporarily increased by a diet and exercise regimen called *carbohydrate loading* or *glycogen supercompensation*. This regimen is often used by endurance athletes to build up glycogen stores before an event. Extra glycogen can mean the difference between running only 20 miles or finishing a 26-mile marathon before exhaustion takes over. Glycogen supercompensation is discussed in more detail in Chapter 13.

STARCHES Starch is the storage form of carbohydrate in plants. Starch is made up of two types of molecules: amylose, which consists of long straight chains of glucose molecules, and amylopectin, which consists of branched chains of glucose molecules (see Figure 4.8). Starch accumulates in roots and tubers (the underground energy storage organ of some plants) where it provides energy for the growth and reproduction of the plant. Therefore we consume starch in roots and

Oligosaccharides present in human milk make the infant stool easier to pass, help promote the growth of a healthy intestinal microflora, and may protect the infant from infection by preventing bacteria from binding to intestinal cells.⁵

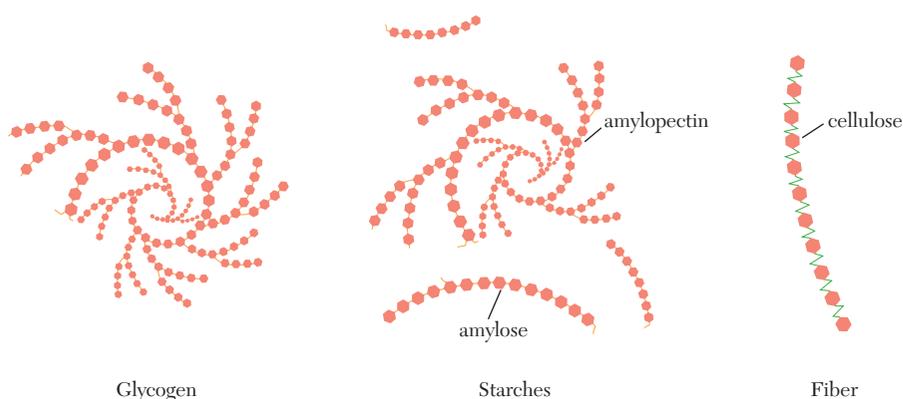


FIGURE 4.8 *Complex carbohydrates are made up of straight or branching chains of monosaccharides.*

tubers such as potatoes, sweet potatoes, beets, turnips, and cassava (Figure 4.9). Starch accumulates in seeds as an energy source for the developing plant embryo. We consume the starch in grain seeds such as wheat, barley, and rye. We also consume starch in **legumes**, such as lentils, soybeans, and pinto and kidney beans.

In addition to the starch naturally present in foods, the diet also contains refined starch such as cornstarch, which is added to thicken foods such as sauces, puddings, and gravies. Starch can be used to thicken foods because the granules swell when heated in water (Figure 4.10). As a starch-thickened mixture cools, high-amylose starches form bonds between the molecules, forming a gel. Some starches are treated to enhance their ability to form a gel. These modified food starches are added to foods as thickeners.

FIBER Fiber includes certain complex carbohydrates and lignins (substances in plants that are not carbohydrates but are classified as fiber) that cannot be digested by human enzymes. Since they cannot be digested, they cannot be absorbed into the body. However, fiber consumed in the diet can have beneficial health effects, from reducing constipation to lowering blood cholesterol. The term **dietary fiber** is used to refer to fiber that is found intact in plants. Fiber that has been isolated from its plant source and has been shown to have beneficial physiological effects is called **functional fiber**. Functional fiber can be added to foods or supplements. For example, oat bran added to bread would be considered functional fiber. **Total fiber** is the sum of dietary fiber and functional fiber.³

Fiber includes a number of different chemical substances that have different physical and physiological properties. Some fibers can be digested by bacteria in the large intestine, producing gas and short-chain fatty acids, small quantities of which can be absorbed. These fibers also form viscous solutions when placed in water and are therefore often referred to as **soluble fibers**. Soluble fibers are found around and inside plant cells. They include pectins, gums, and some hemicelluloses. Food sources of soluble fibers include oats, apples, beans, and seaweed. Fibers that cannot be broken down by bacteria in the large intestine and do not dissolve in water are called **insoluble fibers**. They are primarily derived from the structural parts of plants, such as the cell walls, and include cellulose, some hemicelluloses, and lignins. Food sources of insoluble fibers include wheat bran and rye bran, which are mostly hemicellulose and cellulose, and vegetables such as broccoli, which contain woody fibers composed partly of lignins. Most foods of plant origin contain mixtures of soluble and insoluble fibers (Figure 4.11).

In addition to the soluble and insoluble fibers found in whole grains, fruits, and vegetables, our diet contains fibers that are added to foods during processing. Pectin is a soluble fiber found in fruits and vegetables that forms a gel when sugar and acid are added. It is used to thicken yogurt and to form jams and jellies. Carbohydrate gums such as xanthan gum and locust bean gum are also soluble

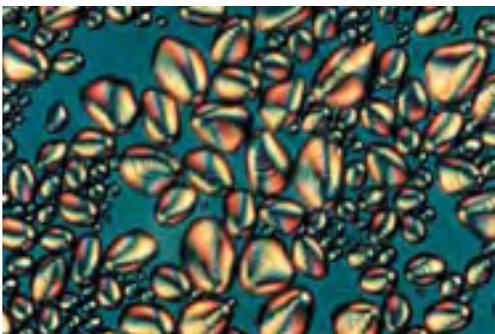


FIGURE 4.10 The starch molecules synthesized by plants are deposited in cells where they form starch grains or granules. Starch granules from different plants have different sizes and shapes. The organization of starch molecules within the granules accounts for some of the properties of various starches in food preparation. The granules shown here are from potato starch. (© Eric V. Grave/Photo Researchers, Inc.)



FIGURE 4.9 Cassava, also known as manioc, is a starchy root vegetable that is the staple of the diet in some parts of western and central Africa. (Magr-StockFood Munich/StockFood America)

LEGUMES Plants in the pea or bean family, which produce an elongated pod containing large starchy seeds. Examples include green peas, kidney beans, and peanuts.

Individuals who are allergic to grains such as wheat or corn should be aware that foods listing modified food starch in their ingredient list are a potential source of allergens. This is because the modified starch may have been made from corn, wheat, potato, rice, or tapioca starch.

DIETARY FIBER A mixture of indigestible carbohydrates and lignin that is found intact in plants.

FUNCTIONAL FIBER Isolated indigestible carbohydrates that have been shown to have beneficial physiological effects in humans.

TOTAL FIBER The sum of dietary fiber and functional fiber.

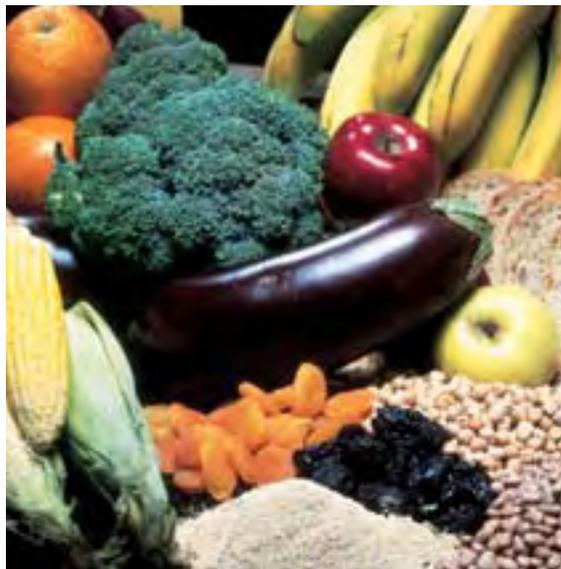
SOLUBLE FIBER Fiber that dissolves in water or absorbs water to form viscous solutions and can be broken down by the intestinal microflora. It includes pectins, gums, and some hemicelluloses.

INSOLUBLE FIBER Fiber that, for the most part, does not dissolve in water and cannot be broken down by bacteria in the large intestine. It includes cellulose, some hemicelluloses, and lignin.



FIGURE 4.11 *These foods are good sources of dietary fiber.*

(Charles D. Winters)



Is there seaweed in your ice cream? The answer might well be yes. It is often added to maintain texture. Carrageenan is a carbohydrate gum extracted from seaweed. Agar and alginates are also gums that come from seaweed, whereas gum arabic, gum karaya, guar gum, locust bean gum, xanthan gum, and gum tragacanth are extracted from shrubs, trees, and seedpods.

fibers. They combine with water and are used to keep solutions from separating. Gravies, puddings, reduced-fat salad dressings, and frozen desserts are examples of products that contain carbohydrate gums. Pectins and gums are also used in reduced-fat products to mimic the texture of fat (see Chapter 5). Insoluble fibers such as wheat bran are added to foods like breads and muffins to reduce kcalorie content and meet consumer demand for high-fiber foods.

CARBOHYDRATES IN THE DIGESTIVE TRACT

Disaccharides and complex carbohydrates must be digested to monosaccharides to be absorbed. Some people are unable to digest the disaccharide lactose. It spills into the colon causing uncomfortable side effects. All humans lack the digestive enzymes needed to completely break down a variety of oligosaccharides, certain forms of starch, and fiber. These indigestible carbohydrates have important effects on the health and function of the digestive system and the body as a whole.

DIGESTIBLE CARBOHYDRATES

Digestion of starch begins in the mouth, where the enzyme salivary amylase starts breaking it into shorter polysaccharides (Figure 4.12). The majority of starch and disaccharide digestion occurs in the small intestine. Here, pancreatic amylases complete the job of breaking down starch into monosaccharides, disaccharides, and oligosaccharides. The digestion of disaccharides and oligosaccharides is completed by enzymes attached to the brush border of the villi in the small intestine. At the brush border maltose is broken down into two glucose molecules by the enzyme maltase, sucrose is broken down by sucrase to yield glucose and fructose, and lactose is broken down by **lactase** to form glucose and galactose. The resulting monosaccharides—glucose, galactose, and fructose—are then absorbed and transported to the liver via the hepatic portal circulation.

LACTASE *An enzyme located in the brush border of the small intestine that breaks the disaccharide lactose into glucose and galactose.*

LACTOSE INTOLERANCE *The inability to digest lactose because of a reduction in the levels of the enzyme lactase. It causes symptoms including intestinal gas and bloating after dairy products are consumed.*

LACTOSE INTOLERANCE

Lactose intolerance is a condition in which there is not enough of the enzyme lactase in the small intestine to digest the milk sugar lactose. When this occurs the undigested lactose passes into the large intestine, where it draws in water and is

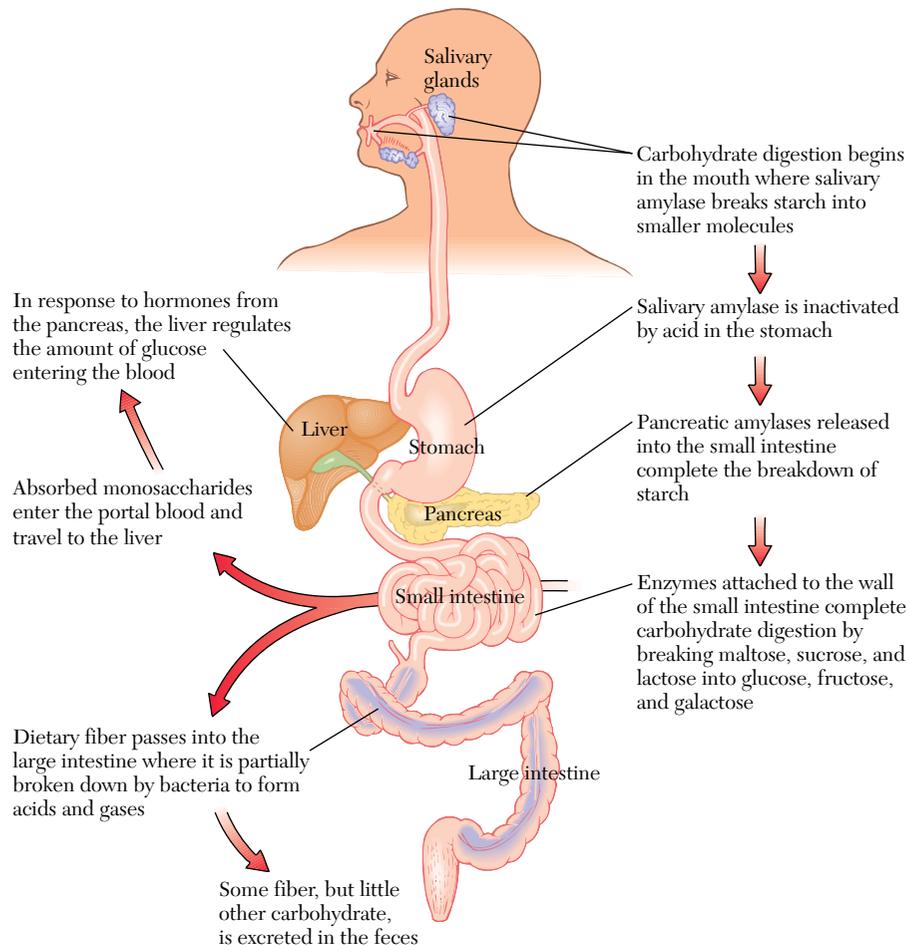


FIGURE 4.12 An overview of carbohydrate digestion and absorption.

metabolized by bacteria producing acids and gas. This causes symptoms that include abdominal distention, flatulence, cramping, and diarrhea. Human infants normally produce enough of the enzyme lactase to digest the lactose in their all-milk diet. Enzyme activity may begin to decrease at 2 years of age but the symptoms of lactose intolerance usually do not become apparent until after the age of 6 years and may not be evident until adulthood. Whether or not an individual retains the ability to digest lactose into adulthood or not depends on the genes they inherit.⁶ Lactose intolerance may also occur as a result of an intestinal infection or other disease. It is then referred to as secondary lactose intolerance and may disappear when the other condition is resolved.

INCIDENCE OF LACTOSE INTOLERANCE In the United States, it is estimated that 30 to 50 million adults cannot fully digest lactose. The incidence varies enormously depending on ethnic background. Lactose intolerance is more common in Asian, African, Native American, and Mediterranean populations than it is among northern and western Europeans. Nearly 100% of adults in Asian populations are lactose intolerant as opposed to just 5% or less of adults in northwestern European populations.⁷ In the U.S. 90% of Asian Americans, 75% of African Americans, and about 15% of Caucasian Americans experience symptoms after consuming lactose.⁸

MEETING CALCIUM NEEDS In the United States, milk is the most important source of calcium. The Dietary Guidelines recommend 3 cups of low-fat milk or milk products each day.⁹ Because the degree of lactose intolerance varies, some individuals can consume small amounts of dairy products without symptoms and can meet their calcium needs by dividing the 3 cups into many smaller portions. Those who cannot tolerate any lactose can meet their calcium needs with foods like tofu, fish, and vegetables. These foods provide dietary calcium in cultures where lactose



FIGURE 4.13 *These foods are good sources of calcium and are also low in lactose. (Andy Washnik)*



intolerance is common. For example, in Asia, tofu and fish consumed with bones supply calcium, and in the Near East, cheese and yogurt provide much of the calcium. These fermented products are more easily tolerated than milk because some of the lactose originally present is digested by bacteria or lost in processing. Calcium-fortified foods, calcium supplements, milk treated with the enzyme lactase, and lactase tablets, which can be consumed with or before milk products, are also available for those with lactose intolerance (Figure 4.13).



For more information about lactose intolerance, go to the National Institute of Diabetes & Digestive & Kidney Diseases at digestive.niddk.nih.gov/ddiseases/pubs/lactoseintolerance/

INDIGESTIBLE CARBOHYDRATES

Carbohydrates that are not digested in the small intestine include fiber, some oligosaccharides, and **resistant starch**. Fiber and oligosaccharides are not digested because human enzymes cannot break the bonds that hold their subunits together. Resistant starch is not digested because the natural structure of the grain protects it or because cooking and processing alter its digestibility. For instance, heating makes potato starch more digestible but cooling the cooked potato reduces its digestibility. Foods high in resistant starch include legumes, unripe bananas, and cold cooked potatoes, rice, and pasta. The presence of indigestible carbohydrates in the diet affects GI motility, the type of intestinal microflora, nutrient absorption, and the amount of intestinal gas.

INDIGESTIBLE CARBOHYDRATES STIMULATE GI MOTILITY Indigestible carbohydrates affect GI motility because they increase the volume of material in the lumen of the large intestine. Insoluble fibers, such as wheat bran, increase the bulk of material in the feces. Soluble fibers and resistant starch draw water into the intestine. The combination of the increased bulk and additional water allow for easier evacuation of the stool. Indigestible carbohydrates also promote healthy bowel function because the extra bulk stimulates peristalsis, causing the muscles of the colon to work more, become stronger, and function better. The increase in peristalsis reduces transit time—the time it takes food and fecal matter to move through the digestive tract. In African countries, where the diet contains 40 to 150 grams of fiber per day, the transit time is 36 hours or less. In the United States, where the usual fiber intake is only about 15 grams per day,¹⁰ it is not uncommon for transit time to be as long as 96 hours (see Science Applied: Cereal Fibers and Health).

INDIGESTIBLE CARBOHYDRATES PROMOTE A HEALTHY MICROFLORA When soluble fibers, resistant starch, and oligosaccharides reach the colon they serve as a food source for the microflora that reside there. Diets high in these substances promote the maintenance of beneficial species of bacteria in the colon. When these carbohydrates are broken down it results in the production of short-chain fatty acids and the acidification of the colonic contents. The short-chain fatty acids serve as a fuel source for cells in the colon as well as other body tissues and may play a role in regulating cellular processes. The acid inhibits the growth of undesirable bacteria and favors the growth of *Lactobacilli* and *Bifidobacteria*, which are well

RESISTANT STARCH *Starch that escapes digestion in the small intestine of healthy people.*



SCIENCE APPLIED

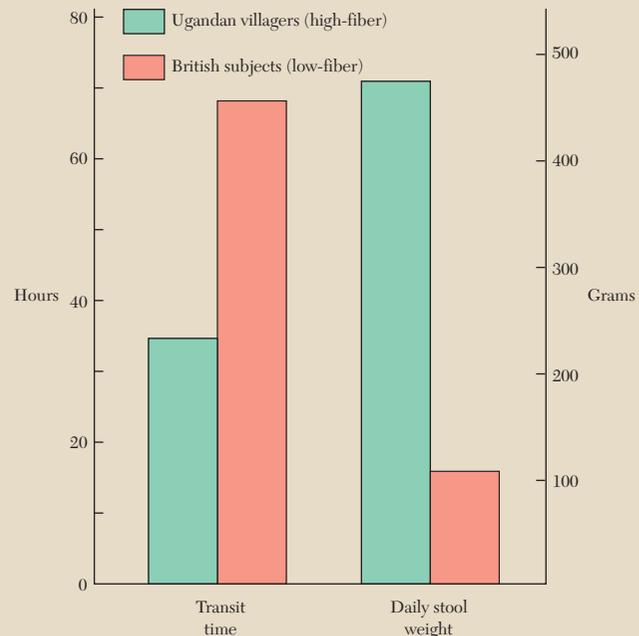
CEREAL FIBERS AND HEALTH

One hundred and fifty years ago, self-proclaimed health advocates Sylvester Graham, John Harvey Kellogg, and Charles W. Post promoted cereal foods as health tonics. These pioneers of what are now the breakfast cereal empires, Kellogg's and Post, were not scientists. Often the health information they promoted was outlandish. Graham preached that food should never be eaten hot, that water should not be consumed with a meal, and that lewdness, along with chicken pie, was the cause of cholera. Kellogg told his patients that coffee could cripple the liver and that bouillon was a solution of poisons. And Post advertised that his cereal, called Grape Nuts, tightened up loose teeth and cured tuberculosis and malaria.¹ While these ideas have not held up over time, the suggestion that whole grains are healthy is part of current nutrition wisdom. The Dietary Guidelines and MyPyramid promote a diet that is based on cereals and other whole grains. This dietary pattern has been shown to promote gastrointestinal health and reduce the risks of the major chronic diseases of today—heart disease, cancer, and diabetes.

Scientific support for the role of cereal grain consumption in health started to accumulate in the 1940s, 1950s, and 1960s when scientists such as Denis Burkitt, Hugh Trowell, and A. R. P. Walker began observing and investigating the effects of high-fiber foods on health. Their hypotheses, which were based primarily on epidemiologic observations, helped change the way we think about fiber. At the time they began their studies fiber was poorly defined, there was no consistent methodology to assess the amount of fiber in foods, and food composition tables did not include fiber values. Fiber was referred to as roughage and many regarded it as a gastrointestinal irritant rather than a dietary component important for health.

Walker and colleagues began to relate the dietary pattern of South African blacks with their disease pattern—emphasizing the role of fiber.² They observed that in Western populations, where fiber intake was between 15 and 30 grams per day, feces were smaller and harder than in African individuals consuming diets containing from 70 to more than 100 grams of fiber per day. They hypothesized that fiber increased stool weight and decreased transit time. This hypothesis was supported by studies that compared intestinal transit time and stool weight in Ugandan villagers, who ate a high-fiber diet to British subjects, who ate a lower-fiber diet (see figure). To further test this hypothesis, they added unprocessed bran to the diet of British subjects. The added fiber reduced transit time and increased stool weight.³

In 1956, Denis Burkitt saw a patient in Uganda with a rare cancer involving his jaws (Burkitt's lymphoma). As he traveled in Africa to establish the geographic distribution of this type of cancer, he noticed that many diseases that were common among whites in Europe and Africa were rare among black African peasants. With these observations in mind, Burkitt studied a hypothesis that proposed that a variety of conditions common in industrial-



Ugandan villagers, who consume an unrefined diet high in fiber, have greater stool weights and shorter transit times than British citizens who consume a more refined, lower-fiber diet.

(Source: Adapted from Burkitt, D. P., Walker, A. R. P., and Painter, N. S. Dietary fiber and disease. *JAMA* 229:1068–1074, 1974.)

ized society, including diabetes, obesity, heart disease, constipation, diverticular disease, hemorrhoids, and varicose veins, were caused by the overconsumption of refined carbohydrates. The hypothesis postulated that three manufactured foods—refined sugar, white flour, and white rice—caused virtually all the diseases of civilization.² In response to his observations, Burkitt proposed that low fiber intake rather than high refined-carbohydrate consumption was the dietary connection. He suggested that the dietary fiber that had been removed during refinement created a deficiency of this substance that may underlie the development of these characteristically Western diseases.^{3,4} This became known as the fiber hypothesis. Burkitt was often quoted as saying that the health of a country's people could be determined by the size of their stools and whether the stools floated or sank.⁵

The fiber hypothesis of Burkitt and others launched an era of fiber research in the United States and elsewhere. Their observations have been the stimulus for much of today's research on fiber and its importance in maintaining normal gastrointestinal function and reducing the incidence of chronic disease. Today the whole-grain cereals promoted by Graham, Kellogg, and Post over a century ago are still considered a sort of health tonic, but this time scientific data is available to support the benefits of the fiber as well as other nutrients and dietary components found in whole grains.

¹Deutsch, R. M. *The New Nuts Among the Berries*. Palo Alto, CA: Bull Publishing Company, 1977.

²Trowell, H. Dietary fibre: A paradigm. In: Trowell, H., Burkitt, D., and Heaton, K., eds. *Dietary Fibre, Fibre-Depleted Foods and Disease*. London: Academic Press, 1985, 1–20.

³Burkitt, D. P., Walker, A. R. P., and Painter, N. S. Dietary fiber and disease. *JAMA* 229:1068–1074, 1974.

⁴Burkitt, D. P., and Trowell, H. C. *Refined Carbohydrate and Disease: Some Implications of Dietary Fibre*. London: Academic Press, 1975.

⁵Story, J. A., and Kritchevsky, D. Denis Parsons Burkitt. *J. Nutr.* 124:1551–1554, 1994.



adapted to acid condition.¹¹ In addition to inhibiting the growth of disease-causing bacteria these short-chain fatty acids may help prevent and treat inflammation in the bowel, which causes diarrhea, as well as protect against colon cancer.^{12,13} (See Chapter 3, Off the Shelf: Should Your Feed Your Flora?)

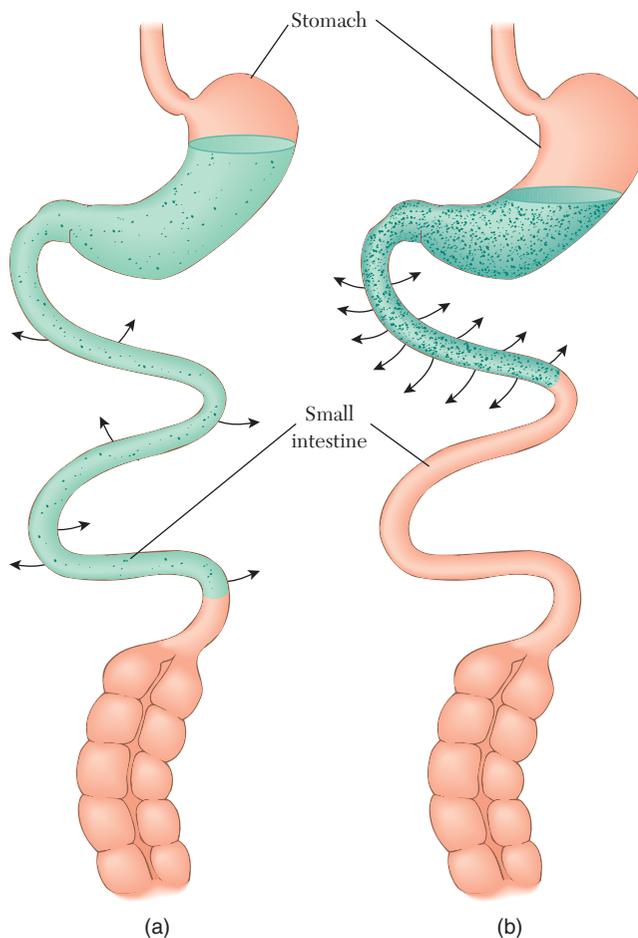
INDIGESTIBLE CARBOHYDRATES SLOW NUTRIENT ABSORPTION Indigestible carbohydrates increase the volume of the intestinal contents and absorb water, forming viscous solutions. These effects reduce nutrient absorption by slowing passage through the GI tract, by decreasing the amount of contact between nutrients and the absorptive surface of the small intestine, and by reducing contact between digestive enzymes and food. In the stomach, fiber causes distention and slows emptying. In the small intestine, the added volume and viscosity slows the absorption of sugars and other nutrients (Figure 4.14). This can be beneficial because it slows the absorption of glucose and thereby reduces fluctuations in blood glucose. Soluble fiber also binds cholesterol and bile, which is made from cholesterol, reducing their absorption. This is beneficial because it can lower blood cholesterol and help reduce the risk of heart disease.

Fiber also binds certain minerals, preventing their absorption. For instance, wheat bran fiber binds the minerals zinc, calcium, magnesium, and iron. Too much fiber can reduce the absorption of these essential minerals. However, when mineral intake meets recommendations, a reasonable intake of high-fiber foods does not compromise mineral status.

A high-fiber diet also increases the volume of food needed to meet energy requirements. This is beneficial for someone who is trying to lose weight because they feel satiated after fewer kcalories are consumed. A high-fiber diet may be a disadvantage for someone with a small stomach capacity because they may satisfy their



FIGURE 4.14 (a) This representation of the stomach and small intestine illustrates how a fiber-rich diet dilutes the intestinal contents and slows the digestion and absorption of nutrients (shown as green dots). (b) When a low-fiber diet is consumed, nutrients are more concentrated and digestion and absorption occur more rapidly.





hunger before their nutrient requirements are met. Generally, this is a problem only when the diet is low in protein or micronutrients or when high-fiber diets are consumed by young children, whose small stomachs limit the amount of food they can eat.

INDIGESTIBLE CARBOHYDRATES INCREASE INTESTINAL GAS Anyone who has ever eaten beans knows of their potentially embarrassing side effect of flatulence. The reason beans cause gas is that they are particularly high in the oligosaccharides raffinose and stachyose, which cannot be digested by enzymes in the human stomach and small intestine. They pass into the large intestine where the bacteria that live there digest them, producing gas and other by-products. This gas can cause abdominal discomfort and flatulence. To alleviate the problem, over-the-counter enzyme tablets and solutions (such as Bean-O) can be consumed to break down oligosaccharides before they reach the intestinal bacteria, thereby reducing the amount of gas produced.

As with oligosaccharides, intestinal gas is a by-product of the bacterial breakdown of fiber and resistant starch. A sudden increase in the fiber content of the diet can cause abdominal discomfort, gas, and diarrhea. Constipation can also be a problem if fiber intake is increased without an increase in fluid intake. To avoid these problems, the fiber content of the diet should be increased gradually and fluid intake should also be increased.

Most of us pass about 600 mL of gas each day. Some of this comes from swallowed air and from gasses that diffuse into the intestines from the bloodstream, but most is from gas produced in our intestines by bacteria.

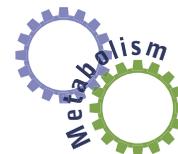
CARBOHYDRATES IN THE BODY

Carbohydrates are central to energy production in the body and also provide other essential functions. The monosaccharide galactose is an important molecule in nervous tissue. It also combines with glucose to make lactose in women who are producing breast milk. Two other monosaccharides that are of great importance to the body are deoxyribose and ribose. These sugars are components of DNA and RNA (ribonucleic acid), respectively, which contain the genetic information for the synthesis of proteins. Deoxyribose and ribose can be synthesized by the body and are not found in significant amounts in the diet. Ribose is also a component of the vitamin riboflavin. Oligosaccharides are also important in our bodies. They are found attached to proteins or lipids on the surface of cells where they help to signal information about the cells. Another type of carbohydrate that is important in the body is mucopolysaccharides. They are a type of polysaccharide that functions with proteins in body secretions and structures. Mucopolysaccharides give mucus its viscous consistency and provide cushioning and lubrication in connective tissue.

USING CARBOHYDRATE TO PRODUCE ENERGY

After absorption, monosaccharides travel to the liver. The monosaccharides fructose and galactose are metabolized for energy. Glucose may also be broken down to produce energy, or passed into the bloodstream for delivery to other body tissues that can use it to produce energy. It may also be stored in the liver as glycogen and, to a lesser extent, used to synthesize fat.

To generate energy, glucose is metabolized through **cellular respiration**. Cellular respiration, also called aerobic metabolism, produces energy in the form of ATP. This metabolic pathway uses 6 molecules of oxygen to convert 1 molecule of glucose into 6 molecules of carbon dioxide, 6 molecules of water, and about 38 molecules of ATP:



CELLULAR RESPIRATION *The reactions that break down carbohydrates, fats, and proteins in the presence of oxygen to produce carbon dioxide, water, and ATP.*



GLYCOLYSIS *Metabolic reactions in the cytoplasm of the cell that split glucose into two 3-carbon pyruvate molecules. The energy released from one molecule of glucose is used to make two ATP molecules.*

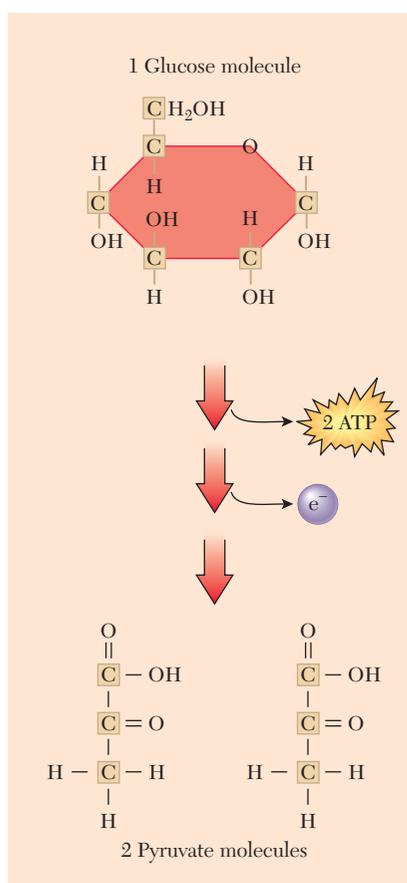
The carbon dioxide produced by cellular respiration is transported to the lungs where it is eliminated in exhaled air. Providing energy through cellular respiration involves four interconnected stages (see Appendix L).

GLYCOLYSIS The first stage of cellular respiration takes place in the cytoplasm of the cell and is called **glycolysis**, meaning glucose breakdown. In glycolysis, the 6-carbon sugar glucose is broken into two 3-carbon molecules called pyruvate (Figure 4.15, Figure 4.16 step 1). The reactions generate two molecules of ATP for each molecule of glucose and release high-energy electrons that are passed to shuttling molecules for transport to the last stage of cellular respiration (Figure 4.16 step 2).

ACETYL-CoA FORMATION In the second stage, which occurs in the mitochondria, one carbon is removed from pyruvate and released as CO_2 . The remaining 2-carbon compound combines with a molecule of coenzyme A (CoA) to form acetyl-CoA (Figure 4.16 step 3). High-energy electrons are released and again passed to shuttling molecules for transport to the last stage of cellular respiration. Acetyl-CoA then enters the third stage of breakdown, the citric acid cycle.

CITRIC ACID CYCLE In the third stage, acetyl-CoA combines with oxaloacetate, a 4-carbon molecule derived from carbohydrate, to form a 6-carbon molecule called citric acid and begin the citric acid cycle (Figure 4.16 step 4). The reactions of the citric acid cycle then remove one carbon at a time, to produce carbon dioxide (Figure 4.16 step 5). After two carbons have been removed in this manner, a 4-carbon oxaloacetate molecule is re-formed and the cycle can begin again. These chemical reactions produce two ATP molecules per glucose molecule and also remove electrons, which are passed to shuttling molecules for transport to the fourth and last stage of cellular respiration, the electron transport chain.

FIGURE 4.15 During glycolysis, shown here, each molecule of glucose is broken into two molecules of pyruvate. Electrons are released and two ATP molecules are produced. These reactions occur in the cytoplasm of the cell and can proceed in the absence of oxygen.



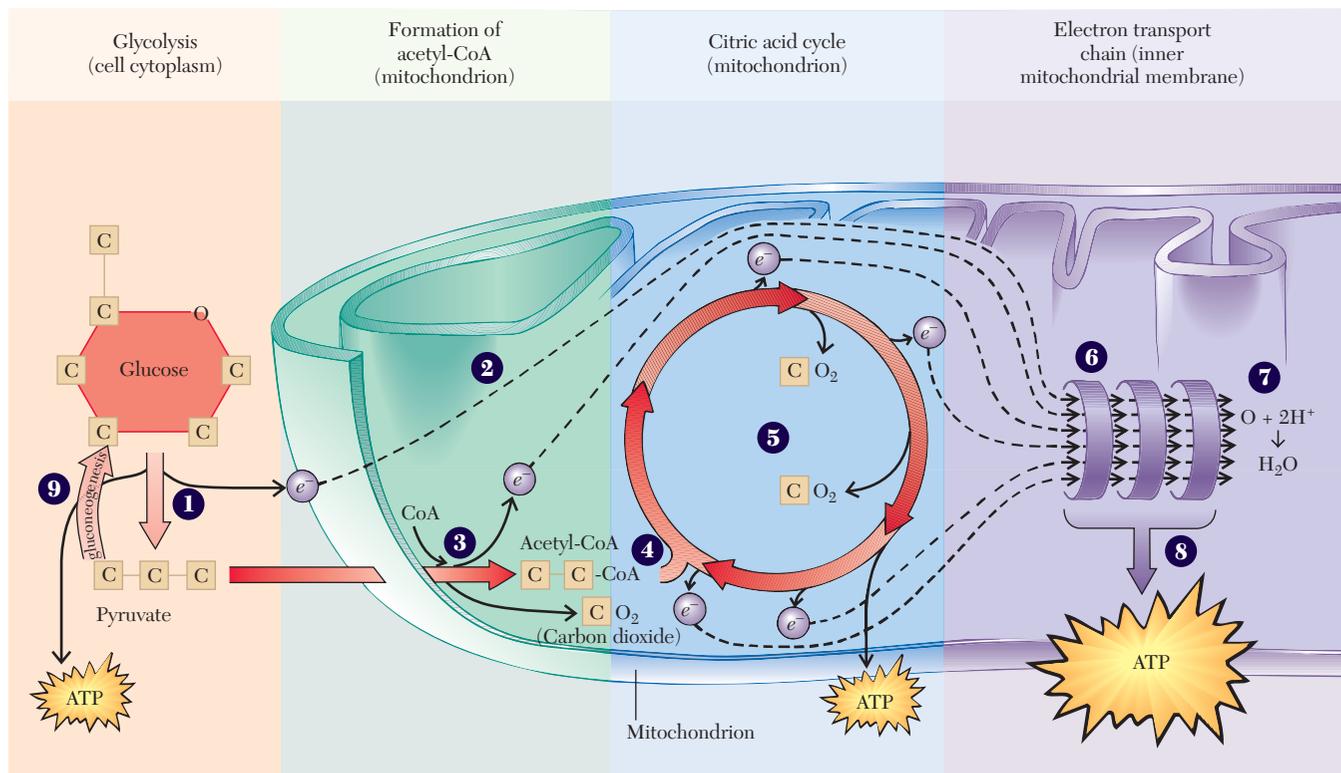
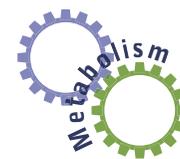


FIGURE 4.16 An overview of glucose metabolism. In the cytoplasm, glycolysis breaks glucose into two 3-carbon pyruvate molecules (step 1). A small amount of ATP is produced and electrons are released (step 2). In the mitochondria pyruvate loses a carbon as carbon dioxide and combines with coenzyme A to form acetyl-CoA (step 3). Acetyl-CoA enters the citric acid cycle (step 4) where two more carbons are lost as carbon dioxide (step 5). High-energy electrons released during each of these stages are transferred to the electron transport chain (step 6). The electrons ultimately combine with oxygen to form water (step 7) and their energy is trapped to produce ATP (step 8). When needed 3-carbon molecules can be used to make glucose by gluconeogenesis (step 9).

ELECTRON TRANSPORT CHAIN The electron transport chain consists of a series of molecules, most of which are proteins, associated with the inner membrane of the mitochondria. These molecules accept electrons from the shuttling molecules and pass them from one to another down the chain (Figure 4.16 step 6) until they are finally combined with oxygen to form water (Figure 4.16 step 7). As the electrons are passed along, their energy is trapped and used to make ATP (Figure 4.16 step 8). The reactions of cellular respiration are central to all energy-producing processes in the body.

MAKING GLUCOSE FROM PROTEIN

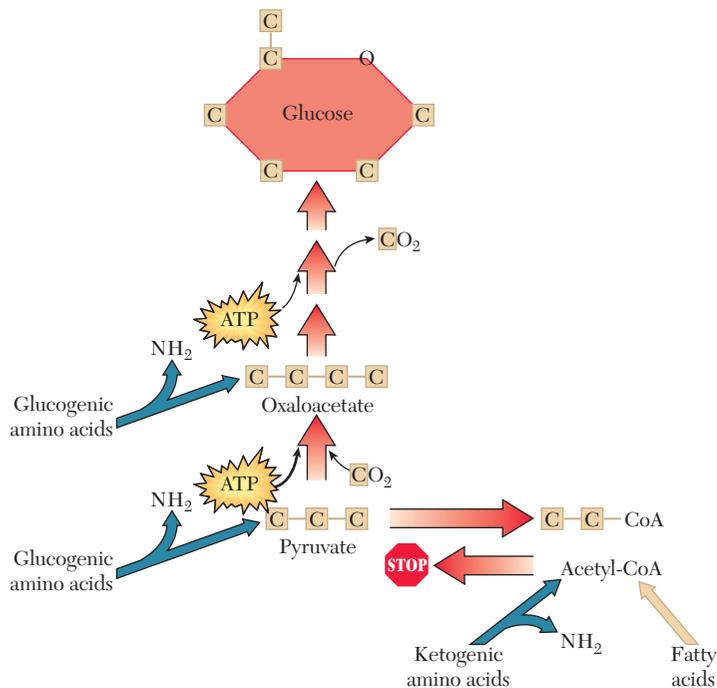
When carbohydrate intake is low, some glucose can be obtained from the breakdown of glycogen. This glucose is released into the blood to prevent blood glucose from dropping below the normal range. Glucose is also supplied by a metabolic pathway called **gluconeogenesis** (production of new glucose). Gluconeogenesis, which occurs in liver and kidney cells, is an energy-requiring process that forms glucose from 3-carbon molecules. These 3-carbon molecules come primarily from proteins that are broken down into amino acids. Some amino acids, referred to as glucogenic amino acids, can form pyruvate and oxaloacetate. These can then be used to make glucose (Figure 4.17, Figure 4.16 step 9). Fatty acids and ketogenic amino acids cannot be used to make glucose because the reactions that break them down produce primarily 2-carbon molecules that form acetyl-CoA. Gluconeogenesis is essential for meeting the body's immediate need for glucose, particularly when carbohydrate intake is very low, but it uses amino acids from proteins that could be used for other essential functions such as growth and maintenance of muscle tissue.



GLUCONEOGENESIS The synthesis of glucose from simple noncarbohydrate molecules. Amino acids from protein are the primary source of carbons for glucose synthesis.



FIGURE 4.17 Gluconeogenesis, shown here, uses 3-carbon molecules and energy from ATP to synthesize glucose. Glucogenic amino acids are those that are broken down to yield 3-carbon molecules or other intermediates that can be used by gluconeogenesis to form glucose. Ketogenic amino acids and fatty acids break down into 2-carbon molecules that form acetyl-CoA, which cannot be used to make glucose because it cannot be converted to pyruvate.



Since adequate dietary carbohydrate eliminates the need to use amino acids from protein to synthesize glucose, carbohydrate is said to spare protein.



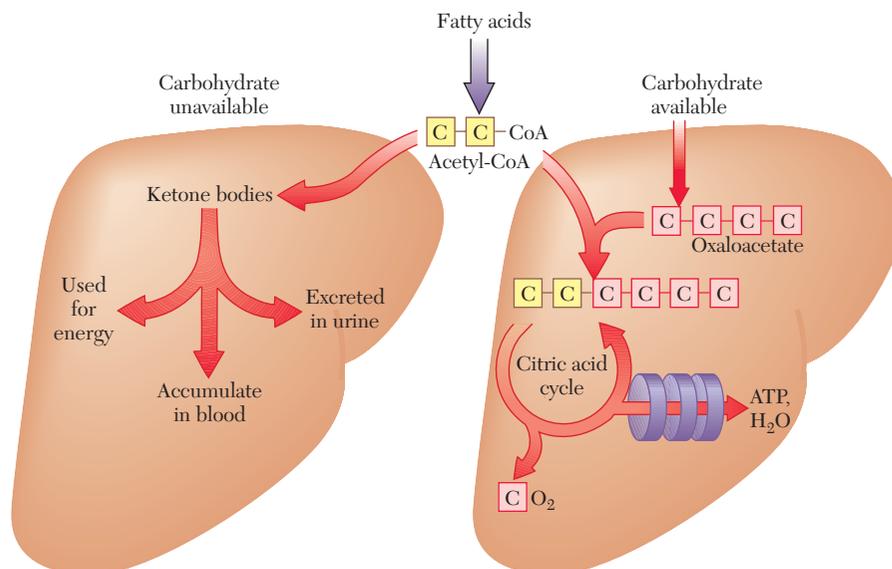
KETONES OR KETONE BODIES

Molecules formed in the liver when there is not sufficient carbohydrate to completely metabolize the 2-carbon units produced from fat breakdown.

BREAKING DOWN FAT

Carbohydrate is also needed for the metabolism of fat, so when the supply of carbohydrate is limited, fat cannot be completely broken down. This is because fatty acids are broken into molecules of acetyl-CoA. Acetyl-CoA can be used to produce energy via the citric acid cycle only if it can combine with a 4-carbon oxaloacetate molecule derived from carbohydrate metabolism. When carbohydrate is in short supply, oxaloacetate is limited and acetyl-CoA cannot be metabolized to carbon dioxide and water. Instead, the liver converts it into compounds known as **ketones** or **ketone bodies**, which are released into the blood (Figure 4.18). Ketones can be used as an energy source by tissues, such as those in the heart, muscle, and kidney.

FIGURE 4.18 The availability of carbohydrate determines how fatty acids are metabolized by the liver. If carbohydrate is available, acetyl-CoA can combine with oxaloacetate and enter the citric acid cycle as is shown on the right side of this figure. If carbohydrate is in short supply (as shown on the left), oxaloacetate will be limited. Acetyl-CoA from fatty acid breakdown will therefore not be able to enter the citric acid cycle. Instead, the liver uses it to make ketone bodies.





Ketone production is a normal response to starvation or to a diet very low in carbohydrate. Even the brain, which requires glucose, can adapt to obtain a portion of its energy from ketones.

Excess ketones are excreted by the kidney in urine. However, if fluid intake is too low to produce enough urine to excrete ketones, or if ketone production is high, ketones can build up in the blood, causing ketosis. Mild ketosis, which may arise during moderate energy restriction, such as might occur with a weight-loss diet, causes symptoms including headache, dry mouth, foul-smelling breath, and a reduction in appetite. High ketone levels, such as might occur with untreated diabetes (discussed later in the chapter), increase the acidity of the blood and can result in coma and death.

REGULATING BLOOD GLUCOSE

In order to provide a steady supply of glucose to cells, the concentration of glucose in the blood is regulated by the liver and by hormones secreted from the pancreas. Normally, fasting blood glucose, measured after an 8- to 12-hour overnight fast, is maintained at about 60 to 100 mg per 100 mL of blood, or 70 to 110 mg per 100 mL of **plasma**. Maintaining this level ensures adequate glucose will be available to body cells. A steady supply of glucose is particularly important for nerve cells, including those in the brain, and red blood cells because these cells rely almost exclusively on glucose as an energy source.

GLYCEMIC RESPONSE The carbohydrate consumed in food is digested and absorbed and enters the bloodstream causing blood glucose to rise. How quickly and how high blood glucose rises after carbohydrate is consumed is referred to as **glycemic response**. It is affected by both the amount and type of carbohydrate eaten and the amount of fat and protein in that food or meal. Because carbohydrate must be digested and absorbed to enter the blood, how quickly a food leaves the stomach and how fast it is digested and absorbed in the small intestine all affect how long it takes glucose to get into the blood. Refined sugars and starches generally cause a greater glycemic response than unrefined carbohydrates containing fiber because sugars and starches consumed alone leave the stomach quickly and are rapidly digested and absorbed causing a sharp, swift rise in blood sugar. For example, when you drink a can of soda or a glass of juice on an empty stomach, your blood sugar increases within minutes. Fiber slows stomach emptying and intestinal absorption so whole grains and other unrefined carbohydrates, which contain fiber along with sugars and starches, cause a slower, lower increase in blood sugar (Figure 4.19). The presence of fat and protein also slow stomach emptying and, therefore, foods high in these macronutrients generally cause less of a glycemic response than foods containing sugar or starch alone. For example, ice cream is high in sugar, but also contains fat and some protein so it causes less of a rise in blood glucose than sorbet, which contains sugar, but no fat or protein.

The glycemic response of a specific food can be quantified by its **glycemic index**. Glycemic index is a ranking of how a food affects blood glucose compared to the response of an equivalent amount of carbohydrate from a reference food such as white bread or pure glucose (see Appendix I for a table of glycemic indexes). The

PLASMA The liquid portion of the blood that remains when the blood cells are removed.

GLYCEMIC RESPONSE The rate, magnitude, and duration of the rise in blood glucose that occurs after a particular food or meal is consumed.

GLYCEMIC INDEX A ranking of the effect on blood glucose of a food of a certain carbohydrate content relative to an equal amount of carbohydrate from a reference food such as white bread or glucose.

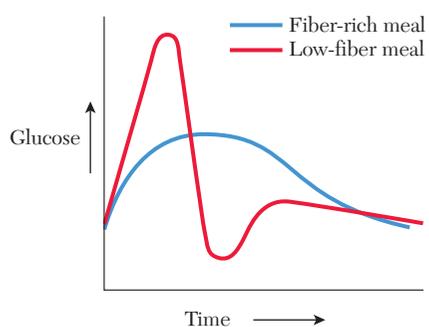


FIGURE 4.19 The fiber content of food affects the rise in blood glucose that occurs after a meal. After a high-carbohydrate, low-fiber meal, blood glucose rises rapidly. Consuming a fiber-rich meal delays and blunts the rise in blood glucose.



GLYCEMIC LOAD An index of the glycemic response that occurs after eating specific foods. It is calculated by multiplying a food's glycemic index by the amount of available carbohydrate in a serving of the food.

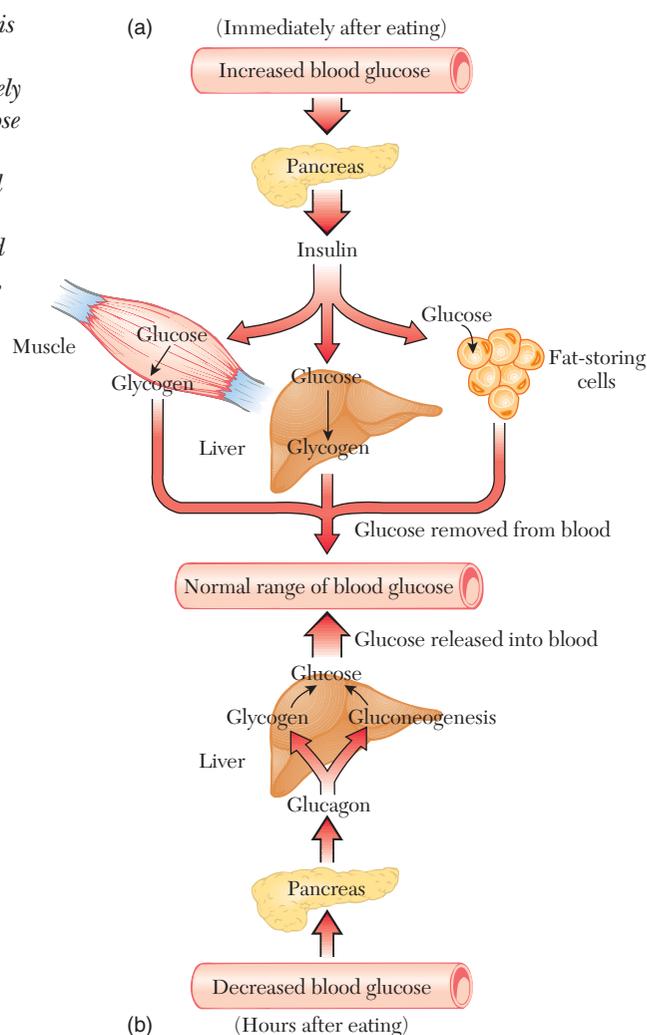
Many low-carbohydrate diets restrict fruit intake because fruit is high in carbs, but the glycemic load of these healthy foods is actually quite low—6 for an apple and 4 for an orange.¹⁴

INSULIN A hormone made in the pancreas that allows the uptake of glucose by body cells and has other metabolic effects such as stimulating protein and fat synthesis and the synthesis of glycogen in liver and muscle.

reference food is assigned a value of 100 and the values for food samples are expressed relative to this. Foods that have a glycemic index of 70 or more compared to glucose are considered high glycemic index foods; those with an index of less than 55 are considered low glycemic index foods. Although glycemic index can be used to evaluate the effect of a specific food on blood glucose, it is not based on amounts of carbohydrate in a typical portion of food. For example, watermelon has a high glycemic index, but this is based on a larger piece of watermelon than is typically consumed. The actual rise in blood glucose from having a slice of watermelon is not large. **Glycemic load** is a newer method of assessing glycemic response that takes into account both the glycemic index of the food and the amount of carbohydrate in a typical portion. To calculate glycemic load, the grams of carbohydrate in a serving of food are multiplied by that food's glycemic index expressed as a percent. A glycemic load of 20 or more is considered high, whereas a value of less than 11 is considered low. A shortcoming of both glycemic index and glycemic load is that they are determined for individual foods, but we typically eat meals containing mixtures of foods. Knowing the glycemic index or glycemic load of a specific food does not tell us much about what blood glucose levels will be after eating this food as part of a mixed meal. For example, a slice of white bread has a high glycemic index and glycemic load, but if the bread is part of a peanut butter sandwich, the rise in blood glucose is much less.

INSULIN A rise in blood glucose triggers the pancreas to secrete the hormone **insulin**, which allows glucose to be taken into the cells of the body (Figure 4.20). In the liver, insulin promotes the storage of glucose as glycogen and, to a lesser ex-

FIGURE 4.20 Blood glucose is regulated by hormones secreted by the pancreas. (a) Immediately after a meal, when blood glucose increases, insulin is released and stimulates the uptake and storage of glucose. (b) Several hours after a meal, when blood glucose levels begin to decrease, glucagon is released and stimulates the breakdown of glycogen into glucose and glucose production by gluconeogenesis.





tent, fat. In muscle, insulin stimulates the uptake of glucose for energy production and the synthesis of muscle glycogen for energy storage. Insulin also stimulates protein synthesis and, in fat-storing cells, it increases glucose uptake from the blood and stimulates lipid synthesis. These actions remove glucose from the blood, decreasing levels.

GLUCAGON When no carbohydrate has been consumed for a few hours, the glucose level in the blood—and consequently the glucose available to the cells—begins to decrease. This triggers the pancreas to secrete the hormone **glucagon** (see Figure 4.20). Glucagon signals liver cells to break down glycogen into glucose, which is released into the bloodstream. Glucagon also stimulates the liver to synthesize new glucose molecules by gluconeogenesis. Newly synthesized glucose is released into the blood to prevent blood glucose from dropping below the normal range. Gluconeogenesis can also be stimulated by the hormone epinephrine, also known as adrenaline. This hormone, which is released in response to dangerous or stressful situations, enables the body to respond to emergencies. It causes a rapid release of glucose into the blood to supply the energy needed for action.

GLUCAGON *A hormone made in the pancreas that stimulates the breakdown of liver glycogen and the synthesis of glucose to increase blood sugar.*

ABNORMAL BLOOD GLUCOSE REGULATION

Blood glucose levels are normally tightly controlled by insulin, glucagon, and other hormones. If these hormones are not produced normally or if the body does not respond to them normally, blood glucose levels can rise too high or drop too low. **Diabetes mellitus** is a disease in which blood glucose levels are consistently above the normal range and **hypoglycemia** is a condition in which blood glucose levels drop below the normal range.

DIABETES MELLITUS

Diabetes mellitus, commonly called diabetes, is a major public health problem in the United States. Over 18 million Americans have diabetes. This disease and its complications account for about \$132 billion in direct medical costs and indirect costs due to disability, lost work, and premature death.¹⁵ Diabetes is characterized by high blood glucose levels due to either a lack of insulin or an unresponsiveness of body cells to insulin (Figure 4.21). The elevated glucose causes damage to the large blood vessels, leading to an increased risk of heart disease and stroke. It also causes changes in small blood vessels and nerves. In the United States diabetes is the leading cause of blindness in adults and accounts for 44% of all new cases of kidney failure and over 60% of nontraumatic lower-limb amputations.¹⁵ There are three main types of diabetes: type 1, type 2, and gestational diabetes, which occurs during pregnancy.

TYPE 1 DIABETES **Type 1 diabetes** is an autoimmune disease in which the body's own immune system destroys the insulin-secreting cells of the pancreas. Once these cells are destroyed, insulin is no longer made in the body. Type 1 diabetes is usually diagnosed before the age of 30 and accounts for only 5% to 10% of diagnosed cases of diabetes.¹⁵ It is not known what causes the immune system to malfunction and attack its own cells but genetics, viral infections, exposure to toxins, and abnormalities in the immune system have been hypothesized to play a role.

TYPE 2 DIABETES **Type 2 diabetes** is the more common form of diabetes. It accounts for about 95% of all cases of diabetes in the United States. It is often the result of a decrease in the sensitivity of cells to insulin; insulin is present, but the cells don't respond to it normally. As a result, only limited amounts of glucose can enter the cells and blood levels of glucose rise. Large amounts of insulin are therefore required to allow cells to take up enough glucose to meet their energy

DIABETES MELLITUS *A disease caused by either insufficient insulin production or decreased sensitivity of cells to insulin. It results in elevated blood glucose levels.*

HYPOLYCEMIA *A low blood glucose level, usually below 40 to 50 mg of glucose per 100 mL of blood.*

TYPE 1 DIABETES *A form of diabetes that is caused by the autoimmune destruction of insulin-producing cells in the pancreas, usually leading to absolute insulin deficiency; previously known as insulin-dependent diabetes mellitus or juvenile-onset diabetes.*

TYPE 2 DIABETES *A form of diabetes that is characterized by insulin resistance and relative (rather than absolute) insulin deficiency; previously known as noninsulin-dependent diabetes mellitus or adult-onset diabetes.*

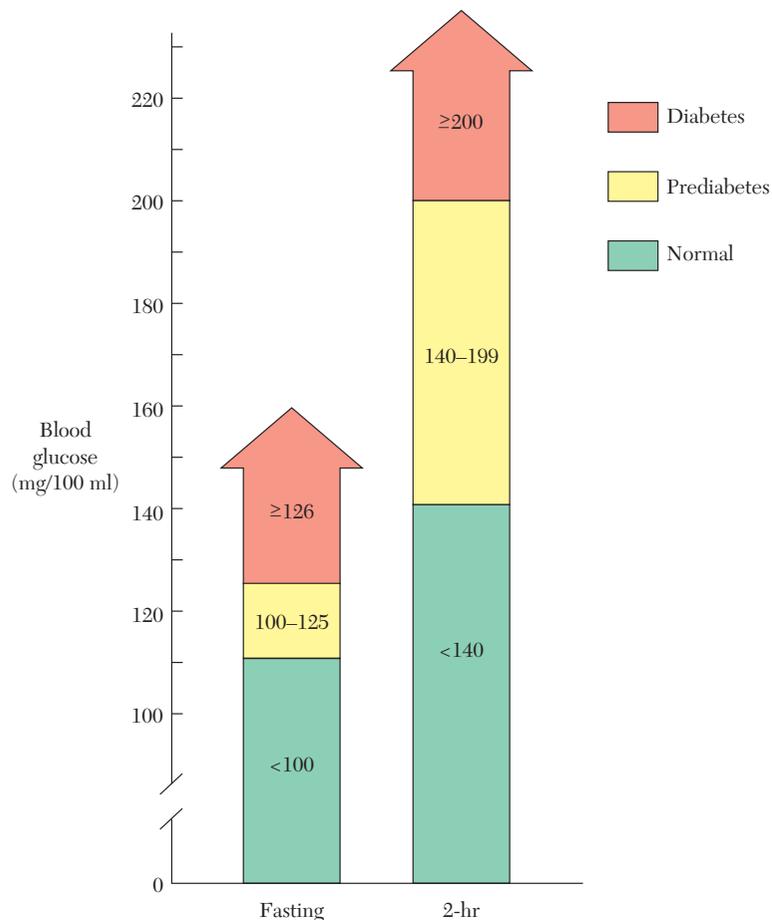


FIGURE 4.21 Blood glucose levels are used to diagnose diabetes. After an 8-hour fast, normal blood glucose is less than 100 mg/100 mL. Pre-diabetes is defined as a fasting blood glucose between 100 and 125 mg/100 mL, and diabetes is defined as a fasting blood glucose of 126 mg/100 mL or above. Blood glucose measured 2 hours after consuming 75 grams of glucose is normally less than 140 mg/100 mL. Pre-diabetes is defined as a blood glucose level between 140 and 199 mg/100 mL 2 hours after a glucose load, and diabetes is defined as a blood glucose of 200 mg/100 mL or greater 2 hours after a glucose load. (Source: American Diabetes Association.)

METABOLIC SYNDROME A

collection of health risks, including excess fat in the abdominal region, high blood pressure, elevated blood triglycerides, low high-density lipoprotein (HDL) cholesterol, and high blood glucose that increases the chance of developing heart disease, stroke, and diabetes. The condition is also known by other names including Syndrome X, insulin resistance syndrome, and dysmetabolic syndrome.

PRE-DIABETES OR IMPAIRED GLUCOSE TOLERANCE A fasting blood glucose level above the normal range but not high enough to be classified as diabetes.

The incidence of type 2 diabetes is higher among minority groups. The age-adjusted prevalence of diabetes is about 18% among Native Americans and Alaska Natives, 13% among non-Hispanic blacks, and 12% among Hispanic/Latino Americans, compared with only 8% among non-Hispanic whites.¹¹

needs. Type 2 diabetes is believed to be due to a combination of genetic and lifestyle factors. Risk of developing this disease is increased in people with a family history of diabetes and also in those who are overweight, those who carry their extra body fat in the abdominal region, and those who have a sedentary lifestyle. Type 2 diabetes may occur as part of a combination of conditions called **metabolic syndrome**, which includes obesity, elevated blood pressure, altered blood lipid levels, and insulin insensitivity.

Type 2 diabetes is often preceded by a condition called **pre-diabetes** or **impaired glucose tolerance** in which blood glucose levels are above normal but not high enough to be diagnosed as diabetes (see Figure 4.21). An estimated 41 million adults between the ages of 40 and 74 have pre-diabetes and are therefore at increased risk for developing diabetes, as well as heart disease and stroke.¹⁶ Progression to diabetes among those with pre-diabetes is not inevitable. Weight loss and increased physical activity among people with pre-diabetes can prevent or delay diabetes and may return blood glucose levels to normal.¹⁶

Type 2 diabetes has typically been diagnosed in persons over the age of 40, but its incidence is increasing among younger individuals. This change is thought to be due to the increasing incidence of obesity and overweight in younger age groups. Before 1994, less than 5% of children with newly diagnosed diabetes were classified as type 2, but recently this has increased to 30% to 50%.¹⁷



GESTATIONAL DIABETES **Gestational diabetes** is a form of diabetes that occurs in women during pregnancy. It may be caused by the hormonal changes of pregnancy. The high levels of glucose in the mother's blood increase the risk of complications for the unborn child (see Chapter 14). Gestational diabetes usually disappears once the pregnancy is complete and hormones return to nonpregnant levels. However, individuals who have had gestational diabetes have an increased risk for developing type 2 diabetes later in life.

DIABETES SYMPTOMS The symptoms of diabetes result from the fact that without sufficient insulin, glucose cannot be used normally. Cells that require insulin for glucose uptake are starved for glucose, and cells that can use glucose without insulin are exposed to damaging high levels.

Immediate Symptoms The immediate symptoms of diabetes may include excessive thirst, frequent urination, blurred vision, and weight loss. Excessive thirst and frequent urination occur because blood glucose levels rise so high that the kidneys excrete glucose, which draws fluid with it, increasing the volume of urine. Blurred vision occurs when excess glucose enters the lens of the eye, drawing in water and causing the lens to swell. Weight loss, and impaired growth in children, occur because glucose cannot enter cells to be used for energy, so the body responds as it does in starvation, breaking down fat and protein to supply fuel. With limited carbohydrate for fatty acid metabolism, ketones are formed and released into the blood. Some ketones are used as fuel by muscle and adipose tissue, but in type 1 diabetes, they are produced more rapidly than they can be used and thus accumulate in the blood. This elevation of ketones causes an increase in the acidity of the blood called *ketoacidosis*. In type 2 diabetes, ketoacidosis usually does not develop because there is enough insulin to allow some glucose to be used so fewer ketones are produced.

Long-Term Complications The long-term complications of diabetes include damage to the heart, blood vessels, kidneys, eyes, and nerves. This damage is thought to be a result of prolonged exposure to high levels of blood glucose. When glucose is high it can bind to proteins contributing to blood vessel damage and abnormalities in blood cell function. Damage to the large blood vessels leads to an increased risk of heart disease and stroke. Heart disease is a major complication and the leading cause of premature death among people with diabetes. Changes in small blood vessels and nerves lead to kidney failure, blindness, and nerve dysfunction. For example, accumulation of glucose in the eye damages small vessels in the retina, leading to blindness (Figure 4.22). High glucose levels cause kidney failure by damaging kidney cells and small blood vessels in the kidney. Exposure to high glucose also affects the function of peripheral nerves, often causing numbness and tingling in the feet. In addition to these problems, infections are more common in diabetes because high blood glucose levels favor microbial growth; infections are usually the cause of amputations of the toes, feet, and legs.



GESTATIONAL DIABETES A form of diabetes that occurs during pregnancy and resolves after the baby is born.

When blood ketone levels are high, acetone is exhaled by the lungs giving the breath a fruity smell. "Acetone breath" is one way in which diabetic ketoacidosis is detected.

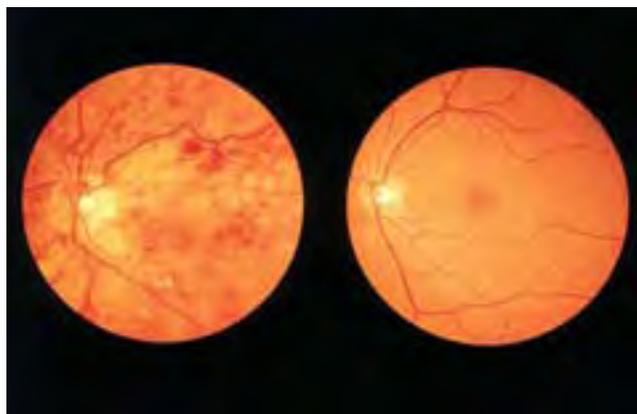


FIGURE 4.22 (left) Damaged blood vessels in the retina caused by diabetes. (right) Normal blood vessels in the retina.
(© SBHA/Stone/Getty Images)



For more information on diabetes go to the American Diabetes Association at www.diabetes.org and the National Diabetes Education Program at ndep.nih.gov/

DIABETES TREATMENT The goal of diabetes treatment is to keep blood glucose levels within the normal range. This involves diet, exercise, and, in many cases, medication. Blood glucose levels should be monitored frequently to assure that levels are staying in the healthy range. Adherence to this type of treatment regimen can reduce the incidence of elevated blood glucose levels and the complications it causes. To reduce disability and death associated with diabetes and its complications, the National Institutes of Health and the Centers for Disease Control and Prevention have established the National Diabetes Education Program. This program is designed to increase public awareness of the seriousness of diabetes, promote better management among individuals with diabetes, and improve the quality of and access to health care.¹⁶

Diet To help control blood glucose levels, carbohydrate intake should be distributed throughout the day. This can be done by using the Exchange Lists or a system of carbohydrate counting to control the amount of carbohydrate consumed at any given time.¹⁸ Recommendations consider total carbohydrate consumption—whether sucrose, fructose (which causes a smaller rise in blood glucose than sucrose), or starch. Unrefined carbohydrates, which contain fiber, cause a slower rise in glucose than refined carbohydrates. Carbohydrate intake must be coordinated with medication and exercise schedules so that glucose and insulin are available in the proper proportions at the same time to maintain normal blood glucose levels. The diet should also be adequate in energy, protein, and micronutrients. To help prevent heart disease, fat intake should be limited to no more than 30% of energy, with no more than 10% from saturated fat. Overweight individuals may need to restrict energy intake to promote weight loss, which can be beneficial for maintaining blood glucose levels in the normal range.

Exercise Exercise is an important component of diabetes management because exercise increases the sensitivity of body cells to insulin. Therefore, more glucose can enter the cells with less insulin. It also promotes weight loss, which further reduces insulin resistance. Individuals with diabetes are encouraged to maintain regular exercise patterns. A change in the amount of exercise an individual participates in may change the amount of food and medication required to keep blood glucose in the normal range.

Medication When diet and exercise cannot keep blood glucose in the normal range, drug treatments are needed. In type 1 diabetes, insulin production is absent, so insulin must be injected. Insulin cannot be taken orally because it is a protein that would be broken down in the GI tract, losing its ability to function. Type 2 diabetes can often be treated with medications that increase pancreatic insulin production, decrease glucose production by the liver, enhance insulin action, or slow carbohydrate digestion to keep blood glucose in the normal range. In some cases of type 2 diabetes, injected insulin is needed to achieve normal blood glucose levels.

HYPOLYCEMIA

Hypoglycemia is a condition in which blood sugar drops low enough to causes symptoms including irritability, nervousness, sweating, shakiness, anxiety, rapid heartbeat, headache, hunger, weakness, and sometimes seizure and coma. It can occur in people with diabetes as a result of over-medication or an imbalance between insulin level and carbohydrate intake. People with diabetes must learn to recognize the symptoms of hypoglycemia and immediately treat them by consuming a source of quickly absorbed carbohydrate, such as juice or hard candy. Following this, a meal should be consumed within about 30 minutes to keep glucose in the healthy range.

In individuals without diabetes, hypoglycemia can result from abnormalities in the production of or response to insulin or other hormones involved in blood sugar regulation. There are two forms of hypoglycemia. The first, reactive hypoglycemia occurs in response to the consumption of high-carbohydrate foods. The rise in blood glucose from the carbohydrate stimulates insulin release. However,



too much insulin is secreted, resulting in a rapid fall in blood glucose to an abnormally low level. The treatment for reactive hypoglycemia is a diet that prevents rapid changes in blood glucose. Small, frequent meals low in simple carbohydrates and high in protein and fiber are recommended. A second form of hypoglycemia, fasting hypoglycemia, is not related to food intake. In this disorder, abnormal insulin secretion results in episodes of low blood glucose levels. This condition is often caused by pancreatic tumors.

CARBOHYDRATES AND HEALTH

Carbohydrate-rich foods are the basis of healthy diets around the world.³ They provide about half of the kcalories in the American diet and as much as two-thirds in developing countries. Nonetheless, the consumption of carbohydrates has been blamed for a host of chronic health problems, from dental caries and hyperactivity to obesity and heart disease. The incongruity relates to the health effects of different forms and sources of dietary carbohydrates: A dietary pattern that is high in unrefined carbohydrates, such as whole grains, fruits, and vegetables, has been associated with a lower incidence of a variety of chronic diseases, whereas diets high in refined carbohydrates, such as added sugars and white flour, may contribute to chronic disease risk.¹⁹

DENTAL CARIES

The most well-documented health problem associated with a diet high in carbohydrates is **dental caries**, or tooth cavities. It is one of the most common childhood diseases in the United States; 85% of people 18 years of age and older have had caries.²⁰ Cavities are caused when bacteria that live in the mouth form colonies on the tooth surface known as plaque. If the plaque is not brushed, flossed, or scraped away the bacteria metabolize carbohydrate from the food we eat, producing acid. The acid can then dissolve the enamel and underlying structure of the teeth, forming cavities. Bacteria can metabolize both naturally occurring and added refined sugars and starches. Some types of food are more cavity-causing than others. Simple carbohydrate, particularly sucrose, is the most rapidly used food source for bacteria and therefore easily produces tooth-damaging acids. But, starchy foods that stick to the teeth can also promote tooth decay. Foods such as gummy candies, cereals, crackers, cookies, and raisins and other sticky dried fruits tend to remain on the teeth longer, providing a continuous supply of nutrients to decay-causing bacteria. Other foods, such as chocolate, ice cream, and bananas, are rapidly washed away from the teeth and therefore are less likely to promote cavities. Frequent snacking, sucking on hard candy, or slowly sipping soda can also increase the risk of cavities by providing a continuous food supply for the bacteria. Limiting sugar intake can help prevent dental caries, but other dietary factors and proper dental hygiene are important even if the diet is low in sugar. Dairy products, sugarless gums (sweetened with sugar alcohols), and fluoride reduce caries formation. Brushing teeth after eating reduces cavity risk no matter what food is consumed.

DENTAL CARIES *The decay and deterioration of teeth caused by acid produced when bacteria on the teeth metabolize carbohydrate.*

The Dietary Guidelines recommends that Americans reduce their incidence of dental caries by practicing good oral hygiene and limiting the consumption of sugar- and starch-containing foods and beverages.

DOES SUGAR CAUSE HYPERACTIVITY?

The consumption of sugary foods has been suggested as a cause of hyperactivity in children (see Chapter 15). The rise in blood glucose following a meal high in simple carbohydrates has been hypothesized to provide the energy for the excessive activity of a hyperactive child. However, a review of the research on sugar intake and behavior failed to support the hypothesis that sugar contributes to behavioral changes in most children.²¹ Hyperactive behavior that is observed after sugar consumption is likely the result of other circumstances. For example, the excitement





FIGURE 4.23 High-carbohydrate foods like baked potatoes are not high in kcalories, but the toppings used on them often are. (FoodCollection/IndexStock)

of a birthday party rather than the cake is more likely the cause of hyperactive behavior. Hyperactivity might also be caused by lack of sleep, overstimulation, caffeine consumption, the desire for more attention, or lack of physical activity.

DO CARBOHYDRATES AFFECT BODY WEIGHT?

Carbohydrates in and of themselves are not “fattening.” They provide 4 kcalories per gram compared with 9 kcalories per gram provided by fat. In fact, it is the fats that we often add to our high-carbohydrate foods that increase their kcalorie tally. A medium-sized baked potato provides about 110 kcalories, but the 2 tablespoons of sour cream you add brings the total to 175 kcalories (Figure 4.23). A plate of plain pasta has about 200 kcalories, but with a high-fat sauce, the kcalories rise to 300; add sausage and the meal is now 450 kcalories. This is not to say that carbohydrate consumed in excess of energy needs will not add pounds. Any energy source consumed in excess of requirements can cause weight gain. But carbohydrates are no more fattening than any other energy source. In fact, excess carbohydrate in the diet is less efficient at producing body fat than excess fat in the diet (see Chapter 7). But, even though carbohydrates are not high in kcalories, the type of carbohydrate affects the impact that carbohydrates have on body weight.

HIGH-FRUCTOSE CORN SYRUP AND BODY WEIGHT High-fructose corn syrup accounts for over 40% of the sweeteners in the American diet, contributing on average about 132 kcalories per person per day. Because its introduction into the food supply in the 1970s correlates with the expansion of American waistlines it has been accused of being the cause of the increase in obesity rates. Fructose is handled by the body differently than glucose. It does not stimulate insulin production and has different effects on other hormonal signals that regulate food intake and body weight.⁴ Fructose metabolism in the liver favors fat synthesis. Studies in mice indicate that dietary fructose produces a greater increase in body fat than the same amount of sucrose.²² So, is high-fructose corn syrup making us fat? It certainly is adding kcalories to our diets, and some evidence suggests that it may contribute to weight gain more than other sugars, but it alone cannot account for the rise in obesity in the United States. The increase in total energy intake and reduction in physical activity remain the most significant factors contributing to the increased incidence of obesity.²³

LOW-CARBOHYDRATE WEIGHT LOSS DIETS The rationale behind consuming a low-carbohydrate diet for weight loss is that foods high in carbohydrate stimulate the release of insulin, which is a hormone that promotes energy storage. It is suggested that the more insulin you release, the more fat you will store. High-glycemic index foods, which increase blood sugar and consequently stimulate insulin release, are therefore hypothesized to shift metabolism toward fat storage. In contrast, a low-carbohydrate diet causes less of a rise in insulin and therefore is suggested to promote fat loss. Weight loss on low-carbohydrate diets may also be affected by the ketones that are produced and the amount of protein in the diet. Ketones help suppress appetite and the high protein content of a low-carbohydrate diet can be satiating, so both help the dieter eat less. Recent studies on the effectiveness of low-carbohydrate diets for weight loss indicate that they result in greater short-term weight loss (6 months) than low-fat diets.^{24,25} The weight loss on these diets, as with any weight loss diet, is caused by consuming less energy than is expended. Whether the greater short-term weight loss is due to greater water loss, changes in metabolism that increase energy expenditure, or changes in hunger and satiety that reduce food intake is still under investigation.²⁶ To date no long-term studies on the efficacy and safety of these diets are available. Trials suggest that it may be difficult to remain compliant with low-carbohydrate diets in the long term and that they may cause excesses and deficiencies of some nutrients and other dietary components.²⁷ (See Critical Thinking: Losing Weight on a Low-Carbohydrate Diet)



For more information on low-carbohydrate diets go to the Weight Control Network at win.niddk.nih.gov/index.htm



CRITICAL THINKING

Losing Weight on a Low-Carbohydrate Diet

Danzel is 5' 10" tall and weighs 200 pounds, about 25 pounds more than he would like to. At the recommendation of a friend he decides to try a low-carbohydrate weight-loss diet. The diet allows an unlimited amount of his favorite breakfast foods—bacon, eggs, and sausage. He can also have all the beef, chicken, fish, and cheese he wants but can't have fruit, bread, cereal, pasta, milk, and starchy vegetables. He can have limited amounts of low-carbohydrate vegetables such as lettuce, spinach, and tomatoes. The goal is to keep his intake of carbohydrates below 20 grams per day. Danzel's typical day's intake while following the diet is given below.

Breakfast: 3 scrambled eggs with 3 sausage links and coffee

Lunch: 3 fried chicken thighs from KFC and water

Snack: 2 hard-boiled eggs

Dinner: 8-ounces of barbecued steak, and a lettuce and tomato salad with oil and vinegar

Danzel is overjoyed with his rapid weight loss. But after only a week he is feeling tired, experiencing headaches, and is bored with his food choices. He misses having sandwiches for lunch and potatoes alongside his steak. He is tempted to have some toast and juice with his breakfast.

How much carbohydrate would 2 slices of toast and 6 ounces of orange juice add to Danzel's breakfast?



ANSWER:

How does the 20 grams of carbohydrate allowed by Danzel's diet plan compare to the RDA?



The RDA for carbohydrate is 130 grams per day. Consuming less than this may cause proteins to be used to synthesize glu-

cose and will limit the amount of carbohydrate available to break down fat, leading to ketone formation. Although the ketones inhibit Danzel's appetite they may be the cause of his headaches.

How many kcalories is Danzel consuming from the meals shown in the table?



Even though Danzel can eat as much as he wants of allowed foods he is only consuming about 1700 kcalories a day. Before starting the diet Danzel was eating about 2800 kcalories a day to maintain his weight.

Danzel has a family history of heart disease. What is his fat intake on this diet?



His diet now has about 114 grams of fat, which is 60% of his kcalories. This is well above the acceptable range for fat intake of 20% to 35%. He is also eating 33 grams of saturated fat, which is 17% of his kcalories. Diets high in saturated fat increase the risk of heart disease. The recommendation is 10% or less of kcalories from saturated fat. His diet also includes over 1300 mg of cholesterol; the recommendation is 300 mg or less per day.

Do you think Danzel should continue to eat this diet as a way to maintain his weight loss long term?



ANSWER:

UNREFINED CARBOHYDRATES AND WEIGHT MANAGEMENT Despite the effectiveness of low-carbohydrate diets for short-term weight loss, diets high in unrefined carbohydrates can help make weight maintenance and weight loss easier. Unrefined carbohydrates are good sources of fiber. Fiber can help reduce energy intake because it adds bulk to the GI tract and causes you to feel full after consuming less. It may also slow the absorption of energy-yielding nutrients by decreasing transit time, adding bulk, and forming viscous solutions, all of which reduce contact between digestion products and the absorptive surface.²⁷ Whole foods that are good sources of fiber also have a lower glycemic response and therefore cause less of a rise in insulin than refined carbohydrates. Diets high in whole foods would therefore have glycemic effects similar to diets low in carbohydrate and high in protein.

An abnormal craving for carbohydrate-rich foods is a component of a variety of disorders including obesity, premenstrual syndrome, bulimia, depression, and seasonal affective disorder.^{28,29} Individuals with these disorders may have an abnormality in the regulation of brain levels of the neurotransmitter serotonin. This causes them to seek carbohydrates like a drug to increase serotonin levels, which improves their mood.



REFINED CARBOHYDRATES AND DIABETES

Evidence is accumulating that the type of dietary carbohydrate plays a role not only in the treatment of diabetes, but in the development of type 2 diabetes in susceptible individuals.¹ The risk of developing type 2 diabetes is lower in populations that consume diets high in whole grains than in populations that eat a diet high in refined starches and added sugars.^{30–32} In particular a high intake of sugar-sweetened beverages has been associated with an increased risk for development of type 2 diabetes.³³ One mechanism that may explain this relationship is that a dietary pattern that is high in refined starches and added sugars causes a greater glycemic response and therefore increases the amount of insulin needed to maintain normal blood glucose levels. Over the long term, in susceptible individuals, the high demand for insulin eventually may wear out the insulin-producing cells in the pancreas. When the diet is lower in simple carbohydrates and refined starches and higher in fiber there is a more gradual rise in blood sugar and therefore a lower insulin demand. So, although a diet high in simple carbohydrates and refined starches does not cause diabetes, it does increase the demand for insulin required to maintain normal glucose levels and may increase the risk of developing diabetes.

CARBOHYDRATES AND HEART DISEASE

Just as with weight management and diabetes, when considering heart disease, some carbohydrates may be protective while others may increase risk. Evidence shows that a diet high in sugar can raise blood lipid levels and thereby increase the risk of heart disease.³⁴ On the other hand, diets high in whole grains have been found to reduce the risk of heart disease.^{35–38} In general, people with the highest intake of whole grains—about 3 servings a day—have a 20% to 30% lower risk of heart disease than those consuming the fewest whole grains. Whole grains provide fiber, resistant starch, oligosaccharides, omega-3 fatty acids, vitamins, minerals, antioxidants, and other phytochemicals that may be protective against heart disease (see Chapter 5).

One of the ways a diet high in whole grains and other unrefined carbohydrates may reduce the risk of heart disease is by reducing blood cholesterol levels. Soluble fiber binds cholesterol and bile acids, which are made from cholesterol, in the digestive tract. Normally, bile acids secreted into the GI tract are absorbed and reused. When bound to fiber, they are excreted in the feces rather than being absorbed. The liver must then use cholesterol from the blood to synthesize new bile acids. This provides a mechanism for eliminating cholesterol from the body and reducing blood cholesterol levels (Figure 4.24). Soluble fibers from legumes, oats, guar gum, pectin, flax seed, and psyllium (a grain used in bulk-forming laxatives such as Metamucil) are effective at reducing cholesterol, but insoluble fibers such as wheat bran or cellulose are not.³⁹ Soluble fiber may also reduce blood cholesterol by inhibiting cholesterol synthesis in the liver or by increasing the removal of cholesterol from the blood.⁴⁰

Because of the beneficial effects of certain fibers on heart disease risk, the FDA permits a health claim on food products containing either soluble fiber from psyllium seed husk or beta-glucan (found in whole oats), which states that these products may reduce the risk of coronary heart disease. In addition to lowering blood cholesterol levels whole grains help lower blood pressure, normalize blood glucose levels, prevent obesity, and affect a number of other parameters, all of which help reduce the risk of heart disease.³⁹

INDIGESTIBLE CARBOHYDRATES AND BOWEL DISORDERS

Whole grains, fruits, and vegetables are good sources of fiber and also contain resistant starch and oligosaccharides. Diets high in these indigestible carbohydrates can relieve or prevent certain bowel disorders that are caused by pressure in the

In an analysis of over 150,000 people, those with the highest dietary fiber intake had a 29% lower risk of coronary heart disease than those with the lowest intake.⁴¹

If you don't care for whole-wheat pasta, you may get similar benefits from eating your refined pasta cold. The lower temperature increases the amount of resistant starch. Resistant starch has been found to decrease glycemic response, lower lipid concentrations, improve insulin sensitivity, increase satiety, and reduce fat storage.⁴²

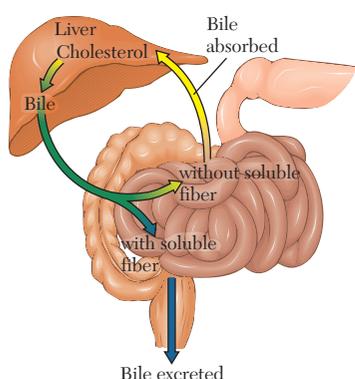


FIGURE 4.24 When the diet is low in soluble fiber, bile, which contains cholesterol and bile acids made from cholesterol, is absorbed and returned to the liver. When soluble fiber is present, it binds cholesterol and bile acids so they are excreted rather than absorbed.



lumen of the colon. As discussed earlier, a mixture of soluble and insoluble fibers in the colon adds bulk and absorbs water. This increases stool weight, speeds transit time, and makes the feces larger and softer, thus reducing the amount of pressure needed for defecation. The presence of these fibers and other indigestible carbohydrates helps to reduce the incidence of constipation. Constipation makes muscles strain to move stool that is too hard and is the main cause of increased pressure in the colon. This excess pressure contributes to the formation of **hemorrhoids**, the swelling of veins in the rectal or anal area. Excess pressure is also believed to cause weak spots in the colon to bulge out and become **diverticula** (Figure 4.25). When these outpouchings form, the condition is called **diverticulosis**. A high-fiber diet reduces pressure in the lumen of the colon and therefore reduces the possibility of developing diverticulosis.⁴³ If diverticulosis does develop, fecal matter may occasionally accumulate in these outpouchings, causing irritation, pain, inflammation, and infection, a condition known as **diverticulitis**. Treatment of diverticulitis usually includes antibiotics to reduce bacterial growth and a temporary decrease in fiber intake to prevent irritation of the inflamed tissues. Once the inflammation is resolved however, a high-fiber intake is recommended to increase fecal bulk, decrease transit time, ease stool elimination, and reduce future attacks of diverticulitis.

Although fiber helps soften stools and prevent constipation, if fiber is consumed without sufficient fluid, it can also cause constipation. The more fiber there is 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 when fiber intake is excessive and fluid intake is low, intestinal blockage can occur.⁴⁵

HEMORRHOIDS Swollen veins in the anal or rectal area.

DIVERTICULA Sacs or pouches that protrude from the wall of the large intestine in the disease **diverticulosis**. When these become inflamed, the condition is called **diverticulitis**.

Diverticulosis is prevalent in developed countries where low-fiber diets are common and rare in parts of the world where high-fiber diets are consumed. Today about 50% of all Americans over the age of 60 have diverticulosis.⁴⁴

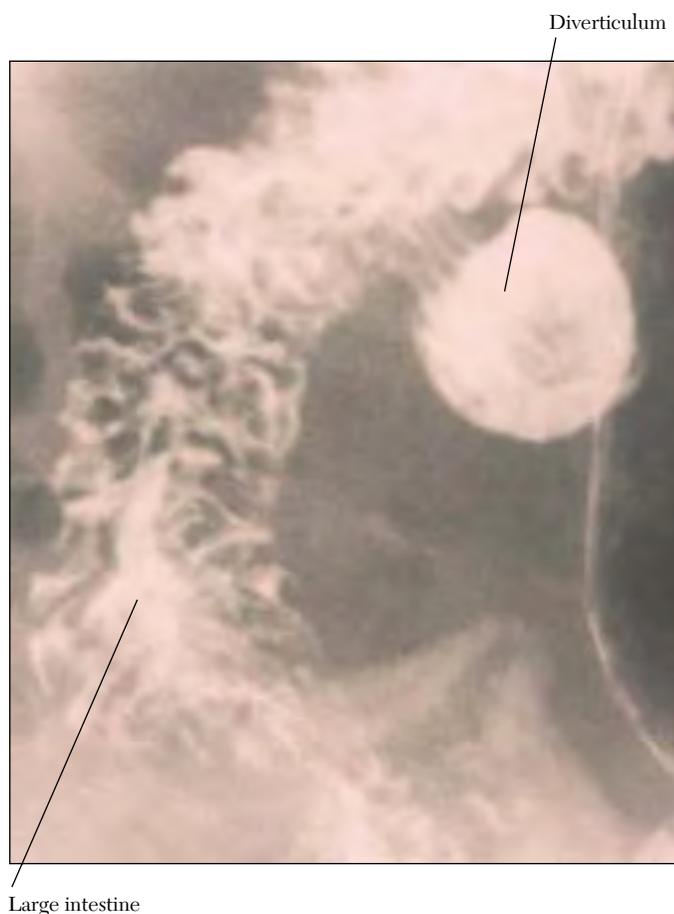


FIGURE 4.25 *Diverticulum in the colon.* (L. V. Bergman/Project Masters, Inc.)



CARCINOGENS *Cancer-causing substances.*

MUTATIONS *Changes in DNA caused by chemical or physical agents.*

MALIGNANCY *A mass of cells showing uncontrolled growth, a tendency to invade and damage surrounding tissues, and an ability to seed daughter growths to sites remote from the original growth.*

Colon cancer is the number two cause of cancer deaths for both men and women in the United States, accounting for about 20% of all cancer deaths.

INDIGESTIBLE CARBOHYDRATES AND COLON CANCER

Cancer is a disease that affects the way cells behave. Different cancers originate in different parts of the body and have different causes and effects. The type of cancer depends on the type of cell that is originally affected—for example, lung, breast, or colon—and on how the genetic material has been altered. Some people are more susceptible to cancer due to a genetic predisposition but the development of most cancers is also believed to be influenced by environmental **carcinogens** from the diet, tobacco smoke, or air pollution. In the case of colon cancer, substances consumed in the diet or produced in the GI tract that come in contact with mucosal cells may contribute to cancer development.

CHARACTERISTICS OF CANCER CELLS Cells become cancerous as a result of **mutations** in their genetic material that allow them to reproduce without restraint and grow in abnormal locations. Normal body cells reproduce only to replace lost cells or to accommodate normal growth, but cancer cells divide continuously, forming enlarged cell masses known as tumors. Further mutations allow them to invade and colonize areas reserved for other cells, referred to as **malignancy** (Figure 4.26). The cancer cells eventually crowd out the normal cells, robbing them of nourishment, and preventing them from functioning properly. Some carcinogens act by damaging DNA and inducing mutations. These are usually referred to as *tumor initiators* since the induction of mutations in key genes is thought to be the initiating event in cancer development. Other carcinogens contribute to cancer development by stimulating cells to divide. Such compounds are referred to as *tumor promoters*, since the increased cell division they induce enlarges the population of mutated cells, which is necessary for cancer to progress.

FIBER AND CANCER DEVELOPMENT Epidemiological studies have shown that the incidence of colon cancer is lower in populations consuming diets high in fiber.^{43,46,47} Several hypotheses have been developed to explain how fiber might affect the development of colon cancer. One is related to its ability to decrease contact between the mucosal cells of the large intestine and the fecal contents, which may contain tumor initiators or tumor promoters. Fiber decreases contact by increasing fecal bulk, diluting the colon contents, and speeding transit. Another relates to the effect of fiber on the intestinal microflora and the by-products of microbial metabolism, such as fatty acids, that accumulate there. These by-products may directly affect colon cells or may cause changes in the environment of the colon that can affect the development of colon cancer. It has also been hypothesized that high-fiber diets protect against colon cancer because of the antioxidant vitamins and phytochemicals that are present along with fiber in plant foods.

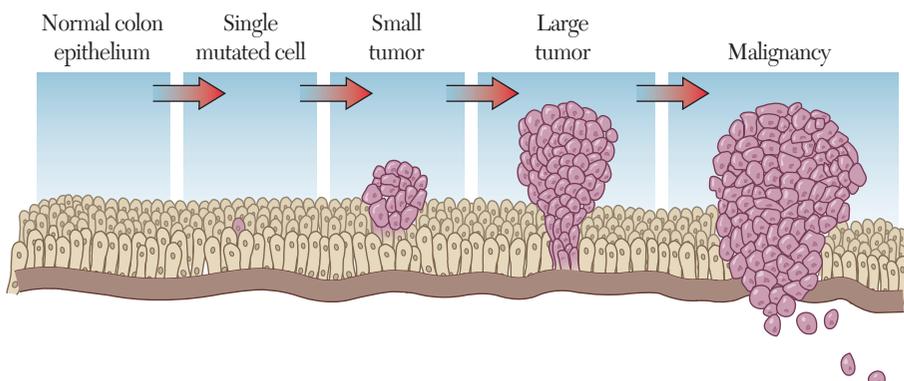


FIGURE 4.26 Colon cancer, like other cancers begins with a single mutated cell. The mutations in this cell allow it to reproduce quickly, forming a mass of cells known as a tumor. Over time cells in the tumor mutate further giving them the ability to break free of the tumor and take up residence in other parts of the body. This is referred to as a malignancy.



Recent intervention studies have not supported the epidemiological observations of a connection between fiber intake and colon cancer.⁴⁸⁻⁵⁰ A number of reasons have been suggested for this discrepancy—the interventions were not long enough, the fiber dose was not high enough, the type of cancer monitored was not appropriate, or the fiber itself is not really protective, but rather some other component in the diet of the low-cancer populations may have a protective effect. Despite these results, the scientific consensus is still that there is enough evidence that diets high in fiber protect against colon cancer to recommend an increase in fiber intake.⁴³

MEETING CARBOHYDRATE RECOMMENDATIONS

The average American diet provides plenty of carbohydrate, but whether or not this carbohydrate promotes or harms our health depends on the food sources and types of carbohydrates we choose. A healthy diet is high in complex carbohydrates from whole grains, legumes, fruits, and vegetables and simple carbohydrates from whole foods such as fresh fruit and low-fat dairy products. This diet is high in fiber, micronutrients, and phytochemicals, and low in saturated fat and cholesterol. Unfortunately, the typical American diet is lower in whole grains, fruits, and vegetables and higher in added sugars than is recommended.

TYPES OF CARBOHYDRATE RECOMMENDATIONS

A small amount of carbohydrate is needed to fuel the brain. Additional carbohydrate provides an important source of energy in the diet and adequate fiber offers many health benefits. Therefore the DRIs make several kinds of recommendations for carbohydrate intake; an RDA for total carbohydrate, a range of acceptable carbohydrate intakes called the Acceptable Macronutrient Distribution Range (AMDR), and an AI for fiber. Because no specific toxicity is associated with high intakes of carbohydrate in general or of different types of carbohydrates, no UL has been established for total carbohydrate, added sugars, or fiber.

THE RDA FOR CARBOHYDRATE The RDA for carbohydrates for adults and children has been set at 130 grams per day based on the average minimum amount of glucose used by the brain.³ In a diet that meets energy needs, this amount will provide adequate glucose and prevent ketosis. This amount of carbohydrate provides only 420 kcalories; that's about 25% of the energy in a 2000-kcalorie diet. It is equivalent to a breakfast of a cup of juice, two slices of toast with jam, and a bowl of cereal with half a banana and milk (Figure 4.27). Most people consume well in excess of this amount over the course of a day. A diet that includes only this much carbohydrate and meets kcalorie needs would be very high in protein and fat.

THE RANGE OF HEALTHY CARBOHYDRATE INTAKES No single ratio of macronutrients defines a perfect diet. Healthy diets can be made up of many different combinations of carbohydrate, protein, and fat. The AMDR for carbohydrate intake for a healthy diet has been set at 45% to 65% of energy. Choosing a diet in this range will allow you to meet your energy needs without consuming excessive amounts of protein or fat. The sources of carbohydrate are more important than the absolute amount. In order to promote a diet that meets needs for all nutrients, the DRIs recommend that most carbohydrate should come from whole food sources; no more than 25% of energy should come from added refined sugars. This percentage is based on the amount of added sugar that can be consumed without reducing the nutrient density of the diet so much that essential nutrient needs cannot be met. The 2005 Dietary Guidelines and MyPyramid consider added sugar as one component of the discretionary kcalories—those kcalories left over once you have met your serving recommendations with healthy choices from

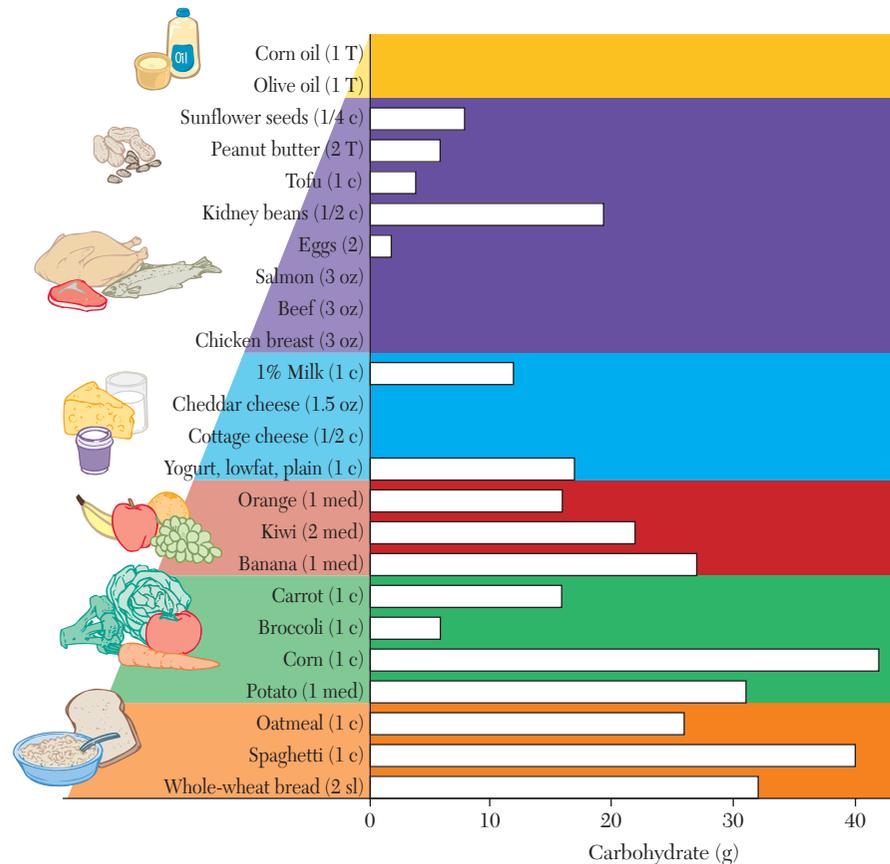


FIGURE 4.27 Carbohydrate content of selections from each food group of MyPyramid. The Grains Group; the Vegetables Group; and legumes from the Meat and Beans Group are the best sources of complex carbohydrates. The Fruits Group and the Milk Group contain good sources of naturally occurring simple carbohydrates.

all of the food groups. The amount allowed depends on the total kcalories that can be consumed without weight gain.⁹ A diet that includes no more than the recommended number of discretionary kcalories will only include about 10% of kcalories from added sugars. This coincides with the recommendation from the World Health Organization that no more than 10% of energy come from added sugars.⁵¹

AN AI FOR FIBER For fiber, an AI has been set at 38 and 25 grams per day for young adult men and women, respectively, based on the amount of fiber needed to reduce heart disease risk.³ Eating a bowl of raisin bran with a half-cup of strawberries for breakfast, a sandwich on whole wheat bread with lettuce and tomatoes and an apple for lunch, eggplant parmesan for dinner and popcorn for a snack will provide about 25 grams of fiber. Specific AIs for fiber have been set for different life-stage groups (see Appendix A).

TOOLS FOR ASSESSING CARBOHYDRATE INTAKE

How does your diet compare to the recommendation of 45% to 65% of kcalories from carbohydrate? Table 4.2 illustrates how to calculate carbohydrate intake as a percent of energy. This same calculation can be used to determine the percent of energy as carbohydrate in individual foods. To calculate the percent of energy as carbohydrate, you need to know the amount of carbohydrate in a food or in the diet. This can be estimated from the Exchange Lists or determined using values from food labels or food composition tables (see Nutrient Content of Foods Supplement).


TABLE 4.2 *Calculating Percent Energy from Carbohydrate*
Determine

- The total energy (kcalorie) intake for the day
- The grams of carbohydrate in the day's diet

Calculate Energy from Carbohydrate

- Carbohydrate provides 4 kcalories per gram
- Multiply grams of carbohydrate by 4 kcalories per gram

$$\text{Kcalories from carbohydrate} = \text{grams carbohydrate} \times 4 \text{ kcalories/gram carbohydrate}$$

Calculate % Energy from Carbohydrate

- Divide energy from carbohydrate by total energy and multiply by 100 to express as a percent

$$\text{Percent of energy from carbohydrate} = \frac{\text{kcalories from carbohydrate}}{\text{Total kcalories}} \times 100$$

For example:

A diet contains 2500 kcalories and 350 grams of carbohydrate

$$350 \text{ grams of carbohydrate} \times 4 \text{ kcal/g} = 1400 \text{ kcal of carbohydrate}$$

$$\frac{1400 \text{ kcal of carbohydrate}}{2500 \text{ kcal}} \times 100 = 56\% \text{ of energy (kcal) from carbohydrate}$$

CARBOHYDRATE EXCHANGE LISTS The Exchange Lists can be used to give a quick estimate of the total amount of carbohydrate in a food or in the diet (Table 4.3). One serving of bread or fruit provides 15 grams of carbohydrate, 1 milk serving provides 12 grams, and 1 vegetable serving provides about 5 grams. Meats and fats provide no carbohydrate. The Exchange Lists cannot be used for calculating fiber intake, but Table 4.4 offers an exchange system for estimating fiber in foods.

CARBOHYDRATES ON FOOD LABELS Food labels list the grams of total carbohydrate, fiber, and sugars in foods. The amounts of soluble and insoluble fiber may be listed if manufacturers choose to include them but are not required. Total carbohydrate and fiber are also listed as a percent of the Daily Value. The Daily Value for total carbohydrate is calculated as 60% of the energy. For a 2000-kcalorie diet, this represents 300 grams of carbohydrate ($[2000 \text{ kcal} \times 0.6]/4 \text{ kcal/g}$ of carbohy-

TABLE 4.3 *Using Exchange Lists to Estimate Carbohydrate Content*

EXCHANGE GROUPS/LISTS	SERVING SIZE	CARBOHYDRATES (g)
Carbohydrate Group		
Starch	1/2 cup rice, cereal, potatoes; 1 slice bread	15
Fruit	1 small apple, peach, pear; 1/2 banana; 1/2 cup canned fruit (in juice)	15
Milk	1 cup milk or yogurt	
Nonfat		12
Lowfat		12
Reduced fat		12
Whole		12
Other carbohydrates	Serving sizes vary	15
Vegetables	1/2 cup cooked vegetables, 1 cup raw	5
Meat/Meat Substitute Group		
Very lean	1 oz meat or cheese	0
Lean		0
Medium-fat		0
High-fat		0
Fat Group		
	1 tsp butter, margarine, or oil; 1 Tbsp salad dressing	0


TABLE 4.4 *Estimating the Fiber in Foods*

FOOD GROUP/SERVING	HIGH FIBER	MEDIUM FIBER	LOW FIBER
<i>Fiber per serving</i>	<i>4–5 g</i>	<i>2–3 g</i>	<i>0.5–1 g</i>
Grain Group			
Breads (1 slice)	—	Whole wheat Rye	White bread Bagel (1/2) Tortilla Roll (1/2) English muffin (1/2) Graham cracker
Cereals (1/2 cup)	All Bran Bran Buds 100% Bran Flakes	40% Bran Shredded Wheat	Cheerios Rice Krispies
Rice and pasta (1/2 cup)	—	Whole-wheat pasta Brown rice	Macaroni Pasta White rice
Fruit Group			
Fruits (1 medium or 1/2 cup)	Berries Prunes	Apple Apricot Banana Orange Raisins	Melon Canned fruit Juices
Vegetable Group			
Vegetables (1/2 cup)	Peas Broccoli Spinach	Green beans Carrots Eggplant Cabbage Potatoes with skin Corn	Asparagus Cauliflower Celery Lettuce Tomatoes Zucchini Peppers Potatoes without skin Onions
Dry Bean Group			
Beans (1/2 cup)	Pinto, red Kidney beans Blackeyed peas	—	—

Source: Adapted from Bright-See, E., Benda, C., Vartouhi, J., et al. Development and testing of a dietary fibre exchange system. *Can. Diet. Assoc. J.* 47:199–205, 1986; and Marlett, J. A. Content and composition of dietary fiber in 117 frequently consumed foods. *J. Am. Diet. Assoc.* 92:175–186, 1992.

drate = 300 g). The Daily Value for fiber is 25 grams in a 2000-kcalorie diet. A slice of whole-wheat bread contains 2 grams of fiber per serving, which is 8% of the Daily Value. No Daily Value has been established for sugars, but labels can help identify products that are high in sugars (see Off the Label: The Scoop on Sugar).

Descriptors such as “high fiber” and “a good source of fiber” can help you find high-fiber products. Foods that contain 20% or more of the Daily Value for fiber per serving can state on the label that they are “high in dietary fiber.” Products containing 10% to 19% of the Daily Value can state that they are “a good source of dietary fiber” (Table 4.5). If you are looking for low-carbohydrate products, be aware that the terms “low carbohydrate” and “low carb” have not been defined by the FDA, so at the moment the definition is up to the manufacturer. Some products may also advertise the number of “net carbs” they provide. Again, there is no official definition of net carbs but usually this number is calculated by subtracting the grams of fiber, and sometimes other poorly absorbed carbohydrates, from the grams of total carbohydrate in the food.

Food labels may also carry health claims related to fiber and chronic disease risk. Fiber-containing grain products, fruits, and vegetables that contain at least 2.5 grams of fiber per serving and are low in fat may claim to reduce the risk of cancer. Fruits, vegetables, and grain products that are low in total fat, saturated fat, and



OFF THE LABEL

THE SCOOP ON SUGAR

We eat about 158 pounds of sweeteners per person per year in the United States.¹ Some of this is from sugar and honey we add to foods at home but most of it is from added sugars in prepared foods like sodas, cookies, and snacks. So cutting down on the sugar you add to your coffee or cereal is only part of the solution to reducing your sugar intake. Recognizing foods high in added sugars is an important step toward cutting down on these empty calories.

Identifying packaged foods that are high in added refined sugar isn't always easy because food labels don't differentiate between added and natural sugar. What's listed in the Nutrition Facts is the total number of grams of sugars, which includes both added and naturally occurring monosaccharides and disaccharides. If you looked at the label on a tin of sweetened frozen strawberries, the grams of sugars includes both the fructose found naturally in the strawberries and sugar added for additional sweetness. Some foods include a nutrition claim such as "no added sugar" or "without added sugar" which indicates that no sugars or sugar-containing ingredients were added in processing (see Table 4.5). For products that do not contain descriptors such as these you can sort out their sugar sources by reading the ingredient list.

The ingredient list on a food label must list all of the ingredients in the food. The only sweetener that can be called "sugar" is sucrose. This could be brown sugar, powdered sugar, granulated sugar, or raw sugar. However, there are many other sweeteners added to foods. They can be added in dry form such as invert sugar, dextrose, lactose, and fructose or as syrups such as corn syrup, honey, molasses, and high-fructose corn syrup. Consumers need to increase their sweetener vocabulary to recognize all the added sugars on the label (see Table).

Some sweeteners such as brown sugar, honey, maple syrup, and fruit juices are thought of as healthier than sucrose be-

cause they contain some nutrients that have been processed out of pure white table sugar. In fact, most are not significantly different from sucrose; the amounts of micronutrients are too small to add much to the diet. Most brown sugar is simply refined white sugar containing some molasses to color it brown. Honey is fructose and glucose. Since it is somewhat sweeter than sucrose, we may use smaller amounts for the same level of sweetness. Maple syrup, formed by boiling down the sap of maple trees, is composed primarily of sucrose, which has been browned by the heat involved in processing. Fruit juices used as sweeteners may add small amounts of micronutrients but primarily contribute the sugar fructose to the product.

There are some easy ways to cut down on added sugar—drink fewer sweetened soft drinks, eat less candy, add less sugar to foods at the table. For less obvious sources of added sugars, check labels for sweeteners listed early in the ingredient list. The sooner they appear the greater the amount the product contains by weight. If there is more than one sweetener, the sum of the two may represent a lot of added sugar even if alone they are not first or second in the ingredient list. For example, the yogurt shown here lists sugar as the second ingredient and high-fructose corn syrup as the fourth. Together these two contribute most of the 28 grams of sugar in this food.

Sweetener Vocabulary

Brown sugar	Invert sugar
Corn sweetener	Lactose
Corn syrup	Maltose
Dextrose	Malt syrup
Fructose	Molasses
Fruit juice	Raw sugar
Glucose	Sucrose
High-fructose corn syrup	Sugar syrup concentrates
Honey	



INGREDIENTS: CULTURED PASTEURIZED GRADE A REDUCED FAT MILK, SUGAR, NONFAT MILK, HIGH FRUCTOSE CORN SYRUP, STRAWBERRY PUREE, MODIFIED CORN STARCH, KOSHER GELATIN, TRICALCIUM PHOSPHATE, NATURAL FLAVOR, COLORED WITH CARMINE, VITAMIN A ACETATE, VITAMIN D₃

Nutrition Facts

Serving Size 1 Container	
Amount Per Serving	
Calories 190	
Calories from Fat 30	
Amount/Serving	%DV*
Total Fat 3.5g	5%
Saturated Fat 2g	10%
Trans Fat 0g	
Cholesterol 15mg	4%
Sodium 100mg	4%
Potassium 310mg	9%
Total Carbohydrate 32g	11%
Sugars 28g	
Protein 7g	14%
Vitamin A 15% • Calcium 30%	

*Percent Daily Values (DV) are based on a 2,000 calorie diet.

¹Coulston, A. M., and Johnson, R. K. Sugar and sugars: Myths and realities. *J. Am. Diet. Assoc.* 102:351–353, 2002.


TABLE 4.5 *Sugar and Fiber on Food Labels^a*

Sugar-free	Product contains no amount, or a trivial amount, of sugars (less than 0.5 g per serving). Synonyms for “free” include “without,” “no,” and “zero.”
Reduced sugar	Nutritionally altered product contains 25% less sugar than the regular or reference product.
Less sugar	Whether altered or not, a food contains 25% less sugar than the reference food. “Fewer” may be used as a synonym for “less.”
No added sugars or without added sugars	No sugar or sugar-containing ingredient is added during processing.
High fiber	Food contains 20% or more of the Daily Value for fiber per serving. Synonymous for “high” include “rich in” and “excellent source of.”
Good source of fiber	Food contains 10% to 19% of the Daily Value for fiber per serving. Synonyms for “good source of” include “contains” and “provides.”
More fiber	Food contains 10% or more of the Daily Value for fiber per serving than an appropriate reference food. Synonyms for “more” include “added” (or “fortified” and “enriched”), “extra,” or “plus.”

^aIf a food is low in total fat, the label must state total fat in conjunction with any fiber claim such as “More Fiber.”

Low-carbohydrate products are not necessarily low in calories. If sugar has been replaced with an artificial sweetener the product will be lower in calories than the original but for many high-carbohydrate foods, such as bread and pasta, low-carb versions are produced by replacing some of the carbohydrate with protein, which like carbohydrate provides 4 calories per gram.

cholesterol and that contain at least 0.6 gram of soluble fiber per serving, and foods that contain at least 0.75 gram of soluble fiber per serving from whole oats or psyllium husks, may claim to reduce the risk of heart disease (see Appendix J).

TRANSLATING RECOMMENDATIONS INTO HEALTHY DIETS

The typical North American diet meets some but not all of these carbohydrate recommendations. We consume about 50% of energy from carbohydrate but most of this comes from refined sources. We consume too little fiber, too few whole grains and other unrefined carbohydrate sources, and too much added sugar. Our average fiber intake is only 15 grams per day, which is well below the AI. In order to promote a healthy balance of carbohydrates, the Dietary Guidelines recommend an increase in whole grains, vegetables, and fruits, and a reduction in added sugars from bakery products, candy, and soft drinks.⁹ MyPyramid helps translate these recommendations into food choices and healthy diets for individuals.

EAT MORE WHOLE GRAINS, FRUITS, AND VEGETABLES To encourage the consumption of healthy sources of carbohydrates the Dietary Guidelines and MyPyramid recommend that you choose half of your grains from whole sources or eat at least three servings of whole grains per day (see *Off the Shelf: Choosing Whole Grains: Not as Easy as it Sounds*). Whole grains are good sources of fiber as well as micronutrients and phytochemicals. Fruits and vegetables are also excellent whole food sources of both complex and simple carbohydrates. For a 2000-kcalorie diet MyPyramid recommends 2 cups of fruit and 2½ cups of vegetables. To maximize fiber intake most fruit choices should be whole fruits rather than juices. An apple provides about 80 to 90 calories and 2.7 grams of fiber, whereas a cup of apple juice provides the same amount of energy but almost no fiber (0.2 gram). Choosing legumes as part of the vegetable servings will increase fiber intake—a half-cup of cooked black beans has about 7 grams of fiber.

LIMIT ADDED SUGARS Foods that contain the most added sugars in the American diet include soft drinks, candy, cakes, cookies, pies, fruit drinks, and dairy desserts, but added sugars are also found in thousands of other processed products. Sugars are also added at home when we sprinkle sugar on our cereal or spoon honey into our tea. The greater your consumption of foods high in added sugars, the harder it is to consume enough nutrients without gaining weight. Added sugars provide calories with little if any of the essential nutrients. People who eat foods and beverages high in added sugars tend to eat more calories and fewer micronutrients.⁹ To avoid exceeding your discretionary calorie limit added sugar intake must be kept


TABLE 4.6 *How Much Added Sugar Do You Eat?*

FOOD	ADDED SUGAR (tsp) ^a
Doughnut, 3-inch diameter	2
Cookies, 2 medium chocolate chip	3
Frosted corn flakes, 1 oz	3
Cake, frosted, 1 piece	6
Pie, fruit, 2 crust, 1 slice	6
Fruit, canned in heavy syrup, 1 cup	4
Chocolate milk, 2%, 1 cup	3
Low-fat fruit yogurt, 1 cup	7
Ice cream, vanilla, 1 cup	3
Chocolate bar, 1 oz	5
Fruit drink, 12 oz	12
Cola, not diet, 12 oz can	9
Cola, not diet, 20 oz bottle	15

^a1 tsp = 4 g dry weight

to a minimum. For example, a 2000-kcalorie diet can include only about 270 discretionary calories. As seen in Table 4.6, a 12-ounce can of Coke has about 9 teaspoons of added sugar, which would use up 160 of your discretionary calories.

PUTTING IT ALL TOGETHER To meet the recommendations for a healthy diet, refined carbohydrates should be replaced with unrefined sources of simple and complex carbohydrates (Table 4.7). For example, choosing a stir-fry meal of a few ounces of beef and plenty of vegetables on brown rice can provide the same calories but more fiber and less fat than a dinner of steak, white rice, and a small salad with dressing. To limit added sugars, foods high in added sugar should be replaced with natural sources of sugar such as fruits and dairy products. If instead of a 20-ounce bottle of soda you have an 8-ounce glass of low-fat milk, you will consume 140 fewer calories, no added sugar, as well as getting plenty of high-quality protein, calcium, and other micronutrients. Using fresh instead of canned fruit can also help increase fiber and decrease added refined sugars. For example, a half-cup of pear halves canned in heavy syrup provides 90 calories, 1 gram of fiber, and almost 20 grams of sugar, most of which is added in the syrup. One large fresh pear provides 90 calories, 4 grams of fiber, and no refined sugar (see Critical Thinking: Becoming Less Refined).

The Dietary Guidelines recommend that Americans choose and prepare foods and beverages with little added sugars or caloric sweeteners.

TABLE 4.7 *How to Choose Carbohydrates Wisely*
Choose more whole grains

- Substitute brown rice, wild rice, bulgur, or quinoa for white rice.
- Make sandwiches with whole wheat rather than white bread.
- Add legumes such as kidney, black, and pinto beans to casseroles and salads.
- Add barley to soups and stews.
- Choose packaged foods that contain 10% or more of the Daily Value for fiber.
- When baking at home, substitute whole-wheat flour for white or unbleached flour.
- Eat whole-grain breakfast cereals, such as Wheaties, Shredded Wheat, Grape Nuts, Kashi, muesli, and oatmeal, or try bran cereals—they are not actually whole-grain cereals but their high-fiber content also makes them a good breakfast choice.
- Substitute whole-grain rolls, tortillas, and crackers for those made from refined grains.
- Substitute whole-wheat pasta or pasta made from 50% whole wheat and 50% white flour for conventional pastas.

Limit added sugars

- When cooking at home, use less sugar; try adding one-fourth less sugar than called for in the recipe.
- Use less added sugar in coffee and tea and on cereals and pancakes.
- Eat fewer high-sugar prepared foods such as cookies, cakes, and candies.
- Snack on fruit. If fresh fruits are not available, choose frozen or canned fruits without added sugar.
- Read food labels to choose foods low in added sugars.



CRITICAL THINKING

Becoming Less Refined

Emma thinks that a good diet is important. She is concerned that she eats too much added sugar and not enough fiber. She records her food intake for a day and calculates its nutrient content. Her fiber and sugar intake are shown below.

Current Diet			
FOOD	SERVING	FIBER (g)	SUGARS (g)
Breakfast			
White bread	2 slices	1.2	2
with jelly and margarine	1 Tbsp	0.1	6
Fruit punch	1 tsp	0	0
	8 fl oz	0	22
Lunch			
Macaroni and cheese	1 cup	1.4	8
Milk	1 cup	0	12
Apple	1 medium	3.7	18
Snack			
Soda	20 oz	0	63
3 Musketeers bar	1 regular	1	34
Dinner			
Roast beef	3 oz	0	0
Flour tortillas	1, 8-inch size	1.4	1
Pinto beans	1 cup	10	1
Snack			
Ice cream	2/3 cup	0.8	17
with cherry syrup	2 Tbsp	0	16
Total		19.6	200

Diet Analysis

Emma's diet analysis indicates that her daily diet provides about 2340 calories, 67 grams of protein, 80 grams of fat, 350 grams of carbohydrate, and 19.6 grams of fiber.

How does her total carbohydrate intake compare to recommendations?

She eats 350 grams of carbohydrate; this is about 55% of her energy intake. Her intake is within the recommended range of 45% to 65% carbohydrate.

Does Emma's fiber intake meet recommendations?

No, she eats only 19.6 grams; the recommendation for someone of her age and gender is 25 grams.

What foods does she eat that are high in fiber?

ANSWER:

What foods does she eat that are high in added refined sugars?

She has fruit punch and jelly at breakfast, soda and a candy bar for a snack, and in the evening she has ice cream with cherry syrup.

What foods does she eat that are whole or unrefined sources of sugars?

ANSWER:

What could Emma eat for snacks instead of the soda and candy bar that would reduce her added refined sugars and increase her fiber intake?

ANSWER:

ALTERNATIVE SWEETENERS

America's love of sweets and the bad press surrounding sugar have driven the technological development of an increasing number of non-nutritive sweeteners (Figure 4.28). These sugar substitutes, which provide little or no energy, are added to a host of low-kcalorie and "light" foods such as yogurts, ice creams, and soft drinks. Although many sugar substitutes are technically not carbohydrates, they were developed to replace simple sugars in food products or as an alternative for table sugar at home. Alternative sweeteners consumed in reasonable amounts are generally safe for healthy people;⁵² however, to assure that they are not misused, the FDA has defined acceptable daily intakes (ADIs)—levels that should not be ex-



FIGURE 4.28 *There are a variety of sugar substitutes on the market. Consumers often recognize their favorite by the color of the packaging. (Andy Washnik)*

ceeded when using these products. The ADI is an estimate of the amount of the sweetener per kilogram of body weight that an individual can safely consume every day over a lifetime with minimal risk.

THE ROLE OF ALTERNATIVE SWEETENERS IN THE DIET The average American eats about 20.5 teaspoons of added sweeteners per day.⁵³ Replacing foods high in added sugars with foods sweetened with sugar substitutes will cut down on calories and decrease sugar intake, but it will not increase the intake of whole grains or fresh fruits and vegetables—key components of a healthy diet. Because foods that are high in added sugar tend to be nutrient-poor choices, replacing them with artificially sweetened alternatives does not increase the nutrient density of the diet. However, these products can be part of a healthy diet when used in moderation as part of a diet that is based on whole grains, vegetables, and fruits.

Alternative sweeteners have been shown to reduce the incidence of dental caries and can be helpful for managing blood sugar levels in diabetes, but their usefulness for weight loss has been more controversial. The rising consumption of sugared beverages has been blamed for the increasing prevalence of overweight in America.⁴ If individuals trying to lose weight replace sugar and high-sugar foods, such as soft drinks, with artificially sweetened products, they will lower their calorie intake. Short-term studies show that this lower energy intake can promote a reduction in body weight, but it is not possible to draw conclusions about the benefits for long-term weight maintenance.⁵⁴ Although alternative sweeteners can help reduce calorie intake, on their own they are not the solution to the obesity epidemic.

TYPES OF ALTERNATIVE SWEETENERS The main competitors in the artificial sweetener market in the United States today are saccharin, aspartame, sucralose, and acesulfame K (acesulfame potassium). These are used alone or in combination to sweeten a variety of foods. Stevia is a sugar substitute that is sold as a dietary supplement. Though it is used extensively in Japan, in the United States it is only sold as a dietary supplement; the FDA considers it an unapproved food additive. Cyclamate, an artificial sweetener that was popular in the 1960s, was banned by the FDA in 1969. It is still sold in Canada and some 50 other countries.

Saccharin Saccharin is a sweetener that is 200 to 700 times sweeter than sugar. In 1977, after large doses of saccharin were found to increase the incidence of bladder cancer in rats, the FDA proposed banning saccharin. However, the public and industry protested. In response to the outcry, a moratorium was imposed on the banning of saccharin, and all products containing saccharin were required to display a warning on the label informing the public that it may cause cancer. In May 2000, saccharin was dropped from the government's list of cancer-causing substances so this warning no longer appears on labels.

The intake of saccharin in the United States is estimated to be about 50 mg per person per day.⁵² The ADI is set at 5 mg per kg body weight per day. For a 154-pound (70-kg) individual, this would be 350 mg per day or 115 mg per day for a 50-pound (23-kg) child.⁵² A 12-ounce diet beverage sweetened with saccharin alone contains about 120 mg. A packet of sweetener contains 36 mg of saccharin.

If you snack on a candy bar, in general you will eat less later in the day. But if you consume extra energy from sweetened beverages, rather than solid food, you are less able to compensate for the extra calories.⁵⁵



For more information on low-calorie sweeteners, go to the Calorie Control Council at www.caloriecontrol.org/



Nutrition Facts	
Serving Size 3 pieces (36 g)	
Servings Per Container about 2.5	
Amount Per Serving	
Calories 110	Calories from Fat 40
%Daily Value*	
Total Fat 4.5g	7%
Saturated Fat 2.5g	13%
Trans Fat 0g	
Sodium 0mg	0%
Total Carbohydrate 28g	9%
Dietary Fiber 1g	4%
Sugars 0g	
Sugar Alcohols 27g	
Protein less than 1g	
Iron	2%
Not a significant source of cholesterol, vitamin A, vitamin C, and calcium.	
*Percent Daily Values are based on a 2,000 calorie diet.	

INGREDIENTS: MALTITOL; LACTITOL; (MILK); CHOCOLATE; ISOMALT; COCOA BUTTER; CONTAINS 2% OR LESS OF; SORBITOL; MILK FAT; POLYDEXTROSE; EGG WHITES; CREAM (MILK)*; SOY LECITHIN; PEPPERMINT OIL; SODIUM CASEINATE (MILK); VANILLIN; ARTIFICIAL FLAVOR; SUCRALOSE; AND PGPR (EMULSIFIER). (U) D
ADDS A NEGLIGIBLE AMOUNT OF SUGAR

FIGURE 4.29 The amount of sugar alcohols only needs to be included on food labels when a claim is made about the sugar or sugar alcohol content of the food. If the food contains only one type of sugar alcohol, the name of that sugar alcohol can be used. For products that contain more than one type, as is the case on the label from sugar-free candy shown here, the term “sugar alcohol” is used on the Nutrition Facts panel.

Aspartame In 1965, James Schlatter, at the pharmaceutical company G. D. Searle, was working with a chemical made up of two amino acids when he spilled some of the chemical on his fingers. Shortly afterward, he licked his finger to pick up a piece of paper and discovered an intensely sweet taste. This accidental discovery led to the development of the artificial sweetener aspartame. Since aspartame is made of two amino acids, the building blocks of protein, it is not a carbohydrate. Approved for some uses in the 1980s, aspartame is used in chewing gum, breakfast cereals, fruit spreads, yogurt, and beverages. Because aspartame breaks down when heated, it works best in products that are not cooked. Common trade names for this sweetener include NutraSweet, Equal, and NutriTaste. Each gram of aspartame contains 4 kcalories, but since it is about 200 times as sweet as sugar, only 1/200th as much of it needs to be used to achieve the same level of sweetness.

As with other artificial sweeteners, safety concerns have been raised about aspartame. It contains the amino acid phenylalanine and, therefore, can be dangerous to individuals with a genetic disorder called phenylketonuria (PKU). These individuals have an abnormality that affects the metabolism of phenylalanine. They must restrict their intake of this amino acid to prevent brain damage (see Chapter 6). There is also a concern that consuming aspartame might cause dangerously high blood phenylalanine levels in the general public. Phenylalanine occurs naturally in protein. A 4-ounce hamburger has 12 times more phenylalanine than a 12-ounce aspartame-sweetened soft drink. However, when phenylalanine is ingested without the other amino acids found in high-protein foods, blood and brain levels increase to a greater extent. Headaches, dizziness, seizures, nausea, allergic reactions, and other side effects have been reported following ingestion of aspartame; however, double-blind placebo-controlled studies have not been able to reproduce these symptoms.⁵² There has also been concern that the use of aspartame might be associated with an increased risk of brain cancer in children, but controlled studies found no evidence that aspartame is a carcinogen or that there is a correlation between aspartame use and brain cancer incidence.⁵⁶ Overall, the consensus of the scientific community is that aspartame is safe for most people.

The FDA has set an ADI of 50 mg of aspartame per kg of body weight. A packet of sweetener contains about 37 mg of aspartame. A 12-ounce soft drink sweetened with aspartame contains about 225 mg. To exceed the ADI, a 70-kg adult would have to consume almost 16 cans of aspartame-sweetened soft drinks a day and a 35-kg child would have to consume almost 8 cans of soft drinks.⁵²

Sucralose Sucralose (trichlorogalactosucrose) was discovered in 1976 and is the only noncaloric sweetener made from sugar. To make this sweetener the sugar molecule is modified so it cannot be digested and passes through the digestive tract unchanged. Approved for use in the United States in 1998, it is about 600 times sweeter than sucrose. It is sold as Splenda and can be used as a tabletop sweetener that is added directly to foods. Since it is heat stable, it can be used in baked goods.⁵² It is used in beverages, chewing gum, frozen desserts, puddings, jams and jellies, syrups, and many other products. It has been extensively tested for safety and found to be safe even for children and pregnant and lactating women.⁵⁷

Acesulfame K Marketed as Sunette or Sweet One, acesulfame potassium, or acesulfame K, is 200 times as sweet as sugar and provides no energy. It was approved for use in 1988 and is used in chewing gum, powdered drink mixes, gelatins, puddings, soft drinks, and nondairy creamers. It is heat stable, so it can be used in baking. The ADI has been set at 15 mg per kg body weight. A packet of sweetener contains about 50 mg of acesulfame K.

Neotame Neotame is a sugar substitute that is 7000 to 13,000 times sweeter than sucrose. Like aspartame it is made from the amino acids aspartic acid and phenylalanine, but the bond between the amino acids is harder to break than the bond in aspartame so it is more stable. Since it cannot be broken down into phenylalanine it is not a problem for people with PKU. The FDA approved the use of neotame as



a general-purpose sweetener in July 2002. Because it does not break down when heated it can be used in both cooking and baking applications as well as in foods and beverages that are not heated.

Sugar Alcohols Sugar alcohols, also called polyols, such as sorbitol, mannitol, lactitol, and xylitol are chemical derivatives of sugar that are used as low-kcalorie sweeteners. Because they are not digested, absorbed, or metabolized to the same extent as monosaccharides and disaccharides, they generally provide less energy than sucrose. Maltitol provides 3 kcalories per gram, lactitol 2 kcalories per gram, and erythritol only 0.2 kcalories per gram.

Sugar alcohols are not monosaccharides or disaccharides, so they can be used in products labeled “sugar free” or “no sugar added.” If a product uses these descriptors, the grams of sugar alcohols in a serving must be listed in the Nutrition Facts portion of the food label under carbohydrates (Figure 4.29). Products sweetened with sugar alcohols, such as chewing gums, candies, ice creams, and baked goods, may carry the health claim statement that they do not promote tooth decay. These products are less likely to promote tooth decay because the bacteria in the mouth cannot metabolize sugar alcohols as rapidly as sucrose. Consumption of large amounts of sugar alcohols (more than 50 grams of sorbitol or 20 grams of mannitol per day) can cause diarrhea.

SUGAR ALCOHOLS *Sweeteners that are structurally related to sugars but provide less energy than monosaccharides and disaccharides because they are not well absorbed.*

ALTHOUGH SHAMARA LOST WEIGHT BY CONSUMING A LOW-CARBOHYDRATE DIET, SHE COULDN'T STICK WITH IT FOR VERY LONG.

The diet plan was based on the premise that high-carbohydrate foods cause a sharp rise in blood sugar and insulin, thereby promoting the storage of body fat. The restrictions of this diet virtually eliminated several food groups—grains, fruits, and vegetables—from her diet. Shamara missed snacking on fruit and having sandwiches at lunch and pasta and rice at dinner, as well as cakes and cookies for dessert. She was always lightheaded and craving sweets. When she stopped her low-carb diet, she went back to her old ways of eating and her old weight crept back on. MyPyramid helped her understand that all carbohydrates are not equal. Added sugars and refined starches cause a sharp rise in blood sugar, which can promote fat deposition. Unrefined carbohydrates from whole grains, fruits, and vegetables do not have this effect. The fiber in these carbohydrate sources limits the rate that glucose is absorbed and hence dampens the rise in blood sugar and insulin. Shamara's new diet is flavorful and varied, and by watching portion sizes and minimizing her refined carbohydrate intake she has lost 4 pounds over the last 2 months. •

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POSTSCRIPT



APPLICATIONS

Personal nutrition:

- How much carbohydrate is in your diet?
 - Use the 3-day diet record you kept in Chapter 2 to calculate your average carbohydrate and energy intake.
 - What is the percent of energy from carbohydrate in your diet?
 - How does your percent carbohydrate compare with the recommended 45% to 65% of energy from carbohydrate?
- What are the sources of carbohydrate in your diet?
 - Are most of your carbohydrate choices from whole, minimally refined, or refined sources?
 - Suggest some changes that would increase your intake of less refined carbohydrates.
 - List some foods in your diet that are high in refined added sugars.
 - Suggest some changes that would reduce the amount of added sugar in your diet.
- How much fiber is in your diet?
 - Calculate the grams of fiber in your original diet using a computer software program or the exchanges in Table 4.3.
 - Does it meet the AI for fiber for someone of your age and gender?
 - How do the changes you suggested in question 2b affect the fiber content of your diet? If your modified diet still does not meet fiber recommendations, how might you further increase your intake?

General nutrition issues:

- Cheryl is trying to increase her fiber intake. For lunch she typically orders a sandwich from a local deli. Her favorite is turkey on a Kaiser roll with lettuce and mayo. Below, column A lists the types of bread available, column B lists the fillings, and column C lists the vegetables that can be added to the sandwiches. Can you suggest three different sandwiches for Cheryl that would provide more fiber than her typical sandwich.

COLUMN A	COLUMN B	COLUMN C
Kaiser roll	Sliced turkey	Lettuce
Sourdough bread	Soyburger	Tomatoes
Whole-wheat bread	Ham	Green and red peppers
Rye bread	Hummus	Onions
Sesame bagel	Falafel	Cucumber
Pumpernickel bread	Tuna salad	Olives
Pita bread	Peanut butter	Pickles
Oat bread	Grilled eggplant	Alfalfa sprouts

- Bob weighs about 30 pounds more than he wants to weigh, so he decides to try to shed pounds quickly with a low-carbohydrate weight-loss diet. The diet allows an unlimited amount of beef, chicken, and fish as well as limited fruits and vegetables; breads, grains, and cereals are not allowed. Bob is overjoyed with his initial rapid weight loss, but after about a week his weight loss slows down and he begins to feel tired and light-headed. He is having headaches and notices a funny smell on his breath. A nutritional assessment suggests that Bob needs about 2500 kcalories a day to maintain his weight. His weight-loss diet provides about 1000 kcalories, 25 g of carbohydrate, 125 g of protein, and 44 g of fat per day. He consumes only about 3 cups of fluid daily.
 - Explain why Bob is tired, light-headed, and has headaches and an unusual odor on his breath.
 - What recommendations do you have to reduce these symptoms?
- Go to a bookstore or the library and look up a sample 1-day menu from a diet book that advocates a low-carbohydrate intake. Enter these foods into the diet analysis computer program.
 - How does this diet compare to the recommended intakes for saturated fat?
 - For calcium?
 - For fiber?

SUMMARY

- Some of the carbohydrates in our diets are from unrefined whole foods such as whole grains, fruits, and vegetables. Others are from refined grain products like white breads and baked goods or added sugars such as those found in candies and soft drinks. Whole grains include the entire grain kernel, which is rich in fiber, micronutrients, and phytochemicals. Added sugars provide energy but few nutrients so they reduce the nutrient density of the diet.
- Carbohydrates are chemical compounds that contain carbon, hydrogen, and oxygen. Simple carbohydrates include monosaccharides and disaccharides and are found in foods such as table sugar, honey, milk, and fruit. Complex carbohydrates include oligosaccharides, polysaccharides, and fiber. Glycogen is a polysaccharide found in animals, and starch and fiber are polysaccharides found in plants.



3. Dietary sugars and starches are broken down in the digestive tract to monosaccharides that can be absorbed into the bloodstream. If the enzyme lactase is lacking, as in lactose intolerance, lactose cannot be digested and passes into the colon. It draws water into the colon and the bacteria there digest it forming gas and acids, resulting in intestinal cramps, gas, and diarrhea.
4. Fiber, some oligosaccharides, and resistant starch are carbohydrates that are not broken down by human digestive enzymes in the stomach and small intestine and therefore pass into the colon. These indigestible carbohydrates benefit health by increasing the amount of water and bulk in the intestine, which stimulates GI motility; promoting the growth of a healthy microflora; and slowing nutrient absorption. These carbohydrates can increase the amount of intestinal gas produced, but this is usually only a problem if intake is increased suddenly.
5. In the body, carbohydrates provide a source of energy—4 kcalories per gram. They also have essential roles as components of DNA and RNA, breast milk, and molecules involved in cell communication and those needed for cushioning and lubrication.
6. Glucose is metabolized through cellular respiration, involving glycolysis, which breaks glucose into pyruvate, forms some ATP, and releases electrons; acetyl-CoA formation, which produces carbon dioxide and electrons; the citric acid cycle, which produces carbon dioxide, electrons, and some ATP; and the electron transport chain, which produces water and uses the energy from electrons to generate ATP. Several tissues, including the brain and red blood cells, require glucose as an energy source. When glucose is not available it can be obtained from the breakdown of glycogen or synthesized from amino acids by the process of gluconeogenesis.
7. Blood glucose rises after eating. How quickly and how high blood glucose rises is referred to as glycemic response. Glycemic response can be quantified using glycemic index or glycemic load. Blood glucose levels are maintained within normal limits by the hormones insulin and glucagon. When blood glucose rises, insulin is released from the pancreas to allow body cells to take up the glucose. When blood glucose falls, glucagon is released to increase blood glucose.
8. Diabetes is an abnormality in blood sugar regulation resulting in high blood glucose levels, which damage tissues and cause complications including heart disease, kidney failure, blindness, and amputations. Diabetes occurs either because insufficient insulin is produced or because there is a decrease in the sensitivity of body cells to insulin. Treatment to maintain glucose in the normal range includes diet, exercise, and medications. Hypoglycemia is a condition in which blood glucose falls to abnormally low levels, causing symptoms such as sweating, headaches, and rapid heartbeat.
9. When carbohydrates, particularly simple carbohydrates, remain in contact with the teeth they increase the risk of dental caries. Sugar consumption has not been found to contribute to hyperactivity in children.
10. Consumption of unrefined carbohydrates can reduce glycemic response, enhance satiety, and help maintain weight. When consumed in excess of needs, carbohydrates contribute to weight gain. Low-carbohydrate diets cause ketosis and have been found to be effective for weight loss in the short term but compliance and health risks may be a problem in the long term.
11. The type of carbohydrate affects the risk of diabetes and heart disease. Refined carbohydrates cause a larger glycemic response than unrefined sources and are associated with an increased risk of type 2 diabetes. Unrefined carbohydrates blunt glycemic response. High-sugar diets can increase heart disease risk by raising blood lipids. Unrefined carbohydrates help lower blood lipids and bring with them other dietary components that help protect you from heart disease.
12. Indigestible carbohydrates make the stool larger and softer. This reduces the pressure needed to move material through the colon, lowering the risk of constipation, hemorrhoids, and diverticular disease.
13. Cancer cells differ from normal cells because they divide without restraint and are able to grow in areas reserved for other cells. Cells in the colon may be affected by exposure to carcinogens in the colon contents. Fiber may help reduce the risk of colon cancer by decreasing the amount of contact between the cells lining the colon and these carcinogenic substances.
14. Guidelines for healthy diets recommend 45% to 65% of energy from carbohydrates and a fiber intake of 38 grams per day for men and 25 grams per day for women. To meet these recommendations complex carbohydrates should be chosen from whole grains, legumes, fruits, and vegetables and simple carbohydrates from fruits, vegetables, and milk. Foods high in added sugars, such as baked goods, candy, and soft drinks should be limited.
15. Alternative sweeteners can be used to reduce the amount of added sugar in the diet. They do not contribute to tooth decay and can help diabetics keep blood sugar in the normal range. They can also be used by dieters to reduce the energy content of the diet.

REVIEW QUESTIONS

1. What foods are good sources of unrefined complex carbohydrates? Unrefined simple carbohydrates?
2. What is the basic unit of carbohydrate?
3. List three common simple carbohydrates. Where are they found in the diet or in the body?
4. Describe three types of complex carbohydrates.
5. Why is added sugar considered a source of empty kcalories?
6. How much energy is provided by a gram of carbohydrate?
7. Explain how fiber affects gastrointestinal health.
8. Describe what happens during the process of glycolysis.
9. What are the end products of cellular respiration? During which step is each produced?



10. Explain why carbohydrate is said to spare protein.
11. What is the main function of glucose in the body?
12. What is diabetes and what are the long-term complications of this disease?
13. Why is ketosis a problem only in type 1 diabetes?
14. What health benefits are associated with a diet high in unrefined carbohydrates?
15. How can you use the information on food labels to help you identify foods that are high in added sugars? In fiber?
16. What are the risks and benefits of alternative sweeteners?

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