Carbohydrates: Sugar, Starch, Glycogen, and Fiber

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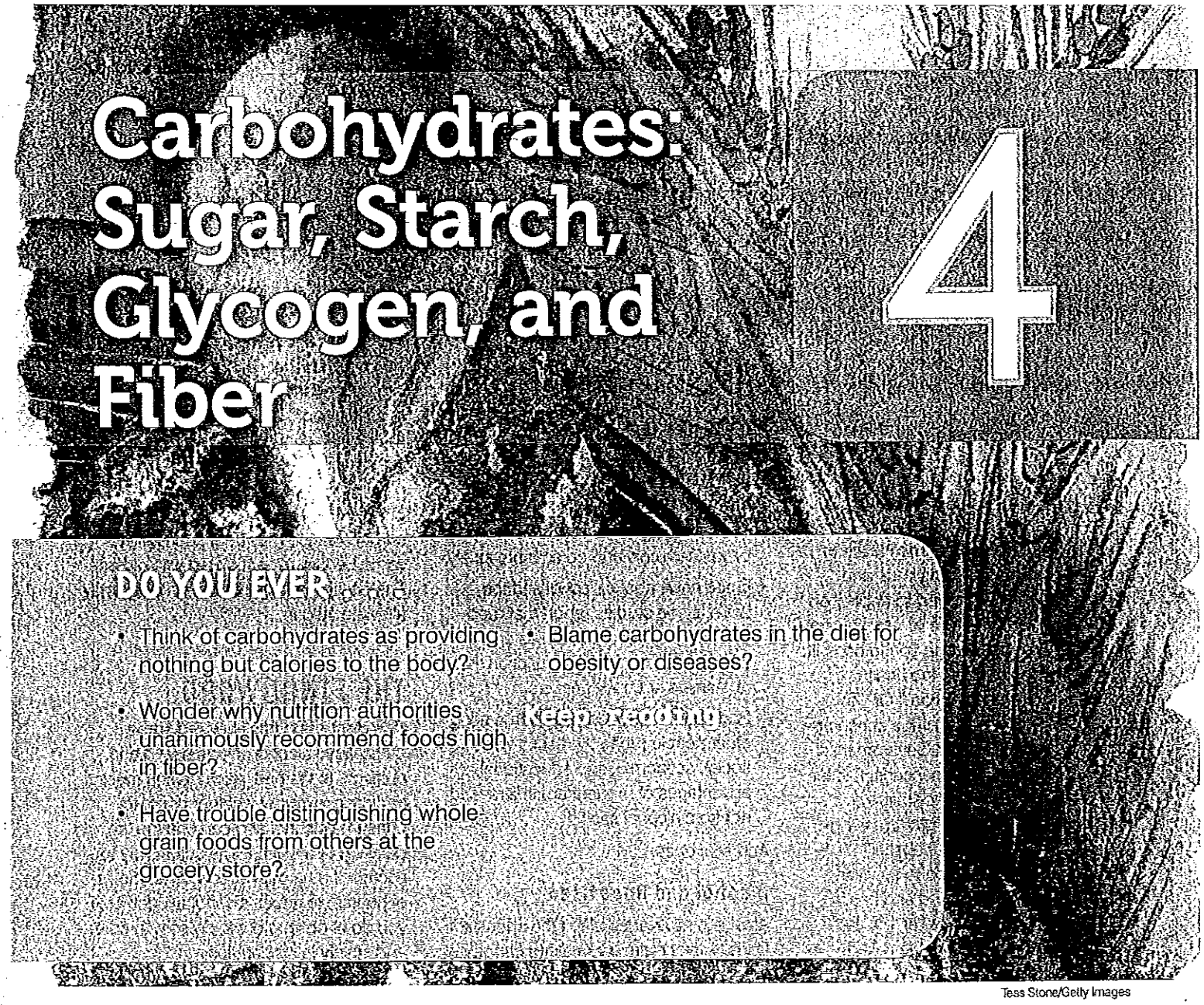

DO YOU EVER . . .

- Think of carbohydrates as providing nothing but calories to the body?
- Wonder why nutrition authorities unanimously recommend foods high in fiber?
- Have trouble distinguishing whole-grain foods from others at the grocery store?
- Blame carbohydrates in the diet for obesity or diseases?

Tess Stone/Getty Images

Learning Objectives

To find learning objective topics in this chapter, look for the text headings with a corresponding "LO" number above the heading. After completing this chapter, you should be able to accomplish the following:

LO 4.1 Describe the major types of carbohydrates, and identify their food sources.

LO 4.2 Describe the various roles of carbohydrates in the body, and explain why avoiding dietary carbohydrates may be ill-advised.

LO 4.3 Summarize how fiber differs from other carbohydrates and how fiber may contribute to health.

LO 4.4 Explain how complex carbohydrates are broken down in the digestive tract and absorbed into the body.

LO 4.5 Describe how hormones control blood glucose concentrations during fasting and feasting.

LO 4.6 Explain the term *glycemic index* and how it may relate to diet planning.

LO 4.7 Describe the scope of the U.S. diabetes problem and educate someone about the long- and short-term effects of untreated diabetes and prediabetes.

LO 4.8 Name components of a lifestyle plan to effectively control blood glucose and describe the characteristics of a diet that can assist in managing type 2 diabetes.

LO 4.9 Compare the symptoms of postprandial hypoglycemia with those of fasting hypoglycemia, and name some diseases associated with the latter type.

LO 4.10 Discuss current research regarding the relationships among dietary carbohydrates, obesity, diabetes, and other ills.

Carbohydrates are ideal nutrients to meet your body's energy needs, to feed your brain and nervous system, to keep your digestive system fit, and within calorie limits, to help keep your body lean. Digestible carbohydrates, together with fats and protein, add bulk to foods and provide energy and other benefits for the body. Indigestible carbohydrates, which include most of the fibers in foods, yield little or no energy but provide other important benefits.

All carbohydrates are not equal in terms of nutrition. This chapter invites you to learn the differences between foods containing **complex carbohydrates** (starch and fiber) and those made of **simple carbohydrates** (the sugars) and to consider the effects of both on the body. Controversy 4 goes on to explore current theories about how consumption of certain carbohydrates may affect human health.

This chapter on the carbohydrates is the first of three on the energy-yielding nutrients. Chapter 5 deals with the fats and Chapter 6 with protein. Controversy 3 in Chapter 3 already addressed one other contributor of energy to the human diet, alcohol.

LO 4.1

A Close Look at Carbohydrates

Carbohydrates contain the sun's radiant energy, captured in a form that living things can use to drive the processes of life. Green plants make carbohydrate through **photosynthesis** in the presence of **chlorophyll** and sunlight. In this process, water (H_2O) absorbed by the plant's roots donates hydrogen and oxygen. Carbon dioxide gas (CO_2) absorbed into its leaves donates carbon and oxygen. Water and carbon dioxide combine to yield the most common of the **sugars,** the single sugar **glucose.** Scientists know the reaction in the minutest detail but have yet to reproduce it—green plants are required to make it happen (see Figure 4-1).[1*]

Light energy from the sun drives the photosynthesis reaction. The light energy becomes the chemical energy of the bonds that hold six atoms of carbon together in the sugar glucose. Glucose provides energy for the work of all the cells of the stem, roots, flowers, and fruits of the plant. For example, in the roots, far from the energy-giving rays of the sun, each cell draws upon some of the glucose made in the leaves, breaks it down (to carbon dioxide and water), and uses the energy thus released to fuel its own growth and water-gathering activities.

Plants do not use all of the energy stored in their sugars, so it remains available for use by the animal or human being that consumes the plant. Thus, carbohydrates form the first link in the food chain that supports all life on earth. Carbohydrate-rich foods come almost exclusively from plants; milk is the only animal-derived food that contains significant amounts of carbohydrate. The next few sections describe the forms assumed by carbohydrates: sugars, starch, glycogen, and fiber.

KEY POINT Through photosynthesis, plants combine carbon dioxide, water, and the sun's energy to form glucose. Carbohydrates are made of carbon, hydrogen, and oxygen held together by energy-containing bonds: *carbo* means "carbon"; *hydrate* means "water."

Sugars

Six sugar molecules are important in nutrition. Three of these are single sugars, or **monosaccharides.** The other three are double sugars, or **disaccharides.** All of their chemical names end in *ose,* which means "sugar." Although they all sound alike at first, they exhibit distinct characteristics once you get to know them as individuals. Figure 4-2 shows the relationships among the sugars.

carbohydrates compounds composed of single or multiple sugars. The name means "carbon and water," and a chemical shorthand for carbohydrate is CHO, signifying carbon (C), hydrogen (H), and oxygen (O).

complex carbohydrates long chains of sugar units arranged to form starch or fiber; also called *polysaccharides.*

simple carbohydrates sugars, including both single sugar units and linked pairs of sugar units. The basic sugar unit is a molecule containing six carbon atoms, together with oxygen and hydrogen atoms.

photosynthesis the process by which green plants make carbohydrates from carbon dioxide and water using the green pigment chlorophyll to capture the sun's energy (*photo* means "light"; *synthesis* means "making").

chlorophyll the green pigment of plants that captures energy from sunlight for use in photosynthesis.

sugars simple carbohydrates; that is, molecules of either single sugar units or pairs of those sugar units bonded together. By common usage, *sugar* most often refers to sucrose.

glucose (GLOO-cose) a single sugar used in both plant and animal tissues for energy; sometimes known as blood sugar or *dextrose.*

monosaccharides (mon-oh-SACK-ah-rides) single sugar units (*mono* means "one"; *saccharide* means "sugar unit").

disaccharides pairs of single sugars linked together (*di* means "two").

*Reference notes are found in Appendix F.

FIGURE 4.1

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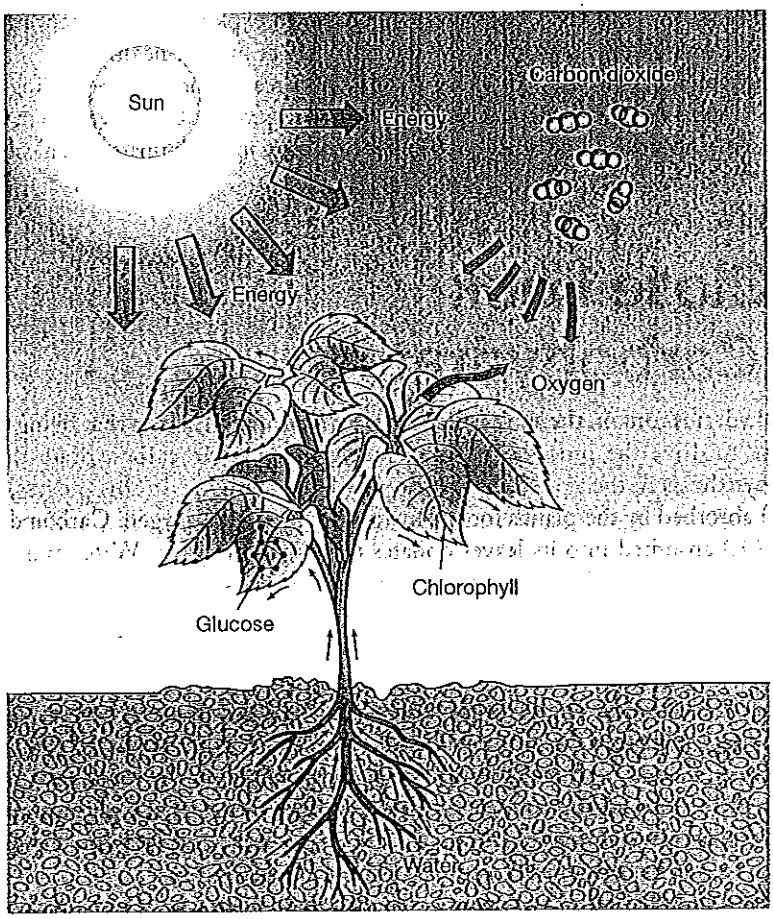
Carbohydrate—Mainly Glucose—Is Made by Photosynthesis

The sun's energy becomes part of the glucose molecule—its calories, in a sense. In the molecule of glucose on the leaf here, black dots represent the carbon atoms; bars represent the chemical bonds that contain energy.



- Single sugars are monosaccharides.
- Pairs of sugars are disaccharides.

fructose (FROOK-tose) a monosaccharide; sometimes known as fruit sugar (*fruct* means "fruit"; *ose* means "sugar").

galactose (ga-LACK-tose) a monosaccharide; part of the disaccharide lactose (milk sugar).

lactose a disaccharide composed of glucose and galactose; sometimes known as milk sugar (*lact* means "milk"; *ose* means "sugar").

maltose a disaccharide composed of two glucose units; sometimes known as malt sugar.

sucrose (SOO-crose) a disaccharide composed of glucose and fructose; sometimes known as table, beet, or cane sugar and, often, as simply *sugar*.

Monosaccharides The three monosaccharides are glucose, fructose, and galactose. **Fructose** or fruit sugar, the intensely sweet sugar of fruit, is made by rearranging the atoms in glucose molecules. Fructose occurs mostly in fruits, in honey, and as part of table sugar. Other sources include soft drinks, ready-to-eat cereals, and other products sweetened with high-fructose corn syrup (defined later on). Glucose and fructose are the most common monosaccharides in nature.

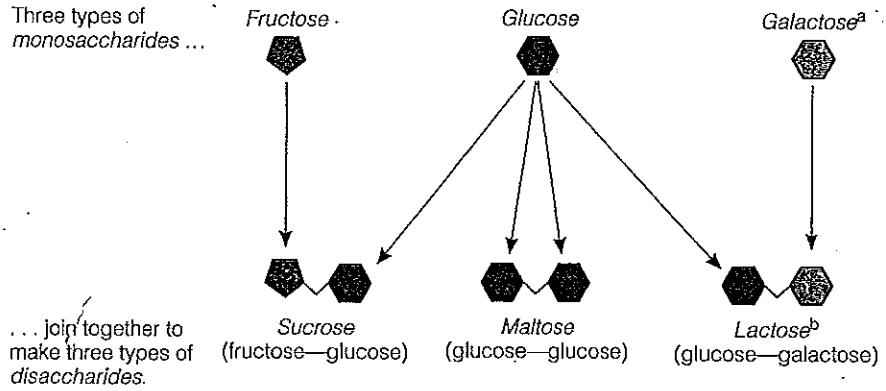
The other monosaccharide, galactose, has the same number and kind of atoms as glucose and fructose but in another arrangement. **Galactose** is one of two single sugars that are bound together to make up the sugar of milk. Galactose rarely occurs free in nature but is tied up in milk sugar until it is freed during digestion.

Disaccharides The three other sugars important in nutrition are disaccharides, which are linked pairs of single sugars, or disaccharides. They are lactose, maltose, and sucrose. All three contain glucose. In **lactose,** the milk sugar just mentioned, glucose is linked to galactose. Malt sugar, or **maltose,** has two glucose units. Maltose appears wherever starch is being broken down. It occurs in germinating seeds and arises during the digestion of starch in the human body.

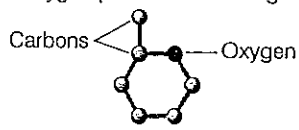
The last of the six sugars, **sucrose,** is familiar table sugar, the product most people think of when they refer to *sugar.* In sucrose, fructose and glucose are bonded to-

FIGURE 4-2 How Monosaccharides Join to Form Disaccharides

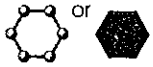
Single sugars are monosaccharides while pairs of sugars are disaccharides.



A note on the glucose symbol:
The glucose molecule is really a ring of 5 carbons and 1 oxygen plus a carbon "flag."



For convenience, glucose is symbolized as



[a] *Galactose does not occur in foods singly but only as part of lactose.*
[b] *The chemical bond that joins the monosaccharides of lactose differs from those of other sugars and makes lactose hard for some people to digest—lactose intolerance (see later section).*

gether. Table sugar is obtained by refining the juice from sugar beets or sugarcane, but sucrose also occurs naturally in many vegetables and fruits. It tastes sweet because it contains the sweetest of the monosaccharides, fructose.

When you eat a food containing monosaccharides, you can absorb them directly into your blood. When you eat disaccharides, though, you must digest them first. Enzymes in your intestinal cells must split the disaccharides into separate monosaccharides so that they can enter the bloodstream. The blood delivers all products of digestion first to the liver, which possesses enzymes to modify nutrients, making them useful to the body. Glucose is the most used monosaccharide inside the body, so the liver quickly converts fructose or galactose to glucose or to smaller compounds that can serve as building blocks for glucose, fat, or other needed molecules.

Although it is true that the energy of fruits and many vegetables comes from sugars, this doesn't mean that eating them is the same as eating concentrated sweets such as candy or drinking cola beverages. From the body's point of view, fruits are vastly different from purified sugars (as a later section makes clear) except that both provide glucose in abundance.

KEY POINT Glucose is the most important monosaccharide in the human body. Most other monosaccharides and disaccharides become glucose in the body.

CONCEPT LINK 4-1

The digestive system was introduced in Chapter 3 (page 78).

Starch

- Strands of many monosaccharides are polysaccharides.

In addition to occurring in sugars, the glucose in food also occurs in long strands of thousands of glucose units. These are the **polysaccharides** (see Figure 4-3). **Starch** is a polysaccharide, as are glycogen and most of the fibers.

Starch is a plant's storage form of glucose. As a plant matures, it not only provides energy for its own needs but also stores energy in its seeds for the next generation. For example, after a corn plant reaches its full growth and has many leaves manufacturing glucose, it links glucose together to form starch, stores packed clusters of starch molecules in **granules,** and packs the granules into its seeds. These giant starch clusters are packed side by side in the kernels of corn. For the plant, starch is useful because it is an insoluble substance that will stay with the seed in the ground and nourish it until it forms shoots with leaves that can catch the sun's rays. Glucose, in contrast, is soluble in water and would be washed away by the rains while the seed lay in the soil. The starch of corn and other plant foods is nutritive for people,

polysaccharides another term for complex carbohydrates; compounds composed of long strands of glucose units linked together (*poly* means "many"). Also called *complex carbohydrates.*

starch a plant polysaccharide composed of glucose. After cooking, starch is highly digestible by human beings; raw starch often resists digestion.

granules small grains. Starch granules are packages of starch molecules. Various plant species make starch granules of varying shapes.

FIGURE 4-3

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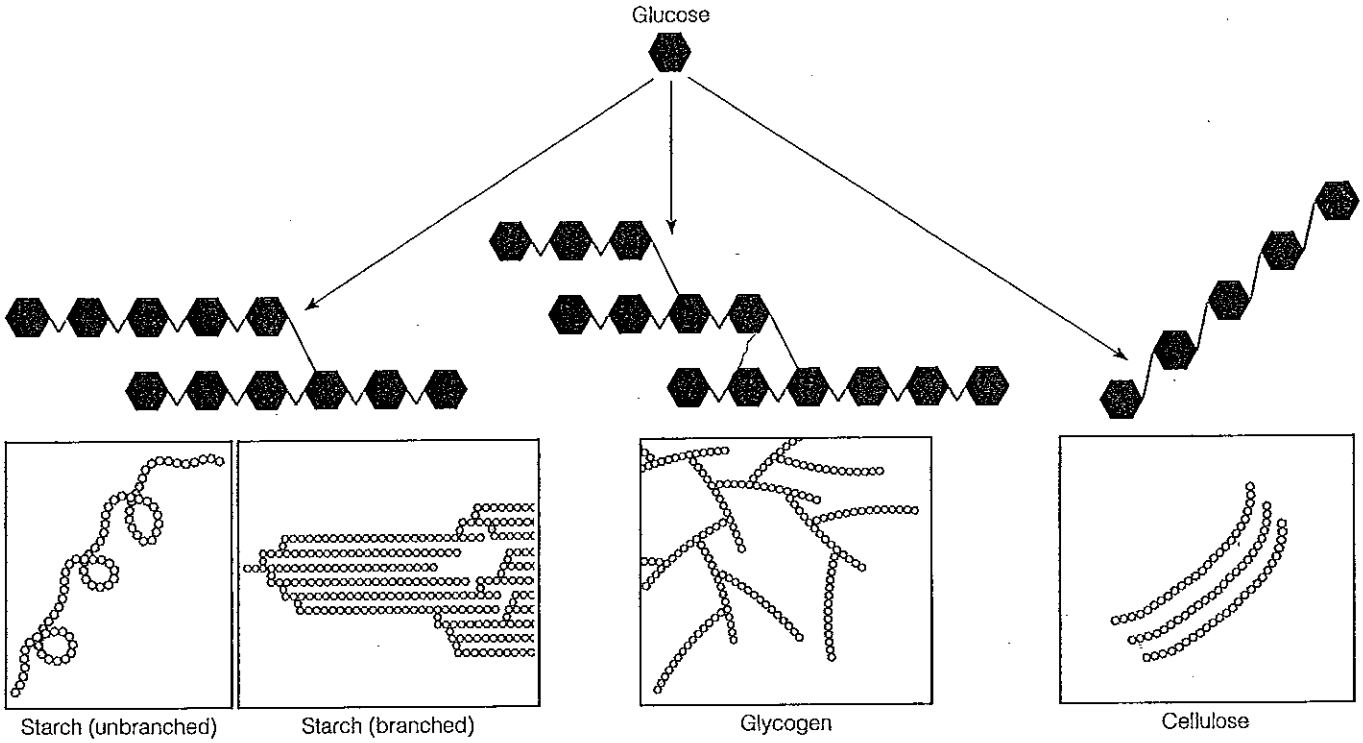
How Glucose Molecules Join to Form Polysaccharides

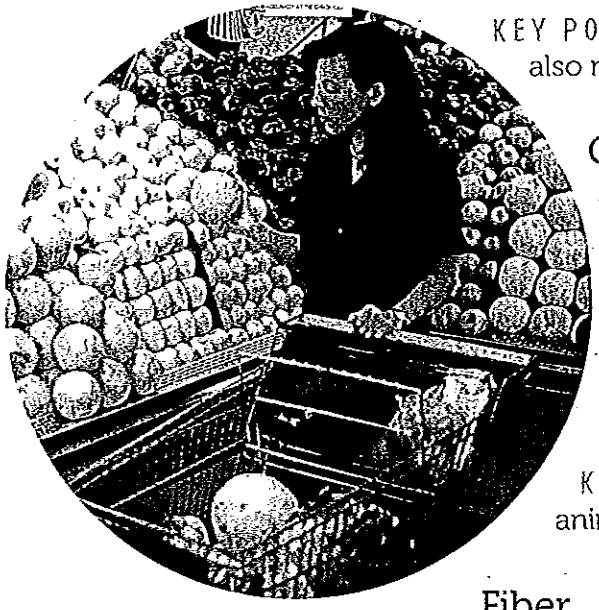


Starch Glucose units are linked in long, occasionally branched chains to make starch. Human digestive enzymes can digest these bonds, retrieving glucose. Real glucose units are so tiny that you can't see them, even with the highest-power light microscope.

Glycogen Glycogen resembles starch in that the bonds between its glucose units can be broken by human enzymes, but the chains of glycogen are more highly branched.

Cellulose (fiber) The bonds that link glucose units together in cellulose are different from the bonds in starch or glycogen. Human enzymes cannot digest them.

too, because they can digest the starch to glucose and extract the sun's energy stored in its chemical bonds. A later section describes starch digestion in detail.



© Gaia/SuperStock

The sugars in fruit are diluted with water and naturally packaged with vitamins, minerals, phytochemicals, and fiber.

KEY POINT Starch is the storage form of glucose in plants and is also nutritive for human beings.

Glycogen

Just as plant tissues store glucose in long chains of starch, animal bodies store glucose in long chains of **glycogen.** Glycogen resembles starch in that it consists of glucose molecules linked together to form chains, but its chains are longer and more highly branched (see Figure 4-3). Unlike starch, which is abundant in grains, potatoes, and other foods from plants, glycogen is nearly undetectable in meats because glycogen breaks down rapidly when the animal is slaughtered. A later section describes how the human body handles its own packages of stored glucose.

KEY POINT Glycogen is the storage form of glucose in animals and human beings.

Fiber

Some of the **fibers** of a plant form the supporting structures of its leaves, stems, and seeds. Other fibers play other roles, for example, to retain water and thus protect

seeds from drying out. Like starch, most fibers are polysaccharides—chains of sugars—but they differ from starch in that the sugar units are held together by bonds that human digestive enzymes cannot break. Most fibers therefore pass through the human body without providing energy for its use. Billions of bacteria residing within the human large intestine, however, do possess enzymes that can digest fibers to varying degrees by fermenting them.[2] Through this process, the fibers are broken down to waste products, mainly tiny fat fragments that the large intestine (colon) absorbs. Many animals, such as cattle, depend heavily on their digestive system's bacteria to make the energy of glucose available from the abundant cellulose, a form of fiber, in their fodder. Thus, when we eat beef, we indirectly receive some of the sun's energy that was originally stored in the fiber of the plants. Beef itself contains no fiber, nor do other meats and dairy products.

Researchers often divide fibers into two general groups by their chemical, physical, and functional properties.[†3] In the first group are fibers that dissolve in water (**soluble fibers**). These form gels (are **viscous**) and are easily digested by bacteria in the human colon (are easily fermented). Commonly found in oats, barley, legumes, and citrus fruits, soluble fibers often lower blood cholesterol and can help to control blood glucose, thus protecting against heart disease and diabetes.[4] In foods, soluble fibers add pleasing consistency, such as the pectin that puts the gel in jelly and the gums added to salad dressings to thicken them.

Other fibers (**insoluble fibers**) do not dissolve in water, do not form gels (are not viscous), and are less readily fermented. Insoluble fibers, such as cellulose, are found in the outer layers of whole grains (bran), the strings of celery, the hulls of seeds, and the skins of corn kernels. These fibers retain their structure and rough texture even after hours of cooking. In the body, they aid the digestive system by easing elimination.

In summary, plants combine carbon dioxide, water, and the sun's energy to form glucose, which can be stored as the polysaccharide starch. Then animals or people eat the plants and retrieve the glucose. In the body, the liver and muscles may store the glucose as the polysaccharide glycogen, but ultimately it becomes glucose again. The glucose delivers the sun's energy to fuel the body's activities. In the process, glucose breaks down to the waste products carbon dioxide and water, which are excreted. Later, these compounds are used again by plants as raw materials to make carbohydrate. Fibers are plant constituents that are not digested directly by human enzymes, but their presence in the diet contributes to the health of the body.

KEY POINT Human digestive enzymes cannot break the bonds in fiber, so most of it passes through the digestive tract unchanged. Some fiber, however, is susceptible to fermentation by bacteria in the colon.

Fiber characteristics in foods:

- *Soluble, viscous, fermentable fibers are often gummy or add thickness to foods.*
- *Insoluble, nonviscous, less fermentable fibers are often tough, stringy, or gritty in foods.*

• Chapter 15 revisits humankind's relationship with the earth's food chain.

LO 4.2, 4.3

The Need for Carbohydrates

Glucose from carbohydrate is an important fuel for most body functions. Only two other nutrients provide energy to the body: protein and fats. Protein-rich foods are usually expensive and, when used to make fuel for the body, they provide no advantage over carbohydrates. Moreover, overuse of dietary protein has disadvantages, as explained in Chapter 6. Fats normally are not used as fuel by the brain and central nervous system. Thus, glucose is a critical energy source, particularly for nerve cells, including those of the brain. And starchy whole foods that supply complex carbohydrates—and especially the fiber-rich ones—are the preferred source of glucose in the diet.

glycogen (GLY-co-gen) a highly branched polysaccharide that is made and stored by liver and muscle tissues of human beings and animals as a storage form of glucose. Glycogen is not a significant food source of carbohydrate and is not counted as one of the complex carbohydrates in foods.

fibers the indigestible parts of plant foods, largely nonstarch polysaccharides that are not digested by human digestive enzymes, although some are digested by resident bacteria of the colon. Fibers include cellulose, hemicelluloses, pectins, gums, mucilages, and the nonpolysaccharide lignin.

soluble fibers food components that readily dissolve in water and often impart gummy or gel-like characteristics to foods. An example is pectin from fruit, which is used to thicken jellies. Soluble fibers are indigestible by human enzymes but may be broken down to absorbable products by bacteria in the digestive tract.

viscous (VISS-cuss) having a sticky, gummy, or gel-like consistency that flows relatively slowly.

insoluble fibers the tough, fibrous structures of fruits, vegetables, and grains; indigestible food components that do not dissolve in water.

[†]The committee on Dietary Reference Intakes (DRI) proposed other fiber definitions to accommodate products that may contain new fiber sources, but consumers may find these too confusing to be used on food labels.

Did You Know?

Alcohol provides energy but it is a toxin, not a nutrient.

Sugars also play vital roles in the functioning of body tissues. For example, sugars that dangle from protein molecules, once thought to be mere hitchhikers, are now known to dramatically alter the shape and function of certain proteins. Such a sugar-protein complex is responsible for the slipperiness of mucus, the watery lubricant that coats and protects the body's internal linings and membranes. Sugars also bind to the outside of cell membranes, affecting cell-to-cell communication, nerve and brain cell function, and certain disease processes. Clearly, the body needs carbohydrates for more than just energy.

If I Want to Lose Weight and Stay Healthy, Should I Avoid Carbohydrates?

Many popular books and magazines wrongly accuse carbohydrates of being the "fattening" ingredient of foods, thereby misleading millions of weight-conscious people into eliminating nutritious carbohydrate-rich foods from their diets.[5] In truth, people who wish to lose fat, maintain lean tissue, and stay healthy can do no better than to attend closely to portion sizes and calorie intakes and to design their diets around carbohydrate-rich whole foods that supply fiber, other needed nutrients, and beneficial phytochemicals.[6]

Lower in Calories

Gram for gram, carbohydrates donate fewer calories than do dietary fats, and converting glucose into fat for storage is metabolically costly. Still, it is possible to consume enough calories of carbohydrate to exceed the need for energy, which reliably leads to weight gain. To lose weight, the dieter must plan a diet to provide fewer calories from all sources that are needed by the body each day; Chapter 9 describes the roles energy nutrients play in management of body weight.

- 1 gram carbohydrates = 4 calories
- 1 gram fat = 9 calories

CONCEPT LINK 4-2

Chapter 1 defined a gram (g) as a unit of weight used in nutrition (page 6).

CONCEPT LINK 4-3

Chapter 2 describes discretionary calories as the balance of calories remaining in a person's energy allowance after consuming the nutrient-dense foods sufficient to meet the day's nutrient needs (page 41).

- Details about controlling body fatness are in Chapter 9.

An Exception: Refined Sugars

Recommendations to choose carbohydrate-rich foods do not extend to refined added sugars. Purified, refined sugars (mostly sucrose or fructose) contain no other nutrients—no protein, vitamins, minerals, or fiber—and thus are low in nutrient density.[7] A person choosing 400 calories of sugar in place of 400 calories of whole-grain bread loses the protein, vitamins, minerals, phytochemicals, and fiber of the bread. You can afford to do this only if you have already met all of your nutrient needs for the day and still have discretionary calories to spend.

Overuse of sugars may have other effects as well. Some evidence suggests that, for many obese people, a diet too high in added sugars and other refined carbohydrates may alter blood lipids in ways that may worsen their heart disease risk (Controversy 4 comes back to this topic).[8] For these people, weight loss on a calorie-controlled diet that provides the recommended amounts of whole grains, legumes, fruits, and vegetables reduces the blood lipid response to sugars and lowers their heart disease risk. In fact, consumption of whole grains consistently lowers the risk of cardiovascular diseases, including heart disease, in research studies.[9]

Guidelines

For health's sake, then, most people should increase their intakes of fiber-rich whole food sources of carbohydrates and reduce intakes of foods high in refined white flour, added sugars, and the kinds of fats associated with heart disease (see Chapter 5).[10] Table 4-1 presents carbohydrate recommendations and guidelines from several authorities. This chapter's Consumer Corner describes various whole-grain foods, and the Food Feature comes back to the sugars in foods. As for weight loss, authorities do not recommend omitting carbohydrates. In fact, many recommend the opposite.

- The DRI committee recommends that 45 to 65 percent of daily calories come from carbohydrate. An example of how to convert this recommendation into grams of carbohydrate in the diet is found in the Food Feature on page 136.

KEY POINT The body tissues use carbohydrates for energy and other functions; the brain and nerve tissues prefer carbohydrate as fuel. Nutrition authorities recommend a diet based on foods rich in complex carbohydrates and fiber.

TABLE 4-1 Recommendations Concerning Intakes of Carbohydrates

1. Recommendations for total carbohydrates

   Dietary Guidelines for Americans
   - Consume between 45% and 65% of calories from carbohydrate.

   Dietary Reference Intakes (DRI)
   - At a minimum, 130 grams per day for adults and children to provide glucose to the brain.
   - For health, most people should consume between 45% and 65% of total calories from carbohydrate.

   USDA Food Guide, MyPyramid
   - Grains, fruit, starchy vegetables, and milk contribute to the day's total carbohydrate intake.

2. Recommendations for added sugars

   Dietary Guidelines for Americans
   - Choose and prepare foods and beverages with little added sugars.

   Dietary Reference Intakes (DRI)
   - Insufficient evidence exists to set an upper limit for added sugars; however, the DRI committee suggests a high maximum of 25% or less of total calories for people who otherwise meet their nutrient needs, maintain a healthy body weight, and need additional energy.[a]

   USDA Food Guide, MyPyramid
   - Added sugars may provide discretionary calories within the energy recommendation after meeting all nutrient recommendations with nutritious foods.

   The American Heart Association
   - A prudent upper limit of not more than one-half the discretionary calorie allowance (no more than 100 calories of added sugars for most women or 150 calories for most men).

3. Recommendations for fiber

   USDA Food Guide, MyPyramid
   - Increase intakes of whole fruits and vegetables, make at least half the grain choices whole grains, and choose legumes several times per week.

   Dietary Reference Intakes (DRI)
   - 38 grams of total fiber per day for men through age 50; 30 grams for men 51 and older.
   - 25 grams of total fiber per day for women through age 50; 21 grams for women 51 and older.

[a]*An example might be an athlete in training whose high energy need allows greater amounts of added sugars from sports drinks without compromising nutrient intakes; for most sedentary people, maximums of 3 to 12 teaspoons per day are suggested.*

Why Do Nutrition Experts Recommend Fiber-Rich Foods? ☆

As mentioned, carbohydrate-rich foods offer additional benefits if they are also rich in fiber. Foods such as whole grains, vegetables, legumes, and fruits supply valuable vitamins, minerals, and phytochemicals, along with a healthy dose of fiber and little or no fat. Fiber's best-known health benefits include:

1. Promotion of normal blood cholesterol concentrations and reduced risk of heart disease.
2. Control of blood pressure (reduced risk of hypertension).[11]
3. Modulation of blood glucose concentrations (reduced risk of diabetes).
4. Maintenance of healthy bowel function (reduced risk of bowel diseases).
5. Promotion of a healthy body weight.

The obvious choice for anyone placing a value on health is to obtain fibers from a variety of sources each day.

Figure 4-4 shows the diverse effects of different fibers, and Figure 4-5 provides a brief guide to finding these fibers in foods. Most unrefined plant foods contain a mix of fiber types. The following paragraphs describe health benefits associated with daily intakes of these foods.

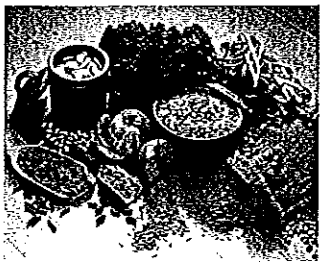
• Appendix A lists the fiber contents of over 2,000 foods.

KEY POINT Fiber-rich diets benefit the body by helping to normalize blood cholesterol and blood glucose and by maintaining healthy bowel function. They are also associated with healthy body weight.

Lower Cholesterol and Heart Disease Risk Diets rich in legumes, vegetables, and whole grains—and therefore rich in complex carbohydrates—may protect against heart disease and stroke. Such diets are generally low in saturated fat, *trans* fat, and cholesterol and high in fibers, vegetable proteins, and phytochemicals—all factors associated with a lower risk of heart disease.[12] Oatmeal was first to be identified among cholesterol-lowering foods; apples, barley, carrots, and legumes are

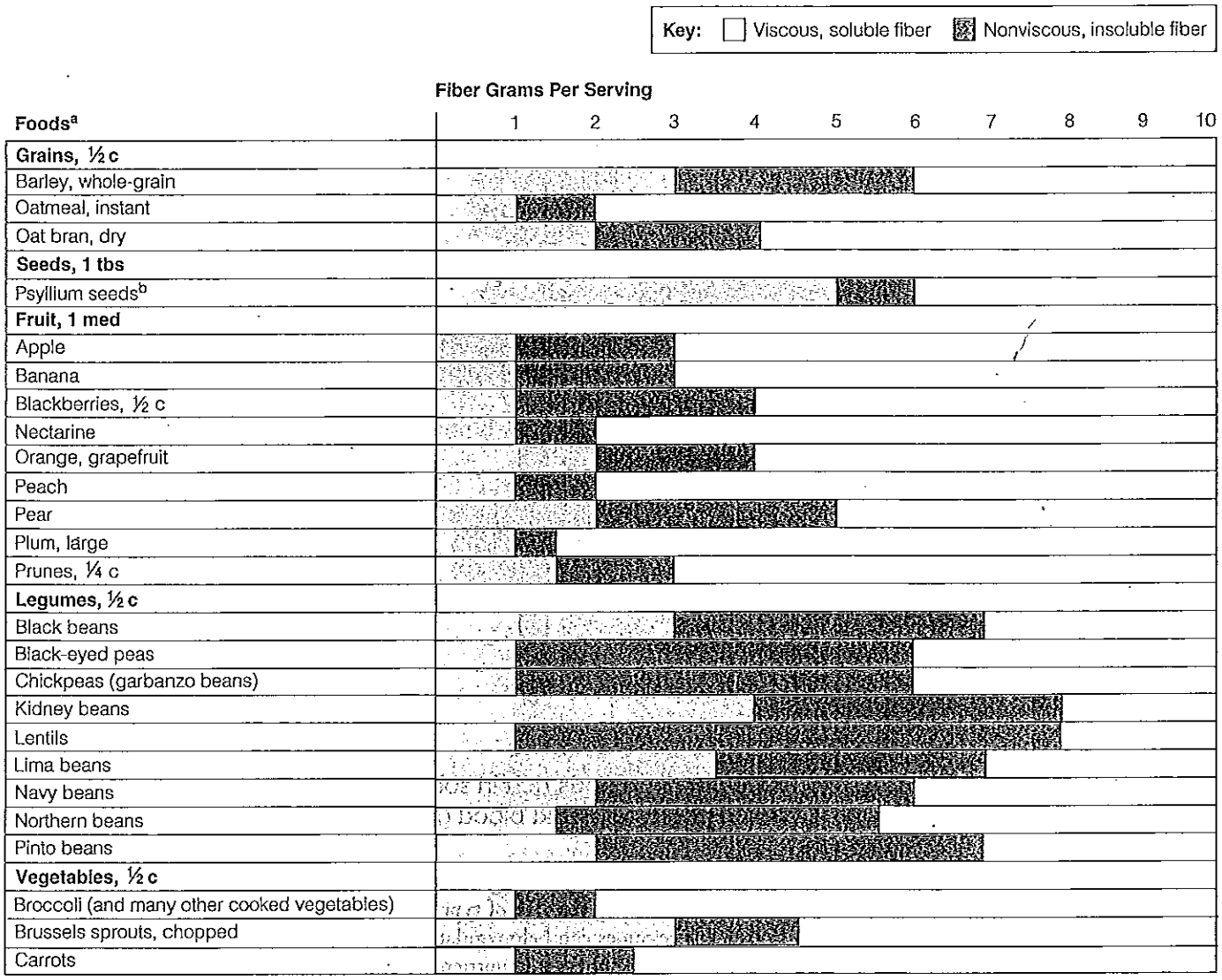
• The roles of saturated fat, *trans* fat, cholesterol, and other lipids in heart disease are discussed in Chapters 5 and 11. The role of vegetable proteins in heart disease is presented in Chapter 6.

FIGURE 4-4 Characteristics, Sources, and Health Effects of Fibers

People who eat these foods...		obtain these types of fibers...	with these actions in the body...	and these probable health benefits...
		Viscous, soluble, more fermentable		
 Stockbyte/Getty Images	• Barley, oats, oat bran, rye, fruits (apples, citrus), legumes (especially young green peas and black-eyed peas), seaweeds, seeds and husks, many vegetables, fibers used as food additives	• Gums • Pectins • Psyllium[a] • Some hemicellulose	• Lower blood cholesterol by binding bile • Slow glucose absorption • Slow transit of food through upper GI tract • Hold moisture in stools, softening them • Yield small fat molecules after fermentation that the colon can use for energy • Increase satiety	• Lower risk of heart disease • Lower risk of diabetes • Lower risk of colon and rectal cancer • Increased satiety, and may help with weight management
		Nonviscous, insoluble, less fermentable		
 Brian Leatart/Getty Images	• Brown rice, fruits, legumes, seeds, vegetables (cabbage, carrots, brussels sprouts), wheat bran, whole grains, extracted fibers used as food additives	• Cellulose • Lignins • Resistant starch • Hemicellulose	• Increase fecal weight and speed fecal passage through colon • Provide bulk and feelings of fullness	• Alleviate constipation • Lower risk of diverticulosis, hemorrhoids, and appendicitis • Lower risk of colon and rectal cancer

[a]*Psyllium, a soluble fiber derived from seeds, is used as a laxative and food additive.*

FIGURE 4-5 Fiber Composition of Common Foods



[a]*Values are for cooked or ready-to-serve foods unless specified.*

[b]*Psyllium is used as a fiber laxative and fiber-rich food additive.*

Source: Data from the National Heart, Lung and Blood Institute. Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel 10, NIH publication no. 02-5215, 2002); V-6; ESHA Research, 2004.

also rich in the viscous fibers having a significant cholesterol-lowering effect.[13] In contrast, diets high in refined grains and added sugars may push blood lipids toward elevated heart disease risk; Controversy 4 explores these concerns.

Foods rich in viscous fibers may lower blood cholesterol by binding with cholesterol-containing compounds in bile. Normally, much of this cholesterol would be reabsorbed from the intestine for reuse, but viscous fiber carries some of it out with the feces (see Figure 4-6).[14] These bile compounds are needed in digestion, so the liver responds to their loss by drawing on the body's cholesterol stocks to synthesize more. Another way in which fiber in the diet may reduce cholesterol in the blood is through the actions of one of the small fatty acids released during bacterial fermentation of fiber. This fatty acid is absorbed and travels to the liver, where it may help to reduce cholesterol synthesis. The net result of either mechanism is lowered blood cholesterol.

CONCEPT LINK 4-4

The benefits of phytochemicals in disease prevention are featured in Controversy 2, page 61.

FIGURE 4-6

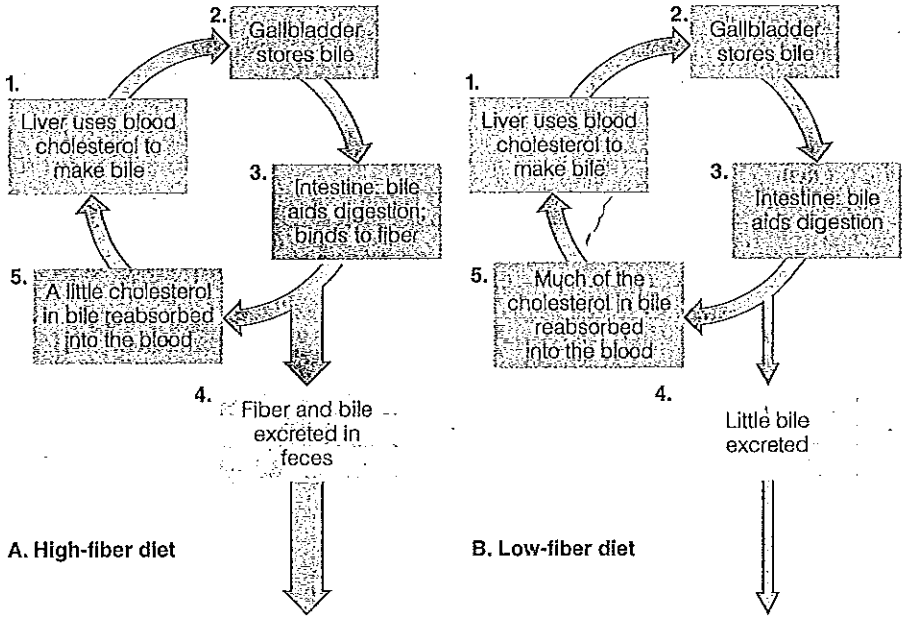
ANIMATED!

One Way Fiber in Food May Lower Cholesterol in the Blood

In some ways, the liver is like a vacuum cleaner, sucking up cholesterol from the blood, using the cholesterol to make bile, and discharging the bile into its storage bag, the gallbladder. The gallbladder empties its bile into the intestine, where bile performs necessary digestive tasks. In the intestine, some of the cholesterol from bile associates with fiber and is carried out of the body in feces instead of being reabsorbed into the blood.

A. When the diet is rich in fiber, more cholesterol (as bile) is carried out of the body.

B. When the diet is low in fiber, most of the cholesterol is reabsorbed and returned to the bloodstream.



KEY POINT Foods rich in soluble viscous fibers help control blood cholesterol and blood glucose.

Blood Glucose Control High-fiber foods—and especially whole grains—play a key role in reducing the risk of type 2 diabetes.[15] The soluble fibers of foods such as oats and legumes can help regulate the blood glucose following a carbohydrate-rich meal. Soluble fibers trap nutrients and delay their transit through the digestive tract, slowing glucose absorption and preventing the glucose surge and rebound often associated with diabetes onset. In people with established diabetes, high-fiber foods can modulate blood glucose and insulin levels, thus helping to prevent medical complications. A later section comes back to diabetes and its control.

KEY POINT Foods rich in viscous fibers help to modulate blood glucose concentrations.

constipation difficult, incomplete, or infrequent bowel movements associated with discomfort in passing dry, hardened feces from the body.

hemorrhoids (HEM-or-oids) swollen, hardened (varicose) veins in the rectum, usually caused by the pressure resulting from constipation.

appendicitis inflammation and/or infection of the appendix, a sac protruding from the intestine.

Maintenance of Digestive Tract Health All kinds of fibers, along with an ample fluid intake, probably play roles in maintaining proper colon function. Fibers such as cellulose (as in wheat bran and other cereal brans, fruits, and vegetables) enlarge and soften the stools, easing their passage out of the body and speeding up their transit time through the intestine. Thus, foods rich in these fibers help to alleviate or prevent **constipation.**

Large, soft stools ease the task of elimination for the rectal muscles. Pressure is then reduced in the lower bowel (colon), making it less likely that rectal veins will swell (**hemorrhoids**). Fiber prevents compaction of the intestinal contents, which could obstruct the appendix and permit bacteria to invade and infect it (**appendicitis**). In addition, fiber stimulates the GI tract muscles so that they retain their

strength and resist bulging out into pouches known as **diverticula** (illustrated in Figure 4-7 in the margin).[16]

Evidence Concerning Digestive Tract Cancer and Inflammation

Many studies support a role for fiber in defending against cancers of the colon and rectum. In a study of over a half-million Europeans, for example, people who ate the most dietary fiber (35 grams per day) reduced their risk of colon cancer by 40 percent compared with those who ate the least fiber (15 grams per day).[17] In the United States, data from over 3,000 people suggest that men (but not women) who were given a diet high in fiber had significantly less risk of developing colon or rectal cancers.[18] In contrast, a study of almost a half-million older U.S. adults suggests that consumption of whole grains, but not fiber itself, may offer moderate protection against these cancers.[19] When researchers examine other lifestyle factors, fiber shows some effect but alcohol intake, physical activity, red and processed meat intakes, and other factors emerge as associated with colon and rectal cancers, too.[20] More investigation into this important area of research is needed.

Fiber-rich foods may work against colon cancer in a number of ways. Fiber attracts water, thereby diluting potential cancer-causing agents and speeding their removal from the colon.[21] Also, many fiber-rich foods supply the vitamin folate, and diets rich in folate correlate with low rates of colon cancer (folate *supplements* have proved ineffective in this regard, however).[22] Another possibility involves the intestine's resident bacteria. In fiber-rich intestinal contents, feasting bacteria reproduce rapidly, and in doing so, they bind nitrogen and carry it out of the body in the feces. Nitrogen is a suspected contributor to cancer causation.

Additionally, the colon's bacteria ferment soluble fibers, forming the small fat molecules mentioned earlier, which activate cancer-killing enzymes and reduce inflammation in the colon.[23] Also, the cells of the colon prefer one of these little fats, **butyrate,** as a source of energy.[24] A colon well supplied with butyrate from a diet high in soluble fibers may resist chemical injury that could otherwise lead to cancer formation. A well-fed colon frequently replaces its own lining, sloughing damaged cells before they can initiate the cancer process.

As research progresses, cancer experts recommend that fiber in the diet come from five to nine ½-cup servings of vegetables and fruit, along with generous portions of whole grains and legumes. Note that fiber supplements or additives are not substitutes for whole, fiber-rich foods—the foods provide valuable nutrients and phytochemicals in a structure that benefits the body, while the supplements provide only fiber.

KEY POINT Fibers in foods help to maintain digestive tract health.

Healthy Weight Management

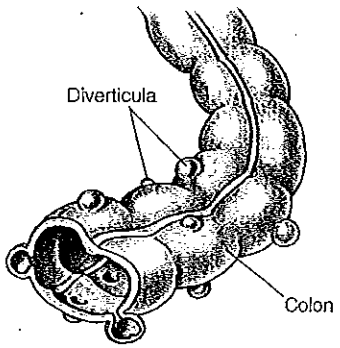
Foods rich in fibers tend to be low in fat and added sugars and can therefore prevent weight gain and promote weight loss by delivering less energy per bite.[25] In addition, fibers absorb water from the digestive juices; as they swell, they create feelings of fullness, delay hunger, and reduce food intake.[26] Soluble fibers may be especially useful for appetite control. In a recent study, soluble fiber from barley modified the mix of appetite-stimulating hormones in the blood in ways that may reduce food intake.[27] By whatever mechanism, as populations choose foods lower in fiber, body fat stores creep up.[28]

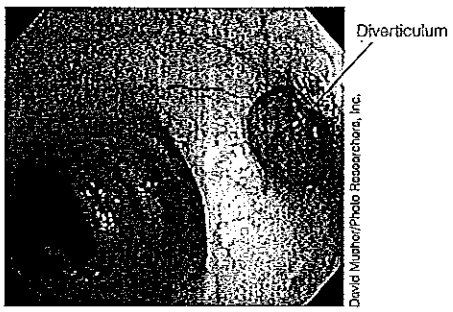
Weight-loss products may contain bulky fibers such as methylcellulose, but pure fiber compounds are not advised. Instead, consumers should select whole grains, legumes, fruits, and vegetables. High-fiber foods not only add bulk to the diet but are economical, nutritious, and supply health-promoting phytochemicals—benefits that no purified fiber preparation can match.

KEY POINT Diets that are adequate in fiber assist the eater in maintaining a healthy body weight.

FIGURE 4-7 **Diverticula**

Diverticula are abnormally bulging pockets in the colon wall. These pockets can entrap feces and become painfully infected and inflamed, requiring hospitalization, antibiotic therapy, or surgery.





- Carbohydrate: 4 cal/g
- Fat: 9 cal/g

diverticula (dye-ver-TIC-you-la) sacs or pouches that balloon out of the intestinal wall, caused by weakening of the muscle layers that encase the intestine. The painful inflammation of one or more of the diverticula is known as *diverticulitis*.

butyrate (BYOO-tier-ate) a small fat fragment produced by the fermenting action of bacteria on viscous, soluble fibers; the preferred energy source for the colon cells.

Fiber DRI:

- Men, age 19–50: 38 g/day.
- Men, age 51 and up: 30 g/day.
- Women, age 19–50: 25 g/day.
- Women, age 51 and up: 21 g/day.

- No Tolerable Upper Intake Level for fiber has been established.

Did You Know?

Chelating agents are often sold by supplement vendors to "remove poisons" from the body. Some valid medical uses, such as treatment of lead poisoning, exist, but most of the chelating agents sold over the counter are based on unproven claims.

TABLE 4-2 A Quick Method for Estimating Fiber Intake

To quickly estimate fiber in a day's meals:

1. Multiply servings (½ c cut up or 1 medium piece) of any fruit or vegetable (excluding juice) by 1.5 g.[a]
   Example: 5 servings of fruits and vegetables × 1.5 = 7.5 g fiber
2. Multiply ½ c servings of refined grains by 1.0 g.
   Example: 4 servings of refined grains × 1.0 = 4.0 g fiber
3. Multiply ½ c servings of whole grains by 2.5 g.
   Example: 3 servings of whole grains × 2.5 = 7.5 g fiber
4. Add fiber values for servings of legumes, nuts, seeds, and high-fiber cereals and breads; look these up in Appendix A.
   Example: ½ c navy beans = 6.0 g fiber
5. Add up the grams of fiber from the previous lines.
   Example: 7.5 + 4.0 + 7.5 + 6.0 = 25 g fiber

Day's total fiber = 25 g fiber

[a]*Most cooked and canned fruits and vegetables contain about this amount, while whole raw fruits and some vegetables contain more.*

chelating (KEE-late-ing) **agents** molecules that attract or bind with other molecules and are therefore useful in either preventing or promoting movement of substances from place to place.

Recommendations and Intakes

Few people in the United States or Canada eat a diet providing all of their needed fiber. To see how fiber stacks up in two day's meals, turn back to Figures 2-14 and 2-15 on pages 57–58. Tuesday's meals, typical of many college students' intakes, provide abundant calories but only half the needed fiber. In contrast, the more nutritious Monday's meals provide more than enough fiber to meet recommendations with calories to spare. The American Dietetic Association suggests 20 to 35 grams of fiber daily, or about two times higher than the average intake of about 14 to 15 grams.[29] The DRI committee's fiber recommendations are based on energy needs and so vary widely among age and gender groups (see the margin).

Fiber recommendations are given in terms of total fiber without distinction between fiber types. This makes sense because most fiber-rich foods supply a mixture of fibers (recall Figure 4-5, page 115). This chapter's Consumer Corner provides detailed information about choosing wisely among grain foods. You can make a quick approximation of a day's fiber intake by following the instructions in Table 4-2.

An effective way to add fiber while lowering fat is to substitute plant sources of protein (legumes) for some of the animal sources of protein (meats and cheeses) in the diet. Another way is to focus on consuming the recommended amounts of fruits, vegetables, and whole grains each day. People choosing high-fiber foods are wise to seek out a variety of fiber sources and to drink extra fluids to help the fiber do its job.

Can My Diet Have Too Much Fiber? Adding purified fibers, such as oat or wheat bran, to foods can be taken to extremes. One enthusiastic eater of purified oat bran in muffins required emergency surgery for a blocked intestine; too much oat bran and too little fluid overwhelmed his digestive system. This doesn't mean that you should avoid bran-containing foods, of course, but that you should approach bran and other purified fibers with an attitude of moderation and be sure to drink an extra beverage with it.

Purified fibers are like refined sugars in one way: the nutrients that originally accompanied the fibers have been lost. Too much purified fiber can displace nutrients from the diet by taking up space ordinarily dedicated to nutritious foods. Fiber can also cause nutrient loss by binding with nutrients in the digestive tract or speeding up their transit out of the body, both effects that prevent nutrient absorption. For health's sake, purified fibers may not affect the body in the same way as fiber-rich foods in the diet. Some of the health benefits attributed to a fiber may in fact come from other constituents of fiber-containing foods.

The Binders in Fiber Binders in some fibers act as **chelating agents.** This means that they link chemically with important nutrient minerals (iron, zinc, calcium, and others) and then carry them out of the body. The mineral iron is mostly absorbed at the beginning of the intestinal tract, and excess insoluble fibers may limit its absorption by speeding foods through the upper part of the digestive tract. Too much bulk in the diet can also limit the total amount of food consumed and cause deficiencies of both nutrients and energy. People with marginal intakes, such as the malnourished, the elderly, and children who consume no animal products, are particularly vulnerable to this chain of events. Fibers also carry water out of the body and can cause dehydration. Add an extra glass or two of water to go along with the fiber added to your diet.

The next section focuses on the handling of carbohydrates by the digestive system. Table 4-3 sums up the points made so far concerning the functions of carbohydrates in the body and in foods.

KEY POINT Most adults need between 24 and 38 grams of total fiber each day, but few consume this amount. Fiber needs are best met with whole foods. Purified fiber in large doses can have undesirable effects. Fluid intake should increase with fiber intake.

TABLE 4-3 Usefulness of Carbohydrates

Carbohydrates in the Body	Carbohydrates in Foods
• *Energy source.* Sugars and starch from the diet provide energy for many body functions; they provide glucose, the preferred fuel for the brain and nerves.	• *Flavor.* Sugars provide sweetness.
• *Glucose storage.* Muscle and liver glycogen store glucose.	• *Browning.* When exposed to heat, sugars undergo browning reactions, lending appealing color, aroma, and taste.
• *Raw material.* Sugars are converted into other compounds, such as amino acids (the building blocks of proteins), as needed.	• *Texture.* Sugars help make foods tender. Cooked starch lends a smooth, pleasing texture.
• *Structures and functions.* Sugars interact with protein molecules, affecting their structures and functions.	• *Gel formation.* Starch molecules expand when heated and trap water molecules, forming gels. The fiber pectin forms the gel of jellies when cooked with sugar and acid from fruit.
• *Digestive tract health.* Fibers help to maintain healthy bowel function (reduce risk of bowel diseases).	• *Bulk and viscosity (thickness).* Carbohydrates lend bulk and increased viscosity to foods. Soluble, viscous fibers lend thickness to foods such as salad dressings.
• *Blood cholesterol.* Fibers promote normal blood cholesterol concentrations (reduce risk of heart disease).	• *Moisture.* Sugars attract water and keep foods moist.
• *Blood glucose.* Fibers modulate blood glucose concentrations (help control diabetes).	• *Preservative.* Sugar in high concentrations dehydrates bacteria and preserves the food.
• *Satiety.* Fibers and sugars contribute to feelings of fullness.	• *Fermentation.* Carbohydrates are fermented by yeast, a process that causes bread dough to rise and beer to brew, among other uses.
• *Body weight.* A fiber-rich diet may promote a healthy body weight.	

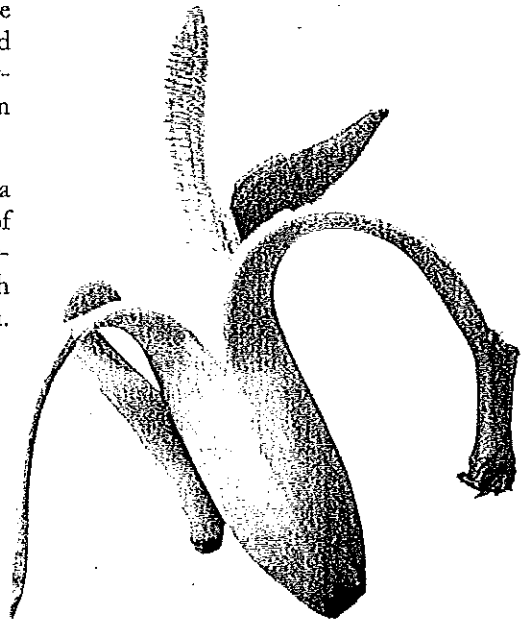
LO 4.4

From Carbohydrates to Glucose

You may eat bread or a baked potato, but the body's cells cannot use foods or even whole molecules of lactose, sucrose, or starch for energy. They need the glucose in those molecules. The various body systems must make glucose available to the cells, not all at once when it is eaten, but at a steady rate all day.

Digestion and Absorption of Carbohydrate

To obtain glucose from newly eaten food, the digestive system must first render the starch and disaccharides from the food into monosaccharides that can be absorbed through the cells lining the small intestine. The largest of the digestible carbohydrate molecules, starch, requires the most extensive breakdown. Disaccharides, in contrast, need be split only once before they can be absorbed.



© iStockphoto.com

Starch

Digestion of most starch begins in the mouth, where an enzyme in saliva mixes with food and begins to split starch into maltose. While chewing a bite of bread, you may notice that a slightly sweet taste develops—maltose is being liberated from starch by the enzyme. The salivary enzyme continues to act on the starch in the bite of bread while it remains tucked in the stomach's upper storage area. As each chewed lump is pushed downward and mixed with the stomach's acid and other juices, the salivary enzyme (made of protein) is deactivated by the stomach's protein-digesting acid. Not all digestive enzymes are susceptible to digestion in the stomach—one enzyme that digests protein works best in the stomach. Its structure protects it from the stomach's acid.

With the breakdown of the salivary enzyme in the stomach, starch digestion ceases, but it resumes at full speed in the small intestine, where another starch-splitting enzyme is delivered by the pancreas. This enzyme breaks starch down into disaccharides and small polysaccharides. Other enzymes liberate monosaccharides for absorption.

Some forms of starch are easily digested. The starch in bread made of refined white flour, for example, breaks down rapidly to glucose that is absorbed high up in

CONSUMER CORNER

Refined, Enriched, and Whole-Grain Foods

The USDA Food Guide, illustrated in Chapter 2, urges everyone to make at least half of their daily grain choices *whole* grains, an amount equal to at least three 1-ounce equivalents of whole grains a day.[1] To do this, you must distinguish among grain foods that are **refined, enriched, fortified,** and **whole grain** (see Table 4-4). For many people, bread supplies much of the carbohydrate, or at least most of the starch, in a day's meals. Bread provides a convenient example, but the principles demonstrated in this section hold true for cereals, rice, pasta, and, in fact, all grain foods.

FLOUR TYPES

The part of a typical grain plant, such as the wheat, that is made into flour and then into bread, other baked goods, cereals, and pasta noodles is the seed or kernel. The kernel (a whole grain) has four main parts: the **germ,** the **endosperm,** the **bran,** and the **husk,** as shown in Figure 4-8. The germ is the part that grows into a new plant, in this case wheat, and therefore contains concentrated food to support the new life—it is especially rich in oils, vitamins, and minerals. The endosperm is the soft, white inside portion of the kernel, containing starch and proteins that help nourish the seed as it sprouts. The kernel is encased in the bran, a protective coating that is similar in function to the shell of a nut; the bran is also rich in nutrients and fiber. The husk, commonly called chaff, is the dry outermost layer and is inedible by human beings but can be used in animal feed.

In earlier times, people milled wheat by grinding it between two stones, blowing or sifting out the chaff, and retaining the

FIGURE 4-8 A Wheat Plant and a Single Kernel of Wheat

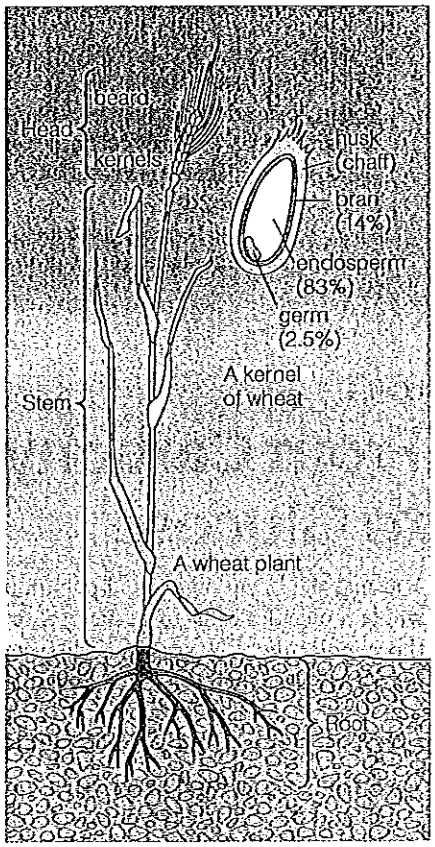


TABLE 4-4 Terms That Describe Grain Foods

- **bran** the protective fibrous coating around a grain; the chief fiber donator of a grain.
- **brown bread** bread containing ingredients such as molasses that lend a brown color; may be made with any kind of flour, including white flour.
- **endosperm** the bulk of the edible part of a grain, the starchy part.
- **enriched, fortified** refers to the addition of nutrients to a refined food product. As defined by U.S. law, these terms mean that specified levels of thiamin, riboflavin, niacin, folate, and iron have been added to refined grains and grain products. The terms *enriched* and *fortified* can refer to the addition of more nutrients than just these five; read the label.[a]
- **germ** the nutrient-rich inner part of a grain.
- **husk** the outer, inedible part of a grain.
- **refined** refers to the process by which the coarse parts of food products are removed. For example, the refining of wheat into flour involves removing three of the four parts of the kernel—the chaff, the bran, and the germ—leaving only the endosperm, composed mainly of starch and a little protein.
- **stone ground** refers to a milling process using limestone to grind any grain, including refined grains, into flour.
- **unbleached flour** a beige-colored refined endosperm flour with texture and nutritive qualities that approximate those of regular white flour.
- **wheat bread** bread made with any wheat flour, including refined enriched white flour.
- **wheat flour** any flour made from wheat, including refined white flour.
- **white flour** an endosperm flour that has been refined and bleached for maximum softness and whiteness.
- **white wheat** a wheat variety developed to be paler in color than common red wheat (most familiar flours are made from red wheat). White wheat is similar to red wheat in carbohydrate, protein, and other nutrients, but it lacks the dark and bitter, but potentially beneficial, phytochemicals of red wheat.
- **100% whole grain** a label term for food in which the grain is entirely whole grain, with no added refined grains.
- **whole grain** grains, or foods made from them, that contain all the essential parts and naturally occurring nutrients of the entire grain seed (except the husk); not refined.
- **whole-wheat flour** flour made from whole-wheat kernels; a whole-grain flour. Also called *graham flour.*

[a] *Formerly,* enriched *and* fortified *carried distinct meanings with regard to the nutrient amounts added to foods, but a change in the law has made these terms virtually synonymous.*

nutrient-rich bran and germ as well as the endosperm. Then milling machinery was "improved," and it became possible to remove the dark, heavy germ and bran, leaving a whiter, smoother-textured flour with a higher starch content and far less fiber. People favored this refined soft white flour more than the crunchy, dark brown, "old-fashioned" flour.

ENRICHMENT OF REFINED GRAINS

In turning to highly refined grains, many people suffered deficiencies of iron, thiamin, riboflavin, and niacin—nutrients formerly obtained from whole grains. To reverse this tragedy, Congress passed the U.S. Enrichment Act of 1942 requiring that iron, niacin, thiamin, and riboflavin be added to all refined grain products before they were sold. In 1996, the vitamin folate (often called *folic acid* on labels) was added to the list. Today, all refined grain products are enriched with at least the nutrients mandated by the Act.

A single serving of enriched grain food is not "rich" in the enrichment nutrients, but people who eat several servings a day obtain significantly more of these nutrients than they would from unenriched refined products, as the bread example of Figure 4-9 shows.

Enriched grain foods are comparable to whole grain only with respect to the added nutrients; whole grains provide more beneficial magnesium, zinc, vitamin B_6, vitamin E, and chromium. Whole grains also provide more fiber (see Table 4-5), along with potentially beneficial phytochemicals and essential oils associated with the bran and germ.

FINDING THE WHOLE GRAINS IN FOODS

Notice the distinctions between **wheat flour, whole-wheat flour, refined flour** (often called *white flour*), and **unbleached flour** among the terms that describe grain foods; also notice that the terms **wheat bread, brown bread,** and **stone ground** on a label do not guarantee that the bread has been made entirely of whole-grain flour (see Figure 4-10). Gaining in popularity is a light-colored bread made from a specially bred **white wheat.**

Whole-grain rice, commonly called brown rice, cannot be judged by color alone. Whole-grain rice comes in red and other colors, too. Also, many rice dishes appear brown because of brown-colored ingredients such as soy sauce, beef broth, or seasonings.

Whole-grain pasta noodles are delicious—but be sure that the ingredients list on the label agrees with any

FIGURE 4-9 **Nutrients in Whole-Grain, Enriched White, and Unenriched White Breads**

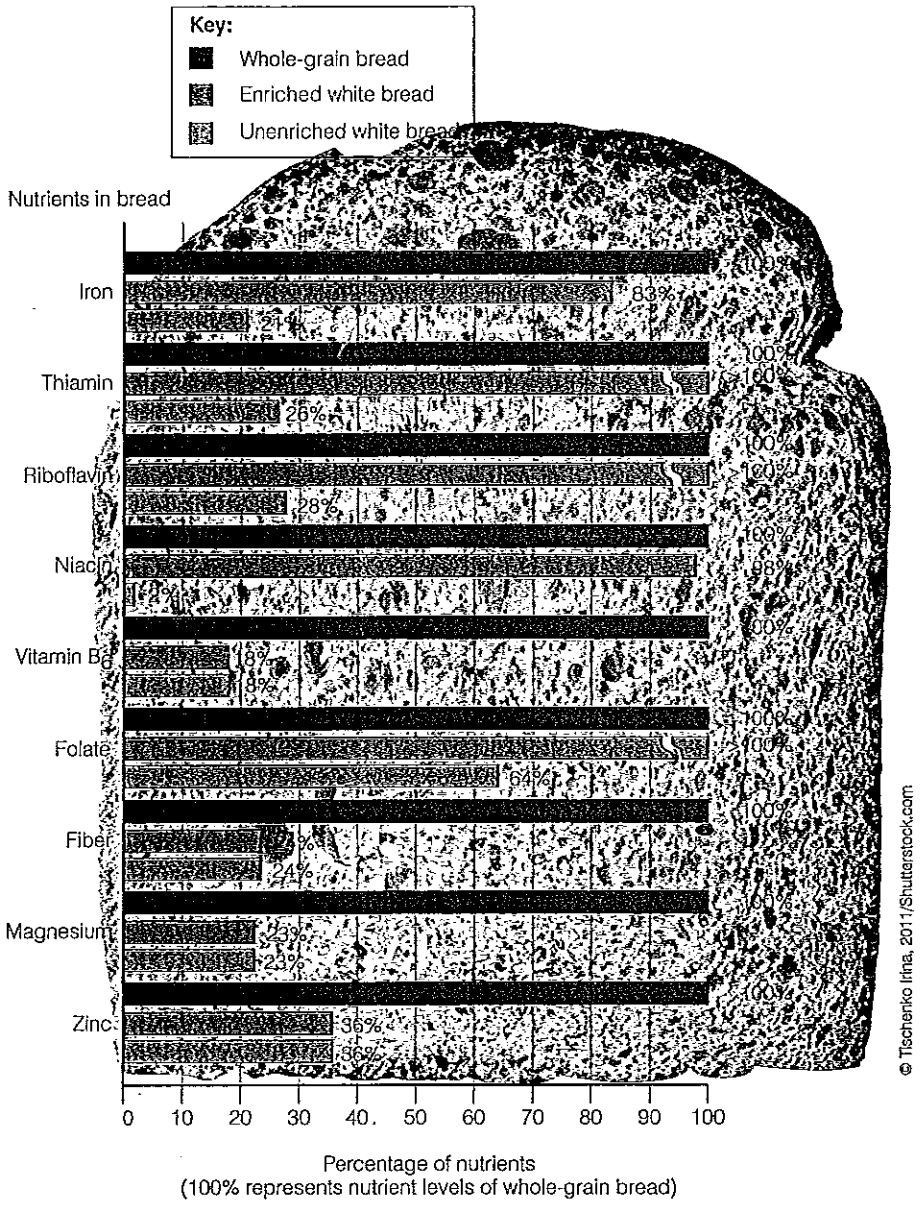


TABLE 4-5 **Grams of Fiber in One Cup of Flour**

Dark rye, 18 g
Whole wheat, 15 g
Light rye, 14 g
Buckwheat, 12 g
Whole-grain cornmeal, 9 g
Enriched white, 3 g

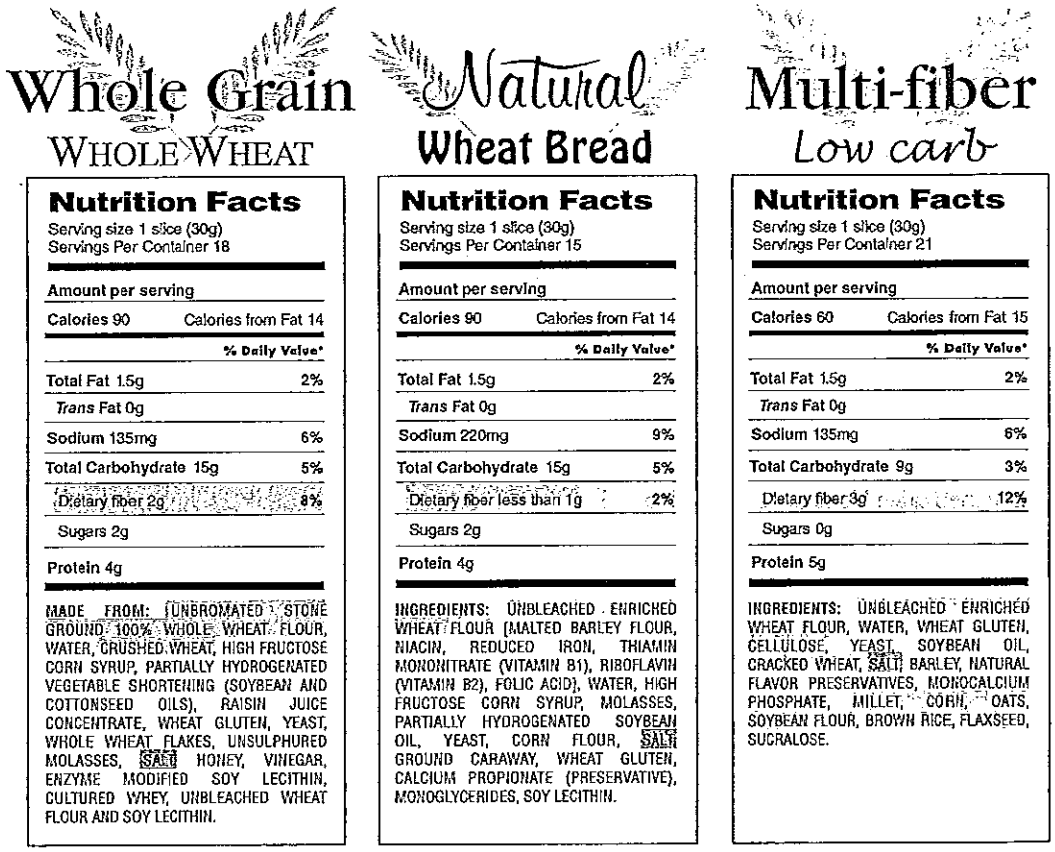
claims being made for the product.[2] For cereals, too, look for whole grains listed as the first ingredients. Food names and marketing claims on labels can be deceiving, so rely on the ingredients list as your guide.

If you are just now making a change to whole grains in your diet, blends of whole and refined grains can make a good starting point. However you go about it, you are well advised to learn to like the hearty flavor of whole-grain foods.

FIGURE 4-10 Bread Labels Compared

Although breads may appear similar, their ingredients vary widely. "High-fiber" breads may derive their fiber from purified cellulose or more nutritious whole grains. "Low carbohydrate" breads may be regular white bread, thinly sliced to reduce carbohydrates per serving, or may contain soy flour, barley flour, or flaxseed to reduce starch content.

A trick for estimating a bread's content of a nutritious ingredient, such as whole-grain flour, is to read the ingredients list (ingredients are listed in order of predominance). Bread generally contains one teaspoon of salt per loaf. Therefore, when a bulky ingredient, such as whole grain, is listed after the salt, you'll know that less than a teaspoonful was added to the loaf—not enough to significantly improve the nutrient value of one slice of bread.



the small intestine. Some starch, such as that of cooked beans, digests more slowly and releases its glucose later in the digestion process. Less digestible starch, called **resistant starch,** is technically a kind of fiber because it passes through the small intestine undigested into the colon, and can contribute to the daily fiber need.[30] The starch of raw potatoes, for example, resists digestion. So does the resistant starch that forms when foods are overheated as well as the starch tucked inside the unbroken hulls of swallowed seeds.[31] Barley, chilled cooked potatoes and pasta, cooked dried beans and lentils, oatmeal, and underripe bananas are all sources. Some resistant starch may be digested, but slowly, and most remains intact until the bacteria of the colon eventually break it down. Similar to insoluble fibers, resistant starch may support a healthy colon.[32]

resistant starch the fraction of starch in a food that is digested slowly, or not at all, by human enzymes.

Sugars Sucrose and lactose from food, along with maltose and small polysaccharides freed from starch, undergo one more split to yield free monosaccharides before they are absorbed. This split is accomplished by enzymes attached to the cells of the lining of the small intestine. The conversion of a bite of bread to nutrients for the body is completed when monosaccharides cross these cells and are washed away in a rush of circulating blood that carries them to the waiting liver. Figure 4-11 presents a quick review of carbohydrate digestion.

The absorbed carbohydrates (glucose, galactose, and fructose) travel in the bloodstream to the liver, which can convert fructose and galactose to glucose. The circulatory system transports the glucose and other products to the cells. Liver and muscle cells may store circulating glucose as glycogen; all cells may split glucose for energy.

Fiber As mentioned, although molecules of most fibers are not changed by human digestive enzymes, many of them can be digested (fermented) by the bacterial inhabitants of the human colon. A by-product of this fermentation can be any of several odorous gases. Don't give up on high-fiber foods if they cause gas. Instead, start with small servings and gradually increase the serving size over several weeks; chew foods thoroughly to break up hard-to-digest lumps that can ferment in the intestine; and try a variety of fiber-rich foods until you find some that do not cause the problem. Some people also find relief from excessive gas by using commercial enzyme preparations sold for use with beans. Such products contain enzymes that help to break down some of the indigestible fibers in foods before they reach the colon. In other people, persistent painful gas may indicate that the digestive tract has undergone a change in its ability to digest the sugar in milk, a condition known as **lactose intolerance.**

KEY POINT With respect to starch and sugars, the main task of the various body systems is to convert them to glucose to fuel the cells' work. Fermentable fibers may release gas as they are broken down by bacteria in the intestine.

Why Do Some People Have Trouble Digesting Milk?

Among adults, the ability to digest the carbohydrate of milk varies widely. As they age, upward of 75 percent of the world's people lose much of their ability to produce the enzyme **lactase** to digest the milk sugar lactose.[33] In the United States, the incidence is estimated to be much lower: about 12 percent.[34] Lactase, which is made by the small intestine, splits the disaccharide lactose into its component monosaccharides glucose and galactose, which are then absorbed. Almost all mammals lose some of their ability to produce lactase as they age.

Symptoms of Lactose Intolerance People with lactose intolerance experience some degree of nausea, pain, diarrhea, and excessive gas on drinking milk or eating lactose-containing products. The undigested lactose remaining in the intestine demands dilution with fluid from surrounding tissue and the bloodstream. Intestinal bacteria use the undigested lactose for their own energy, a process that produces gas and intestinal irritants.

Sometimes sensitivity to milk is due not to lactose intolerance but to an allergic reaction to the protein in milk. Milk allergy arises the same way other allergies do—from sensitization of the immune system to a substance. In this case, the immune system overreacts when it encounters the protein of milk. Food allergies can be serious and should be diagnosed by a specialist (see Chapter 14 for more on food allergies).

Consequences to Nutrition Infants produce abundant lactase, which helps them absorb the sugar of breast milk and milk-based formulas; a very few suffer inborn lactose intolerance and must be fed solely on lactose-free formulas. Because milk is

- Whole grains include:
  - *Amaranth,* a grain of the ancient Aztec people.*
  - *Barley*
  - *Buckwheat**
  - *Corn, including whole cornmeal and popcorn.*
  - *Millet*
  - *Oats, including oatmeal*
  - *Quinoa (KEEN-wah),* a grain of the ancient Inca people.*
  - *Rice, including brown, red, and others.*
  - *Rye*
  - *Sorghum (also called milo), a drought-resistant grain.*
  - *Teff, popular in Ethiopia, India, and Australia.*
  - *Triticale, a cross of durum wheat and rye.*
  - *Wheat, in many varieties such as spelt, emmer, farro, einkorn, Kamut®, durum; and forms such as bulgur, cracked wheat and wheatberries.*
  - *Wild rice*

If some of these sound unfamiliar, why not try them? They could be your new favorites.

**While not botanical grains, these foods are similar to grains in nutrient contents, preparation, and use.*

CONCEPT LINK 4-5

The names of the digestive enzymes were explained in Chapter 3, Table 3-1 (page 82).

Approximate percentages of adults with lactose intolerance by ethnicity:

• 85–100%	Asians
• 80–100%	Native Americans
• 70–95%	Black Africans
• 60–80%	African Americans
• 20–30%	Indians (Northern)
• 60–70%	Indians (Southern)
• 60–80%	Ashkenazi Jews
• 50–80%	Hispanics
• 6–22%	U.S. Whites
• 2–7%	Northern Europeans

Source: Data from S. R. Hertzler and coauthors, Intestinal disaccharidase depletions. Modern Nutrition in Health and Disease *(Philadelphia: Lippincott Williams & Wilkins, 2006), p. 1191.*

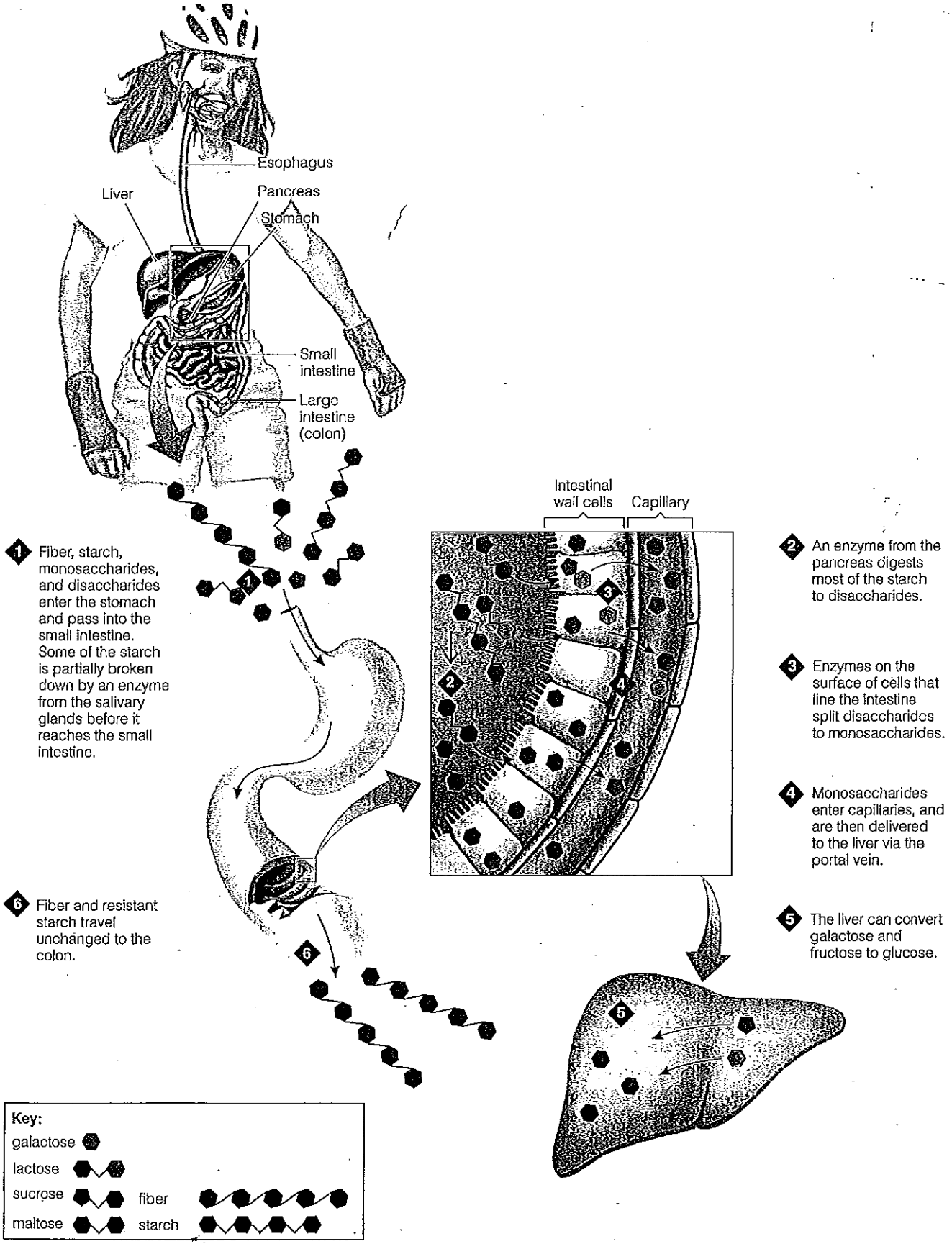
lactose intolerance Impaired ability to digest lactose due to reduced amounts of the enzyme lactase.

lactase the intestinal enzyme that splits the disaccharide lactose to monosaccharides during digestion.

FIGURE 4-11

ANIMATED!

How Carbohydrate in Food Becomes Glucose in the Body



an almost indispensable source of the calcium every child needs for growth, a milk substitute must be found for any child who becomes lactose intolerant. Disadvantaged young children of the developing world sustain the most severe consequences of lactose intolerance when it combines with disease, malnutrition, or parasites to produce a loss of nutrients that greatly reduces the children's chances of survival. And girls everywhere who fail to consume enough calcium may later develop weak bones, so young women must find substitutes if they become unable to tolerate milk.

Milk Tolerance and Strategies The failure to digest lactose affects people to differing degrees. Only a few people cannot tolerate lactose in any amount. Many affected people can consume up to 6 grams of lactose (½ cup milk) without symptoms. The most successful strategies seem to be increasing intakes of milk products gradually, consuming them with meals, and spreading them out through the day. Often, people overestimate the severity of their lactose intolerance, blaming it for symptoms most probably caused by something else—a mistake that could cost them the health of their bones.

Aged cheese often causes little trouble for lactose-intolerant people—the bacteria or molds that help create cheese digest lactose as they convert milk to a fermented product. Some kinds of yogurt contain live bacterial cultures that may take up residence in the intestinal tract, where they seem to reduce symptoms of lactose intolerance. This bacterial shift allows some lactose-intolerant people to adapt to consuming some milk products.[35] Yogurts that contain added milk solids also contain extra lactose that can overwhelm the system; such yogurts list milk solids and live cultures among the ingredients on their labels.

Lactose-free milk products that have undergone treatment with lactase are available at most grocery stores. Alternatively, people can treat milk products themselves with over-the-counter enzyme pills and drops. The pills are taken with milk-containing meals, and the drops are added to milk-based foods; both products help to digest lactose by replacing the missing natural enzyme. The trick is to find ways of splitting lactose to glucose and galactose so that the body can absorb the products, rather than leaving the lactose undigested to feed the bacteria of the colon. Other choices to replace the calcium of milk are calcium-fortified orange juice, calcium- and vitamin-fortified soy drink, and canned sardines or salmon with the bones.

KEY POINT In lactose intolerance, the body fails to produce sufficient amounts of the enzyme needed to digest the sugar of milk. Uncomfortable symptoms result and can lead to milk avoidance. Lactose-intolerant people and those allergic to milk need milk alternatives that contain the calcium and vitamins of milk.

• Chapter 8 and its Controversy examine the topic of milk in adult diets in relation to the adult bone disease osteoporosis.

Lactose in selected foods:

• Whole-wheat bread, 1 slice	0.5 g
• Dinner roll, 1	0.5 g
• Cheese, 1 oz	
• *Cheddar or American*	*0.5 g*
• *Parmesan or cream*	*0.8 g*
• Doughnut (cake type), 1	1.2 g
• Chocolate candy, 1 oz	2.3 g
• Sherbet, 1 c	4.0 g
• Cottage cheese (low-fat), 1 c	7.5 g
• Ice cream, 1 c	9.0 g
• Milk, 1 c	12.0 g
• Yogurt (low-fat, 1 c with added milk solids)	15.0 g

LO 4.5, 4.6

The Body's Use of Glucose

Glucose is the basic carbohydrate unit used for energy by each of the body's cells. The body handles its glucose judiciously—maintaining an internal supply to be used when needed and tightly controlling its blood glucose concentration to ensure a steady supply. Recall that carbohydrates serve functional roles, too, such as forming part of mucus, but they are best known for providing energy.

Splitting Glucose for Energy

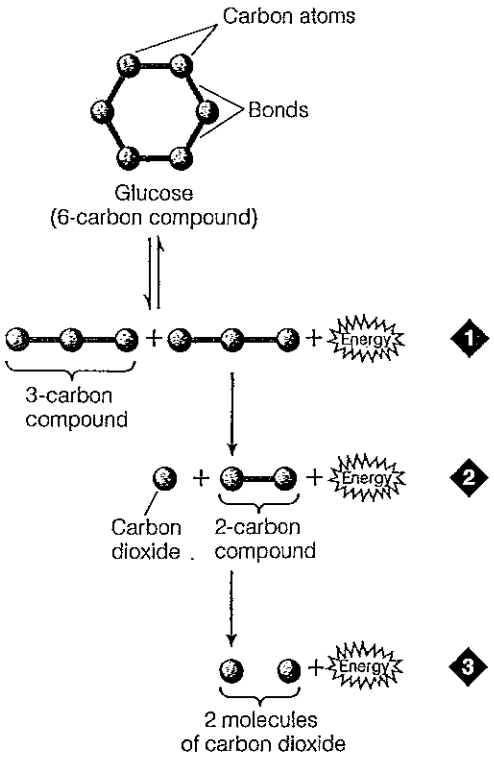
Glucose fuels the work of every cell in the body to some extent, but the cells of the brain and nervous system depend almost exclusively on glucose, and the red blood cells use glucose alone. When a cell splits glucose for energy, it performs an intricate sequence of maneuvers that are of great interest to the biochemist—and of no interest whatever to most people who eat bread and potatoes. What everybody needs to

FIGURE 4-12

ANIMATED!

The Breakdown of Glucose Yields Energy and Carbon Dioxide

Cell enzymes split the bonds between the carbon atoms in glucose, liberating the energy stored there for the cell's use. ❶ The first split yields two 3-carbon fragments. The two-way arrows mean that these fragments can also be rejoined to make glucose again. ❷ Once they are broken down further into 2-carbon fragments, however, they cannot rejoin to make glucose. ❸ The carbon atoms liberated when the bonds split are combined with oxygen and released into the air, via the lungs, as carbon dioxide. Although not shown here, water is also produced at each split.



understand, though, is that there is no good substitute for carbohydrate. Carbohydrate is *essential,* as the following details illustrate.

The Point of No Return

At a certain point in the process of splitting glucose energy, glucose itself is forever lost to the body. First, glucose is broken in half, releasing some energy. Then, two pathways open to these glucose halves. They can be put back together to make glucose again, or they can be broken into smaller molecules. If they are broken further, they cannot be reassembled to form glucose.

The smaller molecules can also take different pathways. They can continue along the breakdown pathway to yield still more energy and eventually break down completely to just carbon dioxide and water. Or, they can be formed into building blocks of protein or be hitched together into units of body fat. Figure 4-12 shows how glucose is broken down to yield energy and carbon dioxide.

Below a Healthy Minimum

Although glucose can be converted into body fat, body fat cannot be converted into glucose to feed the brain adequately. When the body faces a severe carbohydrate deficit, it has two problems. Having no glucose, it must turn to protein to make some (the body has this ability), diverting protein from its own critical functions, such as maintaining the body's immune defenses. When body protein is used, it is taken from blood, organ, or muscle proteins; no surplus of protein is stored specifically for such emergencies. Protein is indispensable to body functions and carbohydrate should be kept available precisely to prevent the use of protein for energy. This is called the **protein-sparing action** of carbohydrate. As for fat, it cannot regenerate enough glucose to feed the brain and prevent ketosis.

Ketosis

The second problem with an inadequate supply of carbohydrate concerns a precarious shift in the body's energy metabolism. Instead of producing energy by following its main metabolic pathway, fat takes another route in which fat fragments combine with each other. This shift causes an accumulation of the normally scarce acidic products, **ketone bodies.**[36]

Ketone bodies can accumulate in the blood (**ketosis**) to reach levels high enough to disturb the normal acid-base balance. Diets that produce ketosis may also promote deficiencies of vitamins and minerals, increase loss of bone minerals, elevate blood cholesterol, set the stage for kidney stones, and impair mood.[37] Glycogen stores become too scanty to meet a metabolic emergency or to support vigorous muscular work.

Ketosis isn't all bad, however. Ketone bodies provide fuel for brain and nerve cells when glucose is lacking, such as in starvation or very-low-carbohydrate diets.[38] Not all brain areas use ketones—some rely exclusively on glucose, so the body must still sacrifice protein to provide it, but at a slower rate. Some children and adults with epilepsy may benefit from a therapeutic ketosis-inducing diet, used along with medication, although many find the diet difficult to follow for long periods.[39]

The DRI Minimum Recommendation for Carbohydrate

The minimum amount of digestible carbohydrate determined by the DRI committee to adequately feed the brain and reduce ketosis has been set at 130 grams a day for an average-sized person.[40] Several times this minimum is recommended to maintain health and glycogen stores (explained in the next section). The amounts of vegetables, fruits, legumes, grains, and milk recommended in the USDA Food Guide (see Chapter 2) deliver abundant carbohydrates.

KEY POINT Without glucose, the body is forced to alter its uses of protein and fats. To help supply the brain with glucose, the body breaks down protein to make glucose and converts its fats into ketone bodies, incurring ketosis.

protein-sparing action the action of carbohydrate and fat in providing energy that allows protein to be used for purposes it alone can serve.

ketone (kee-tone) **bodies** acidic, fat-related compounds that can arise from the incomplete breakdown of fat when carbohydrate is not available.

ketosis (kee-TOE-sis) an undesirable high concentration of ketone bodies, such as acetone, in the blood or urine.

How Is Glucose Regulated in the Body?

Should your blood glucose ever climb abnormally high, you might become confused or have difficulty breathing. Should your glucose supplies ever fall too low, you

would feel dizzy and weak. The healthy body guards against both conditions with two safeguard activities:

- siphoning off excess blood glucose into the liver and into the muscles for storage as glycogen and to the adipose tissue for storage as body fat.
- replenishing diminished blood glucose from liver glycogen stores.

Two hormones prove critical to these processes. The hormone **insulin** stimulates glucose storage as glycogen while the hormone **glucagon** helps to release glucose from its glycogen nest.

The Role of Insulin After a meal, as blood glucose rises, the pancreas is the first organ to respond. It releases insulin, which signals the body's tissues to take up surplus glucose. Muscle and adipose tissue respond by taking up some of this excess glucose to build the polysaccharide glycogen (in muscles) or convert it into fat (in fat cells). The liver takes up excess glucose and makes glycogen, too, but it needs no help from insulin to do so.[41]

Tissue Glycogen Stores The muscles hoard two-thirds of the body's total glycogen to use for physical activity. The brain stores a tiny fraction of the total as an emergency reserve to fuel the brain for an hour or two in severe glucose deprivation.[42] The liver stores the remainder and is generous with its glycogen, releasing glucose into the bloodstream for the brain or other tissues when the supply runs low. Without carbohydrate from food to replenish it, the liver glycogen stores can be depleted in less than one waking day.

The Release of Glucose from Glycogen The glycogen molecule is highly branched with hundreds of ends bristling from each molecule's surface (review this structure in Figure 4-3 on page 110). When blood glucose starts to fall too low, the hormone glucagon floods the bloodstream and triggers the breakdown of liver glycogen to free glucose. Enzymes within the liver cells respond to glucagon by attacking a multitude of glycogen ends simultaneously to release a surge of glucose into the blood for use by all the body's cells. Thus, the highly branched structure of glycogen uniquely suits the purpose of releasing glucose on demand.

Be Prepared: Eat Carbohydrate Another hormone, epinephrine, also breaks down liver glycogen as part of the body's defense mechanism in times of danger.[‡] To store glucose for emergencies, we are advised to eat carbohydrate at each meal.

You may be asking, "What kind of carbohydrate?" Candy, "energy bars," and sugary beverages are quick sources of abundant sugar energy, but they are not the best choices. Balanced meals and snacks, eaten on a regular schedule, help the body to maintain its blood glucose. Meals with starch and fiber combined with some protein and a little fat slow digestion so that glucose enters the blood gradually in an ongoing, steady rate.

KEY POINT Glucose stored as liver glycogen is released and used by the whole body. Muscles store their own glycogen for their own use. Insulin promotes glycogen storage, whereas glucagon acts to liberate glucose from liver glycogen. Healthy people have no problem regulating their blood glucose when they consume mixed meals at regular intervals.

Handling Excess Glucose

Suppose you have eaten dinner and are now sitting on the couch, munching pretzels and drinking cola as you watch a ball game on television. Your digestive tract is delivering molecules of glucose to your bloodstream, and your blood is carrying these

CONCEPT LINK 4-6

The acid-base balance of the blood was described in Chapter 3 on page 83.

© Gene Lee, 2011/Shutterstock.com

CONCEPT LINK 4-7

Epinephrine and the body's stress response were described in Chapter 3, page 76.

insulin a hormone secreted by the pancreas in response to a high blood glucose concentration. It assists cells in drawing glucose from the blood.

glucagon (GLOO-cah-gon) a hormone secreted by the pancreas that stimulates the liver to release glucose into the blood when blood glucose concentration dips.

[‡]Epinephrine is also called adrenaline.

THINK FITNESS

What Can I Eat to Make Workouts Easier?

A working body needs carbohydrate fuel to replenish glycogen, and when it runs low, physical activity can seem more difficult. If your workouts seem to drag and never get easier, take a look at your diet. Are your meals regularly timed? Do they provide abundant carbohydrate from nutritious whole foods to fill up glycogen stores so they last through a workout and provide nutrients to use that fuel?

Here's a trick: at least an hour before your workout, eat a small snack of about 300 calories of foods rich in complex carbohydrates and drink some extra fluid (see Chapter 10 for ideas). Remember to cut back your intake at other meals by an equivalent amount. The snack provides glucose at a steady rate to spare glycogen, and the fluid helps to maintain hydration.

START NOW CENGAGENOW Body control a chance? Consult this online behavior change planner for a method for changing your current behavior at www.cengage.com/ESS

molecules to your liver and other body cells. The body cells use as much glucose as they can for their energy needs of the moment. Excess glucose is linked together and stored as glycogen until the muscle and liver stores are full to overflowing with glycogen. Still, the glucose keeps coming.

To handle the excess, body tissues shift to burning more glucose for energy in place of fat. As a result, more fat is left to circulate in the bloodstream until it is picked up by the fatty tissues and stored there. If these measures still do not accommodate all of the incoming glucose, the liver has no choice but to handle the excess. Excess glucose left circulating in the blood can harm the tissues.

Ryan McVay/Photodisc/Getty Images

You had better play the game if you are going to eat the food.

Carbohydrate Stored as Fat The liver breaks the extra glucose into smaller molecules and assembles these into its durable energy-storage compounds—fats. These newly made fats are then released into the blood, carried to the adipose tissues, and deposited. Fat cells also take up some glucose directly and convert it to fat. Unlike the liver cells, which store only about 2,000 calories of glycogen, the fat cells of an average-size person store over 70,000 calories of fats, and their capacity to store fat is almost limitless.

Human beings possess enzymes to convert excess glucose to fat, but the process requires many enzymatic steps costing a great deal of energy. The body is thrifty by nature, so when presented with both glucose and fat from a mixed meal, it prefers to store the fat and use the glucose to meet immediate energy needs. In this way, the maximum available food energy is retained because the dietary fat slips easily into storage with few conversions—its energy is conserved. Moral: You had better play the game if you are going to eat the food. (The Think Fitness feature offers tips to help you play.)

Carbohydrate and Weight Maintenance A balanced diet that is high in complex carbohydrates helps control body weight and maintain lean tissue. Bite for bite, carbohydrate-rich foods contribute less to the body's available energy than do fat-rich foods, and they best support physical activity to promote a lean body. Thus, if you want to stay healthy and remain lean, you should make every effort to choose a calorie-appropriate diet providing 45 to 65 percent of its calories from mostly unrefined sources of complex carbohydrates and 20 to 35 percent from the right kind of fats.

glycemic index (GI) a ranking of foods according to their potential for raising blood glucose relative to a standard such as glucose or white bread.

glycemic load (GL) a mathematical expression of both the glycemic index and the carbohydrate content of a food, meal, or diet (glycemic index × carbohydrate).

This chapter's Food Feature provides the first set of tools required for the job of designing such a diet. Once you have learned to identify the carbohydrates in foods, you must then set about learning which fats are which (Chapter 5) and how to obtain adequate protein without overdoing it (Chapter 6). By Chapter 9, you can put it all together with the goal of achieving and maintaining a healthy body weight.

KEY POINT The liver has the ability to convert glucose into fat; under normal conditions, most excess glucose is stored as glycogen or used to meet the body's immediate needs for fuel.

The Glycemic Index of Food

Carbohydrate-rich foods vary in the degree to which they elevate both blood glucose and insulin concentrations. When this effect is measured, a food's average score can be ranked on a scale known as the **glycemic index (GI).** It can then be compared with the score of a standard food, usually white bread or glucose, taken by the same person.[43] A food's ranking may surprise you. For example, baked potatoes rank higher than ice cream, partly because ice cream contains sucrose. Fructose makes up half of each sucrose molecule, and fructose only slightly elevates blood glucose. The starch of the potatoes is all glucose. Figure 4-13 shows where some foods fall on the glycemic index scale on average, but test results vary widely.

Diabetes and the Glycemic Index The glycemic index, and its mathematical offshoot, **glycemic load (GL),** may be of interest to people with diabetes who must regulate their blood glucose to protect their health.[44] The lower the GL of the diet, the less glucose builds up in the blood and the less insulin is needed to maintain normal blood glucose concentrations. Study subjects given carefully controlled diets of low-glycemic foods may indeed lower their blood glucose levels, and some may improve their blood lipids, too.[45]

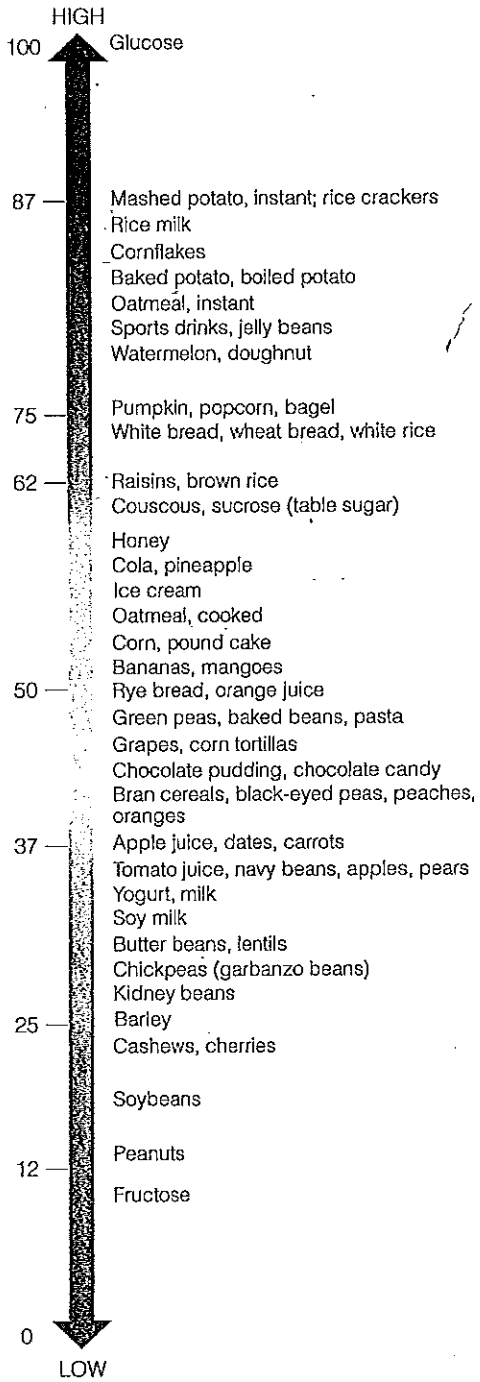
Interpreting studies on the GI and GL proves to be complex because other dietary factors affect the results.[46] For example, although popular books claim that consumers can lose weight on a low-GL diet, research is mixed on whether the GL of the diet can truly assist in weight loss.[47] Low-GI foods often provide abundant soluble fiber, which slows glucose absorption, sustains feelings of fullness, and improves blood lipids; soluble fiber may in fact be responsible for some effects attributed to the GI.[48] In any case, the glycemic index is not of primary concern for diabetes control, but modest benefit may come from choosing foods low on the scale in addition to using primary strategies for controlling blood glucose.[49]

Limitations of the Glycemic Index Some researchers cast doubt on whether the glycemic index is practical or beneficial.[50] An individual's blood glucose may rise predictably after eating a particular food, but for groups of people, many problems exist in applying the glycemic index.[51] Among them:

- the glycemic response to any one food varies widely among individuals.
- a person's body size and weight, blood volume, and metabolic rate affect glycemic response.[52]
- glycemic responses tend to differ more between individuals for the same food than within one person for different foods.
- within the same person, results for a particular food vary with the time of day.
- many *food* factors also change glycemic index results, including plant variety, food ripeness, processing, preparation, and *other* foods eaten at the same time.[53]
- very few foods have been tested and for those that have, different laboratories often yield different results.[54]

Given these limitations, it becomes clear why researchers dismiss the notion of "good" and "bad" foods based on the glycemic response (see this chapter's Controversy section).

FIGURE 4-13 **Glycemic Index of Selected Foods**

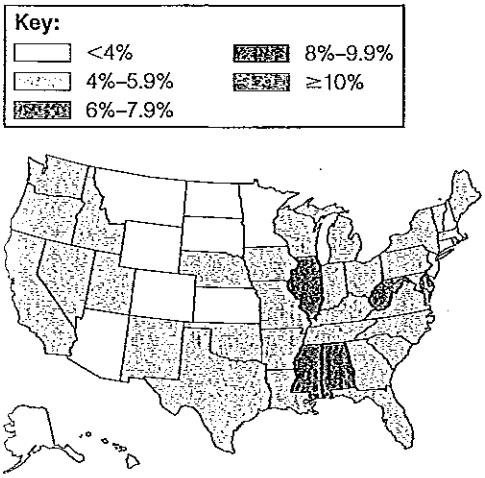


Source: F. S. Atkinson, K. Foster-Powell, and J. C. Brand-Miller, International tables of glycemic index and glycemic load values: 2008, Diabetes Care *31 (2008): 2281–2283.*

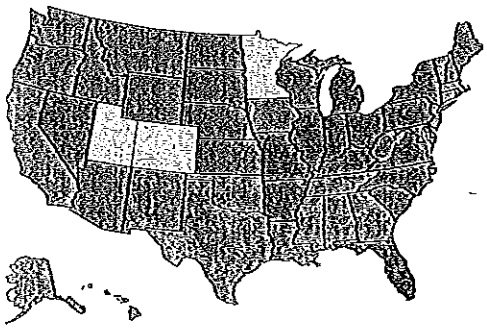
FIGURE 4-14

Prevalence of Diabetes Among Adults in the United States

The maps below depict regional changes in U.S. diabetes incidence.



1997: Ten states had a prevalence of diabetes of less than 4% and only five states had a prevalence of 6% or greater.



2007: No state had a prevalence of diabetes of less than 4%; all but three states had a prevalence of 6% or greater, with eight states reporting a prevalence of 10% or greater.

Source: Centers for Disease Control and Prevention, www.cdc.gov/needphp/aag/aag_ddt.htm.

diabetes (dye-uh-BEET-eez) a disease characterized by elevated blood glucose and inadequate or ineffective insulin, which impairs a person's ability to regulate blood glucose normally. The technical name is *diabetes mellitus* (*mellitus* means "honey-sweet" in Latin, referring to sugar in the urine).

prediabetes condition in which blood glucose levels are higher than normal but not high enough to be diagnosed as diabetes; considered a major risk factor for future diabetes and cardiovascular diseases.

KEY POINT The glycemic index is a measure of blood glucose response to foods relative to the response to a standard food. The glycemic load is the product of the glycemic index multiplied by the carbohydrate content of a food. The concept of good and bad foods based on the glycemic response is an oversimplification.

LO 4.7

Diabetes

What happens if the body cannot handle carbohydrates normally? One result is **diabetes,** which is common in developed nations and can be detected by a blood test. Diabetes afflicts a rapidly growing number of U.S. adults (see Figure 4-14), and diabetes has reached record numbers in children. Almost 24 million people in the United States have been diagnosed with diabetes.[55] As many as 57 million U.S. adults 20 years of age and older have **prediabetes**—their blood glucose is elevated but not to such an extent as to be classified as diabetes.[56] Of these, over 6 million are unaware of it and so go untreated.

The Perils of Diabetes

Diabetes ranks seventh among all causes of death in the United States.[57] For people with diabetes, the risk of heart disease and stroke is doubled, and in the United States diabetes is the leading cause of permanent blindness and of fatal kidney failure.[58] Each year, diabetes costs nearly $132 billion in U.S. health-care services.[59] The common forms of diabetes are type 1 and type 2, both disorders of blood glucose regulation; their characteristics are summarized in Table 4-6.[60]

The Toxic Effects of Excess Glucose Chronically elevated blood glucose associated with diabetes alters metabolism in virtually every cell of the body. Some cells convert excess glucose to toxic alcohols, causing the cells to swell—in the lenses of the eyes, for example, the distended cells distort vision. Other cells respond by at-

TABLE 4-6 Types 1 and 2 Diabetes Compared

	Type 1	Type 2
Percentage of cases	5–10%	90–95%
Age of onset	<30 years	>40 years[a]
Associated characteristics	Autoimmune diseases, viral infections, inherited factors	Obesity, aging, inherited factors
Primary problems	Destruction of pancreatic beta cells; insulin deficiency	Insulin resistance, insulin deficiency (relative to needs)
Insulin secretion	Little or none	Varies; may be normal, increased, or decreased
Requires insulin	Always	Sometimes
Older names	Juvenile-onset diabetes Insulin-dependent diabetes mellitus (IDDM)	Adult onset-diabetes Noninsulin-dependent diabetes mellitus (NIDDM)

[a]*Incidence of type 2 diabetes is increasing in children and adolescence; in more than 90 percent of these cases, it is associated with overweight or obesity and a family history of type 2 diabetes.*

taching excess glucose to protein molecules in abnormal ways; these altered proteins cannot function, causing many problems. The structures of the blood vessels and nerves become damaged, leading to loss of circulation and nerve function. Loss of blood flow to the kidneys damages them, often resulting in the need to cleanse the blood by means of kidney **dialysis**, or, in later stages, to undergo kidney transplant.

Inflammation Chronic inflammation of body tissues accompanies diabetes and may contribute to **insulin resistance**, a condition related to diabetes, discussed later.[61] Inflammation also occurs in obesity, heart disease, and cancer, as other chapters point out, and may contribute to disease progression.[62]

Circulation Problems Poor circulation also increases the likelihood of infections. With loss of both circulation and nerve function, undetected injury and infection may lead to death of tissue (gangrene), necessitating amputation of the limbs (most often the legs or feet).

KEY POINT Diabetes is an example of the body's abnormal handling of glucose. It is a major threat to health and life, and its prevalence is rapidly increasing.

Prediabetes and the Importance of Testing

Prediabetes, a fasting blood glucose level just slightly higher than normal, presents few or no warning signs (see Table 4-7), but tissue damage may silently progress.[63] According to one estimate, 54 million people in the United States have prediabetes, but few are aware of it.[64] Yet, treatment can delay or prevent the progression to diabetes, sparing much misery and pain. Therefore, the American and Canadian diabetes associations call for everyone over 45 years of age (40 in Canada), and younger people with risk factors such as overweight, to be tested regularly.

Diagnosis is made when two or more fasting blood glucose tests register positive. In this test, a clinician draws blood after a night of fasting and measures an indicator of blood glucose to determine whether it falls within the normal range (values are listed in the margin). A registered dietitian, a Certified Diabetes Educator, or a physician can help those with prediabetes or diabetes learn to manage their condition.

KEY POINT Prediabetes silently threatens the health of tens of millions of people in the United States.

Type 1 Diabetes

Type 1 diabetes is responsible for 5 to 10 percent of diabetes cases. It commonly occurs in childhood and adolescence but can occur at any age, even late in life.[65] Its incidence seems to be on the rise and it currently ranks as the leading chronic disease among children and adolescents.[66] An **autoimmune disorder** influenced by genetic inheritance, type 1 diabetes arises when the person's own immune system misidentifies the protein insulin as an enemy and attacks the cells of the pancreas that produce it.[67] Soon the pancreas can no longer produce insulin. Then, after each meal, glucose concentration builds up in the blood while body tissues are simultaneously starving for glucose, a life-threatening situation. The person must receive insulin from an external source to assist the cells in taking up the fuels they need from the bloodstream that is carrying too much.

Insulin is a protein and if it were taken orally, the digestive system would digest it. Insulin must therefore be taken as daily shots or pumped from an insulin pump that delivers it through a tiny tube implanted under the skin. Fast-acting and long-lasting forms of insulin allow more flexibility in managing meals and treatments, but users must still plan ahead to balance blood insulin and glucose concentrations.[68] Doing so can make a difference to health—those who control their blood glucose suffer less cardiovascular and other diseases than those who do not.[69] Experimental

TABLE 4-7 Warning Signs of Diabetes

These signs appear reliably in type 1 diabetes and, often, in the later stages of type 2 diabetes.

- Excessive urination and thirst
- Glucose in the urine
- Weight loss with nausea, easy tiring, weakness, or irritability
- Cravings for food, especially for sweets
- Frequent infections of the skin, gums, vagina, or urinary tract
- Vision disturbances; blurred vision
- Pain in the legs, feet, or fingers
- Slow healing of cuts and bruises
- Itching
- Drowsiness
- Abnormally high glucose in the blood

- Fasting blood glucose (milligrams per deciliter)
  - *Normal:* *70–99 mg/dL*
  - *Prediabetes:* *100–125 mg/dL*
  - *Diabetes:* *≥126 mg/dL*

dialysis (die-AL-ih-sis) in kidney disease, treatment of the blood to remove toxic substances or metabolic wastes; more properly, *hemodialysis*, meaning "dialysis of the blood."

insulin resistance a condition in which a normal or high level of circulating insulin produces a less-than-normal response in muscle, liver, and adipose tissues; thought to be a metabolic consequence of obesity.

type 1 diabetes the type of diabetes in which the pancreas produces no or very little insulin; often diagnosed in childhood, although some cases arise in adulthood. Formerly called *juvenile-onset* or *insulin-dependent diabetes*.

autoimmune disorder a disease in which the body develops antibodies to its own proteins and then proceeds to destroy cells containing these proteins. Examples are type 1 diabetes and lupus.

Did You Know?

The first use of genetic engineering was to alter the DNA of a bacterium to produce insulin for treatment of diabetes.

treatments such as surgical transplants of insulin-producing pancreatic cells and a vaccine to prevent type 1 diabetes are under development.[70]

KEY POINT Type 1 diabetes is an autoimmune disease that attacks the pancreas. Inadequate insulin leaves blood glucose high and cells undersupplied with glucose energy. People with type 1 diabetes depend on external sources of insulin.

Type 2 Diabetes

The past few decades have seen a sharp rise in the rate of the predominant type of diabetes mellitus, **type 2 diabetes** (responsible for 90 to 95 percent of cases).[71] In type 2 diabetes, body tissues lose their sensitivity to insulin. The insulin-resistant muscle and adipose tissues no longer respond to insulin by increasing their uptake of glucose from the blood. As blood glucose climbs higher, the pancreas compensates by producing larger and larger amounts of insulin. Blood insulin may rise abnormally high, but to no avail. Eventually, the overtaxed cells of the pancreas begin to fail and reduce their insulin output while blood glucose spins further out of control.

Type 2 Diabetes and Obesity Obesity underlies many cases of type 2 diabetes.[72] Middle age and physical inactivity also foreshadow its development. The greater the accumulation of body fat, particularly around the waistline, the more insulin-resistant the cells become, and the higher the blood glucose rises.[73] Even moderate weight gain in adults increases the risk. Among children and adolescents, both obesity and type 2 diabetes have increased dramatically during the past two decades.[74]

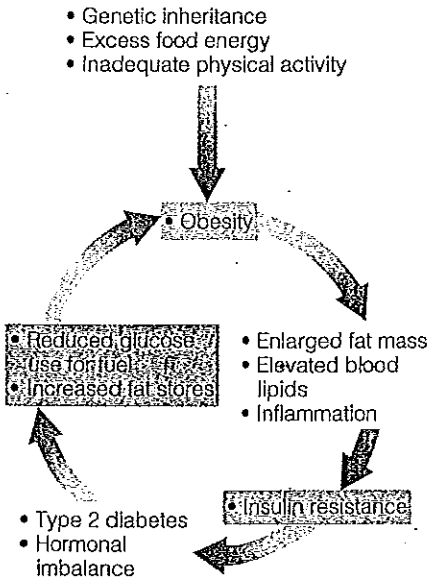
• Controversy 13 describes the trends in childhood obesity and chronic diseases.

One theory of how obesity and type 2 diabetes may worsen each other is depicted in Figure 4-15. Many factors may contribute to obesity but according to the theory, once obesity sets in, inflammation and other metabolic changes trigger the tissues to resist insulin.[75] As insulin resistance develops, glucose builds up in the blood while the tissues are deprived of glucose (type 2 diabetes). Meanwhile, blood lipid levels also rise, resulting in an overabundance of circulating fuels available to be stored as fat in the adipose tissue. Fat mass increases, insulin resistance worsens, and obesity is perpetuated. Given this series of events, is it any wonder that obese people with type 2 diabetes have trouble losing weight?

A person's genetic inheritance also strongly influences the risk of developing type 2 diabetes, and genetic researchers are working steadily toward pinpointing genetic risk factors.[76] A goal of this research, to develop genetic tests to identify susceptible people, holds the potential to avert much disease and suffering.

Preventing Type 2 Diabetes In the great majority of cases today, however, prevention is not only possible but is also likely when individuals take action to control their lifestyle choices. Men and women who maintain a healthy body weight; choose a diet high in vegetables, fruit, fish, poultry, and whole grains; and exercise regularly, restrict alcohol, and abstain from smoking have a greatly reduced inci-

FIGURE 4-15 **An Obesity-Diabetes Cycle**



MY TURN

Liz

Ariela

21st Century Epidemic?

Two young people talk about living with diabetes.

CENGAGENOW To hear their stories, log on to www.cengage.com/sso.

dence of type 2 diabetes compared to those with less healthy lifestyles. It's never too late—even older adults can lower their diabetes risk by changing their lifestyles.[77]

KEY POINT Type 2 diabetes is a growing problem. The risk of developing it rises with weight gain, aging, and physical inactivity and falls with a nutritious diet as part of a healthy lifestyle.

LO 4.8

Management of Diabetes

The effects of diabetes can be severe, but controlling blood glucose can reduce the likelihood of harm.[78] Monitoring blood glucose and taking medication often become part of the daily routine. A person with diabetes is especially advised to control body fatness because overweight worsens diabetes and its associated conditions. All lifestyle factors that affect heart and blood vessel diseases (discussed in Chapter 11) demand special attention from those with diabetes because diabetes greatly elevates the risks for developing those diseases. A person diagnosed with diabetes must establish patterns of eating, exercise, and medication to control blood glucose.

Nutrition

A major goal of medical nutrition therapy for diabetes and prediabetes is to keep blood glucose levels in the normal range or as close to normal as is safely and practically possible.[79] Controlling carbohydrate intake, in turn, plays a central role in controlling the blood glucose. A common misconception is that people with diabetes need to avoid sugar and sugar-containing foods. As far as blood glucose is concerned, the *amount* of carbohydrate often matters more than its *source*.

How Much Carbohydrate Is Best?

The amount of carbohydrate recommended for a person with diabetes varies with glucose tolerance. A low-carbohydrate diet (less than 130 grams of carbohydrate per day) is not recommended.[80] A dietary pattern that includes carbohydrate from fruits, vegetables, whole grains, legumes, and low-fat milk promotes good health, so long as the carbohydrate in the diet is monitored. Several approaches can be used to plan such diets, but many people with diabetes learn to count carbohydrates using the exchange system that is presented in Appendix D (Appendix B for Canadians). As is true for everyone, people with diabetes should choose at least half of their grains as whole grains.

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Like others, people with diabetes benefit from fruits, vegetables, whole grains, legumes, and low-fat milk products.

- Lifestyle factors that lower diabetes risk:
  - *Physical activity.*
  - *Never smoking.*
  - *Diet follows the* Dietary Guidelines for Americans.
  - *Limited alcohol intake.*
  - *Healthy body weight.*

Source: D. Mozaffarian and coauthors, Lifestyle risk factors and new-onset diabetes mellitus in older adults: The Cardiovascular Health Study, Archives of Internal Medicine *169 (2009): 798–807.*

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Monitoring blood glucose is a critical step in learning to manage diabetes.

type 2 diabetes the type of diabetes in which the pancreas makes plenty of insulin but the body's cells resist insulin's action; often diagnosed in adulthood. Formerly called *adult-onset* or *noninsulin-dependent diabetes.*

CONCEPT LINK 4-8

Exchange systems, introduced in Chapter 2, provide a valuable tool for estimating the carbohydrate and other energy nutrients in foods. They are presented in full in Appendix D.

- For more on low-carbohydrate, high-protein diets, see Chapter 9.

Why Is Timing of Carbohydrate Important? To maintain near-normal blood glucose levels, food should deliver the same amount of carbohydrate each day, spaced evenly throughout the day. Eating too much carbohydrate at one time can raise blood glucose too high, stressing the already compromised insulin-producing cells. Eating too little carbohydrate can lead to abnormally low blood sugar (**hypoglycemia**). The glycemic index of foods is not of primary importance for diabetes control.[81]

Sugar Alcohols and Artificial Sweeteners Products sweetened with **sugar alcohols,** such as cookies, sugarless gum, hard candies, and jams and jellies, are safe in moderation.[82] They provide fewer calories and a lower glycemic response compared with sugars (see margin list). Most sugar alcohols provide about half the calories of sugars. The exception, erythritol, cannot be metabolized by human beings and so is calorie-free.

- Sweeteners, calories per gram:
  - *Sugars 4*
  - *Artificial sweeteners 0*
  - *Sugar alcohols:*
    - *Erythritol 0*
    - *Isomalt, lactitol, maltitol 2*
    - *Mannitol 1.6*
    - *Sorbitol 2.6*
    - *Xylitol 2.4*

Sugar alcohols are safer for teeth than sugars, making them useful in chewing gums, breath mints, toothpaste, and other products that people keep in their mouths for a while. Mouth bacteria rapidly metabolize regular sugars into acids that cause **dental caries;** sugar alcohols resist such metabolism. Side effects such as gas, abdominal discomfort, and diarrhea arise from ingesting large quantities of sugar alcohols.

In the same vein, **artificial sweeteners** can sweeten foods without calories but people have concerns about their use. Their nature and safety is discussed in Chapter 12.

Diet Recommendations in Summary Constructed of a balanced pattern of foods, the same diet that best controls diabetes can also help to control body weight and support physical activity. This diet is:

- Controlled in total carbohydrate (to regulate glucose concentration).
- Low in saturated and *trans* fat (these worsen cardiovascular disease risks) and should provide some raw unsaturated oils (to provide essential nutrients).[83]
- Adequate in nutrients from food, not supplements (to avoid deficiencies).
- Adequate in fiber (from whole grains, fruits, legumes, and vegetables).
- Moderate in added sugars (must be counted among the day's carbohydrates).
- Adequate but not too high in protein (too much may damage kidneys weakened by diabetes).[84]

- Chapter 13 discusses a form of diabetes seen only in pregnancy—gestational diabetes.

Such a diet also has all the characteristics important to prevention of chronic diseases and meets most of the recommendations of the United States and Canada. A person at risk for diabetes can do no better than to adopt such a diet long before symptoms appear.

KEY POINT Diet plays a central role in controlling diabetes and the illnesses that accompany it. The balanced diet recommended for diabetes also supports a healthy body weight and physical activity.

hypoglycemia (HIGH-poh-gly-SEE-mee-uh) a blood glucose concentration below normal, a symptom that may indicate any of several diseases, including impending diabetes.

sugar alcohols sugarlike compounds in the chemical family *alcohol* derived from fruits or the sugar dextrose that are absorbed more slowly than other sugars, are metabolized differently, and do not elevate the risk of dental caries. Examples are maltitol, mannitol, sorbitol, xylitol, isomalt, and lactitol.

dental caries decay of the teeth (*caries* means "rottenness"). Dental caries are a topic of Chapter 14.

artificial sweeteners sugar substitutes that provide negligible, if any, energy; also called *nonnutritive sweeteners*.

© Craig M. Moore

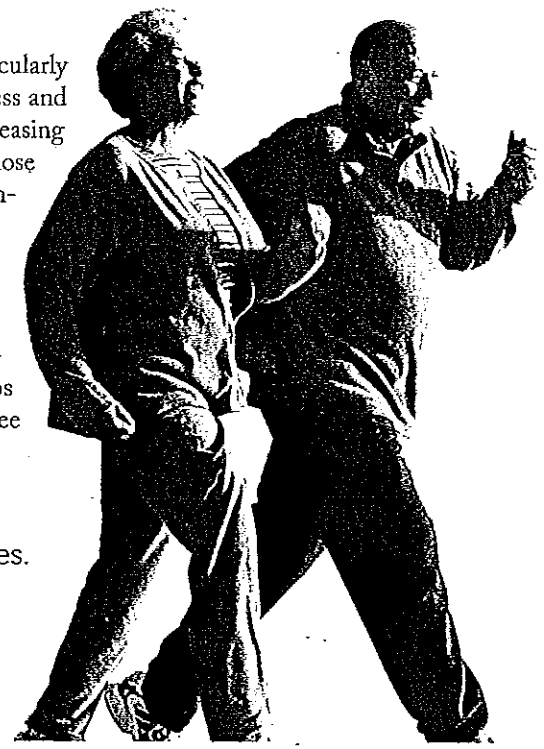
Sugar alcohols can protect the teeth against decay.

Physical Activity

The role of regular physical activity in preventing and controlling diabetes, particularly type 2 diabetes, cannot be overstated.[85] Exercise helps reduce the body's fatness and also heightens tissue sensitivity to insulin. Even with modest weight loss, increasing physical activity in overweight people seems to delay type 2 diabetes onset; in those with the disease, increased activity, even without weight loss, often helps to control it, sometimes to the degree that medication can be reduced or eliminated.

People with type 1 diabetes should check with a physician before increasing their physical activity. Hypoglycemia can occur during or after physical activity.[86] Scrupulous monitoring of blood glucose before and after activity can identify needed changes in insulin or food intake, and both carbohydrate-rich foods and insulin should be kept at the ready. Like a juggler who keeps three balls in motion, the person with diabetes must constantly balance three factors—diet, exercise, and medication—to control the blood glucose level.

KEY POINT Regular physical activity, in addition to diet and medication, contributes to controlling blood glucose in diabetes.



Purestock/Getty Images

Physical activity: a key player in controlling diabetes.

LO 4.9

If I Feel Dizzy Between Meals, Do I Have Hypoglycemia?

The disease *hypoglycemia* is rare as a true disease, but many people believe they experience its symptoms at times. The term *hypoglycemia* refers to abnormally low blood glucose.

Postprandial Hypoglycemia

People with the condition **postprandial hypoglycemia**—literally, "low blood glucose after a meal"—may experience fatigue, weakness, dizziness, irritability, a rapid heartbeat, anxiety, sweating, trembling, hunger, or headaches. They may feel confused or find mental work difficult. These symptoms are so general and common, however, that people can easily misdiagnose themselves as having postprandial hypoglycemia. A true diagnosis requires a test to detect low blood or tissue glucose while the symptoms are present to confirm that both occur simultaneously. Most often, however, no correlation is found.[87]

Fasting Hypoglycemia

A person who has symptoms while fasting (overnight, for example) has a different kind of hypoglycemia—**fasting hypoglycemia**—heralded by headache, mental dullness, fatigue, confusion, amnesia, and even seizures and unconsciousness. It can arise from serious conditions, such as cancer, pancreatic damage, uncontrolled diabetes, liver infection (hepatitis), and advanced liver damage from alcohol overuse. Fasting hypoglycemia requires immediate medical evaluation.

For Most People

To bring on even mild hypoglycemia with symptoms in normal, healthy people requires extreme measures—administering drugs that overwhelm the body's glucose-controlling hormones, insulin and glucagon. Without such intervention, these hormones hardly ever fail to keep blood glucose within normal limits in healthy people. Still, those who believe their symptoms arise from hypoglycemia may benefit from eating regularly timed, balanced meals. Minimizing alcohol intake and eliminating smoking can be important because alcohol can injure an otherwise healthy pancreas and smoking makes hypoglycemia likely.[88]

KEY POINT Postprandial hypoglycemia is an uncommon medical condition in which blood glucose falls too low. It can be a warning of organ damage or disease.

postprandial hypoglycemia an unusual drop in blood glucose that follows a meal and is accompanied by symptoms such as anxiety, rapid heartbeat, and sweating; also called *reactive hypoglycemia*.

fasting hypoglycemia hypoglycemia that occurs after 8 to 14 hours of fasting.

Part of eating right is choosing wisely among the many foods available. As we have discussed, largely without your awareness, the body responds to the carbohydrates supplied by your diet. Now you take the controls by learning how to integrate carbohydrate-rich foods into a diet that meets your body's needs for nutrients and phytochemicals.

FOOD FEATURE

Finding the Carbohydrates in Foods

- Example for 45% of calories in a 2,700-calorie diet:
  - *2,700 cal × 0.45 = 1,215 cal*
  - *1,215 cal ÷ 4 cal/g = 304 g*
- Example for 65% of calories in a 2,700-calorie diet:
  - *2,700 cal × 0.65 = 1,755 cal*
  - *1,775 cal ÷ 4 cal/g = 439 g*
- The range of carbohydrate intake recommended in a 2,700-calorie diet ranges between about 300 and 440 grams per day.

- Fiber recommendations are listed in the margin on page 118.

- The U.S. Food Exchange System (Appendix D) lists carbohydrate values for a variety of foods. Gram values listed in this section are from the Exchange System.

To support optimal health, a diet must supply enough of the right kinds of carbohydrate-rich foods. Dietary recommendations for a *health-promoting,* 2,000-calorie diet suggest that carbohydrates provide in the range of 45 percent and 65 percent of calories, or 225 and 325 grams, respectively, each day. This amount more than meets the minimum DRI amount of 130 grams needed to feed the brain and ward off ketosis.[89] People needing more or less energy need proportionately more or less carbohydrate.

If you are curious about your own carbohydrate need, find your DRI estimated energy requirement (see the inside front cover, page A) and multiply by 45 percent to obtain the bottom of your carbohydrate intake range and then by 65 percent for the top; then divide both answers by 4 calories per gram (see the example in the margin).

Breads and cereals, starchy vegetables, fruits, and milk are all good contributors of starch and dilute sugars. Many foods also provide fiber in varying amounts, as Figure 4-16 demonstrates. Concentrated sweets provide sugars but little else, as the last section demonstrates.

FRUITS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A fruit portion of ½ cup of juice, a small banana, apple, or orange, ½ cup of most canned or fresh fruit, or ¼ cup of dried fruit supplies an average of about 15 grams of carbohydrate, mostly as sugars, including the fruit sugar fructose. Fruits vary greatly in their water and fiber contents and in their sugar concentrations. Juices should contribute no more than one-half of a day's intake of fruit. Except for avocado and olives, which are high in fat, fruits contain insignificant amounts of fat and protein.

VEGETABLES


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Starchy vegetables are major contributors of starch in the diet. Just one small white or sweet potato or ½ cup of cooked dry beans, corn, peas, plantain, or winter squash provides 15 grams of carbohydrate, as much as in a slice of bread, though as a mixture of sugars and starch. One-half cup of carrots, okra, onions, tomatoes, cooked greens, or most other nonstarchy vegetables or a cup of salad greens provides about 5 grams as a mixture of starch and sugars.

BREADS, GRAINS, CEREALS, RICE, AND PASTA


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Breads and other starchy foods are famous for their carbohydrate. Nutrition authorities encourage people to eat grains often and recommend that half of the grain choices should be whole grains. A slice of bread, half an English muffin, a 6-inch tortilla, ⅓ cup of rice or pasta, or ½ cup of cooked cereal provides about 15 grams of carbohydrate, mostly as starch.

Not all high-fiber foods are whole grains. One hundred percent bran cereal and bran muffins may be high-fiber foods, but added bran doesn't qualify as whole grain. Bran is just one part of the grain, and it may be added to mostly refined, enriched white flour and sugar in cereals and muffins. Conversely, puffed

FIGURE 4-16

Fiber in the Food Groups

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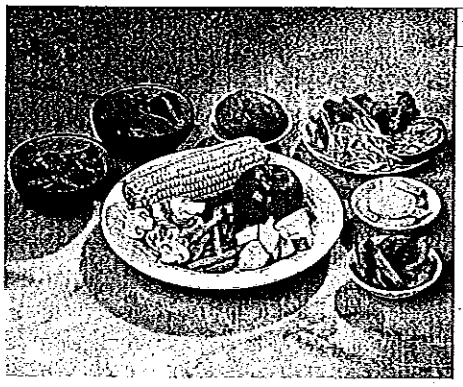
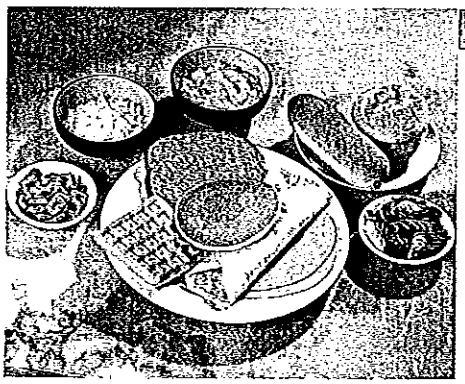
Fruits

Food[a]	Fiber (g)	Food	Fiber (g)
Pear, raw, 1 medium	5	Other berries, raw, 1/2 c	2
Blackberries/raspberries, raw, 1/2 c	4	Peach, raw, 1 medium	2
Prunes, cooked, 1/4 c	4	Strawberries, sliced, 1/2 c	2
Figs, dried, 3	3	Cantaloupe, raw, 1/2 c	1
Apple, 1 medium	3	Cherries, raw, 1/2 c	1
Apricots, raw, 4 each	3	Fruit cocktail, canned, 1/2 c	1
Banana, raw, 1	3	Peach half, canned	1
Orange, 1 medium	3	Raisins, dry, 1/4 c	1
		Orange juice, 3/4 c	<1



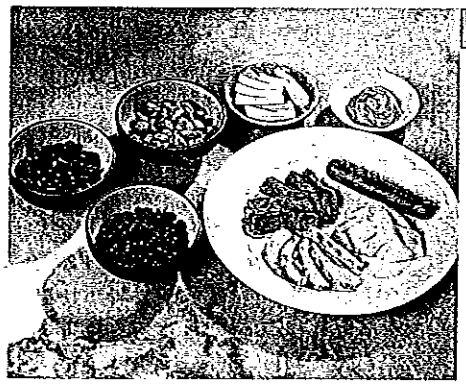
Vegetables

Food	Fiber (g)	Food	Fiber (g)
Baked potato with skin, 1	4	Mashed potatoes, home recipe, 1/2 c	2
Broccoli, chopped, 1/2 c	3	Bell peppers, 1/2 c	1
Brussels sprouts, 1/2 c	3	Broccoli, raw, chopped, 1/2 c	1
Spinach, 1/2 c	3	Carrot juice, 1/2 c	1
Asparagus, 1/2 c	2	Celery, 1/2 c	1
Baked potato, no skin, 1	2	Dill pickle, 1 whole	1
Cabbage, red, 1/2 c	2	Eggplant, 1/2 c	1
Carrots, 1/2 c	2	Lettuce, romaine, 1 c	1
Cauliflower, 1/2 c	2	Onions, 1/2 c	1
Corn, 1/2 c	2	Tomato, raw, 1 medium	1
Green beans, 1/2 c	2	Tomato juice, canned, 3/4 c	1



Grains

Food	Fiber[a] (g)	Food	Fiber (g)
100% bran cereal, 1 oz	10	Pumpernickel bread, 1 slice	2
Barley, pearled, 1/2 c	3	Shredded wheat, 1 large biscuit	2
Cheerios, 1 oz	3	Cornflakes, 1 oz	1
Whole-wheat bread, 1 slice	3	Muffin, blueberry, 1	1
Whole-wheat pasta,[b] 1/2 c	3	Puffed wheat, 1 1/2 c	1
Wheat flakes, 1 oz	3	White pasta,[b] 1/2 c	1
Brown rice, 1/2 c	2	Cream of wheat, 1/2 c	<1
Light rye bread, 1 slice	2	White bread, 1 slice	<1
Muffin, bran, 1 small	2	White rice, 1/2 c	<1
Oatmeal, 1/2 c	2		
Popcorn, 2 c	2		



Meat, Poultry, Fish, Dry Peas and Beans, Eggs, and Nuts

Food	Fiber (g)	Food	Fiber (g)
Lentils, 1/2 c	8	Soybeans, 1/2 c	5
Kidney beans, 1/2 c	8	Almonds or mixed nuts, 1/4 c	4
Pinto beans, 1/2 c	8	Peanuts, 1/4 c	3
Black beans, 1/2 c	7	Peanut butter, 2 tbs	2
Black-eyed peas, 1/2 c	6	Cashew nuts, 1/4 c	1
Lima beans, 1/2 c	5	Meat, poultry, fish, and eggs	0

[a]All values are for ready-to-eat or cooked foods unless otherwise noted. Fruit values include edible skins. All values are rounded values.

[b]Pasta includes spaghetti noodles, lasagna, and other noodles.

wheat cereal, a whole-grain food, registers low in fiber per cup because the air that puffs up the grains takes up space in the measuring cup.

Also, do not assume that a brown-colored grain food is a whole grain; rather, rely on ingredient lists organized in descending order of prominence as your guide. Brown-colored baked goods may be made from white flour with brown coloring and flecks of bran added. Also, product names like "multigrain," "seven-grain," and the like mean only that the product contains some portion of grains other than wheat, but they say nothing about their degree of refinement or the amounts added—ingredients lists tell the truth.

Most grain choices should be low in fat and sugar. When extra calories are required to meet energy needs, some selections higher in fat (specifically, unsaturated fat; see Chapter 5) and sugar can supply discretionary calories and pleasure in eating. These choices might include biscuits, cookies, croissants, muffins, and snack crackers.

MEAT, POULTRY, FISH, DRY BEANS, EGGS, AND NUTS

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With two exceptions, foods of this group provide almost no carbohydrate to the diet. The exceptions are nuts, which provide a little starch and fiber along with their abundant fat, and legumes (dried beans), revered by diet-watchers as low-fat sources of both starch and fiber. Just ½ cup of cooked beans, peas, or lentils provides 15 grams of carbohydrate, an amount equaling the richest carbohydrate sources. Among sources of fiber, legumes are peerless, providing as much as 8 grams in ½ cup.

MILK, CHEESE, AND YOGURT

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A cup of milk or plain yogurt is a generous contributor of carbohydrate, donating about 12 grams. Cottage cheese provides about 6 grams of carbohydrate per cup, but most other cheeses contain little if any carbohydrate. These foods also contribute high-quality protein (a point in their favor), as well as several important vitamins and minerals. Calcium-fortified soy beverages (soy milk) and soy yogurts approximate the nutrients of milk, providing some amount of added calcium and 14 grams of carbohydrate. Milk and soy milk products vary in fat content, an important consideration in choosing among them; Chapter 5 provides the details. Sweetened milk and soy products contain added sugars.

Butter and cream cheese, though dairy products, are not equivalent to milk because they contain little or no carbohydrate and insignificant amounts of the other nutrients important in milk. They are appropriately associated with the solid fats.

OILS, SOLID FATS, AND ADDED SUGARS

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Oils and solid fats are devoid of carbohydrate, but sweets provide almost pure carbohydrate. Most people enjoy sweets, so it is important to learn something of their nature and to account for them in the diet. First, the definitions of "sugar" come into play (Table 4-8 defines sugar terms).

All sugars originally develop by way of photosynthesis in a plant. A sugar molecule inside a grape (one of the **naturally occurring sugars**) is chemically indistinguishable from one taken from sugar cane or corn and added at the factory (**added sugars**) to sweeten grape jam. The term *added sugars* refers to all sugars that have been extracted from their original source and added to other foods. Honey added to food is also an added sugar. The combined total of naturally occurring and added sugars appears on food labels in the line reading "sugars." The body handles all the sugars in the same way, whatever their source.

The committee on the *Dietary Guidelines for Americans 2005* offers clear advice on added sugars: treat them as discretionary calories.[90] That is, added sugars bring only calories, with no other significant nutrients, to the diet; conversely, the naturally occurring sugars of, say, an orange provide calories but also the vitamins, minerals, fiber, and phytochemicals of oranges. Because current law requires manufacturers to list only total sugars on food labels, consumers remain largely in the dark about how much added sugar, and therefore how many discretionary calories, their foods contain. Added sugars can contribute to nutrient deficiencies by displacing nutritious food from the diet.[91] Most people can afford only a little added sugar in their diets if they are to meet nutrient needs within calorie limits. The USDA Food Guide suggests about 9 teaspoons of sugar, or one soft drink's worth, in a nutrient-dense 2,200-calorie diet (the margin on page 139 lists other amounts).

Whether they come from beets, corn, grapes, honey, or sugar cane, the added sugars in foods are all alike. All arise naturally and, through processing, are purified of most or all of the original plant material—bees process honey and machines process the other types. The health effects of refined sugars are discussed in Controversy 4. A strawberry spread sweetened with grape juice concentrate, for example, may claim to be "100% fruit" but can contain more sugars than regular sucrose-sweetened jam.

THE NATURE OF SUGAR

Each teaspoonful of any sweet can be assumed to supply about 16 calories and 4 grams of carbohydrate. You may not think of candy or molasses in terms of *teaspoons,* but this helps to emphasize that all sugary items are like white sugar—in spite of many people's belief that some are different or "better." If you use ketchup liberally, remember that a tablespoon of it contains a teaspoon of sugar. And for the soft-drink user, a 12-ounce can of sugar-sweetened cola contains about 8 or more teaspoons of added sugar, usually in the form of **high-fructose corn syrup.** Figure 4-17 shows that processed foods contain surprisingly large amounts of sugar.

TABLE 4-8 Terms That Describe Sugar

Note: The term *sugars* here refers to all of the monosaccharides and disaccharides. On a label's ingredients list, the term *sugar* means sucrose. See Chapter 12 for terms related to noncaloric artificial sweeteners.

- **added sugars** sugars and syrups added to a food for any purpose, such as to add sweetness or bulk or to aid in browning (baked goods). Also called *carbohydrate sweeteners,* they include glucose, fructose, corn syrup, concentrated fruit juice, and other sweet carbohydrates.
- **agave syrup** a carbohydrate-rich sweetener made from a Mexican plant; a higher fructose content gives some agave syrups a greater sweetening power per calorie than sucrose.
- **brown sugar** white sugar with molasses added, 95% pure sucrose.
- **concentrated fruit juice sweetener** a concentrated sugar syrup made from dehydrated, deflavored fruit juice, commonly grape juice; used to sweeten products that can then claim to be "all fruit."
- **confectioner's sugar** finely powdered sucrose, 99.9% pure.
- **corn sweeteners** corn syrup and sugar solutions derived from corn.
- **corn syrup** a syrup, mostly glucose, partly maltose, produced by the action of enzymes on cornstarch.
- **dextrose** an older name for glucose.
- **evaporated cane juice** raw sugar from which impurities have been removed.
- **fructose, galactose, glucose** the monosaccharides.
- **granulated sugar** common table sugar, crystalline sucrose, 99.9% pure.
- **high-fructose corn syrup** a commercial sweetener used in many foods, including soft drinks. Composed almost entirely of the monosaccharides fructose and glucose, its sweetness and caloric value are similar to sucrose.
- **honey** a concentrated solution primarily composed of glucose and fructose, produced by enzymatic digestion of the sucrose in nectar by bees.
- **invert sugar** a mixture of glucose and fructose formed by the splitting of sucrose in an industrial process. Sold only in liquid form and sweeter than sucrose, invert sugar forms during certain cooking procedures and works to prevent crystallization of sucrose in soft candies and sweets.
- **lactose, maltose, sucrose** the disaccharides.
- **levulose** an older name for fructose.
- **maple sugar** a concentrated solution of sucrose derived from the sap of the sugar maple tree, mostly sucrose. This sugar was once common but is now usually replaced by sucrose and artificial maple flavoring.
- **molasses** a syrup left over from the refining of sucrose from sugar cane; a thick, brown syrup. The major nutrient in molasses is iron, a contaminant from the machinery used in processing it.
- **naturally occurring sugars** sugars that are not added to a food but are present as its original constituents, such as the sugars of fruit or milk.
- **raw sugar** the first crop of crystals harvested during sugar processing. Raw sugar cannot be sold in the United States because it contains too much filth (dirt, insect fragments, and the like). Sugar sold as "raw sugar" is actually evaporated cane juice.
- **turbinado** (ter-bih-NOD-oh) **sugar** raw sugar from which the filth has been washed; legal to sell in the United States.
- **white sugar** pure sucrose, produced by dissolving, concentrating, and recrystallizing raw sugar.

What about the nutritional value of a product such as molasses, honey, or concentrated fruit juice sweetener compared to white sugar? Molasses contains 1 milligram of iron per tablespoon so, if used frequently, it can contribute some of this important nutrient. Molasses is less sweet than the other sweeteners, however, so more molasses is needed to provide the same sweetness as sugar. Also, the iron comes from the iron machinery in which the molasses is

- The USDA Food Guide suggests that, within calorie limits, small amounts of added sugars can be enjoyed as part of the discretionary calories in a nutrient-dense diet:
  - *3 tsp for 1,600 cal*
  - *5 tsp for 1,800 cal*
  - *8 tsp for 2,600 cal*
  - *9 tsp for 2,200 cal*
  - *12 tsp for 2,400 cal*

FIGURE 4-17 Sugar in Processed Foods

½ c canned corn = 1 tsp sugar[a]

12 oz cola = 10 tsp sugar

1 tbs ketchup = 1 tsp sugar

1 tbs creamer = 2 tsp sugar

8 oz sweetened yogurt = 8 tsp sugar

2 oz chocolate = 8 tsp sugar

[a]*Values based on 1 tsp = 4g.*

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Did You Know?

Sugars on the Nutrition Facts panel of a food label reflect both added and naturally occurring sugars in foods. Sugars listed among the ingredients are all added.

Did You Know?

Sugar alcohols protect against tooth decay.

TABLE 4-9 The Empty Calories of Sugar

At first glance, honey, jelly, and brown sugar look more nutritious than plain sugar, but when compared with a person's nutrient needs, none contributes anything to speak of. The cola beverage is clearly an empty-calorie item, too.

Food	Energy (cal)	Protein (g)	Fiber (g)	Calcium (mg)	Iron (mg)	Magnesium (mg)	Potassium (mg)	Zinc (mg)	Vitamin A (μg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)	Vitamin B_6 (mg)	Folate (μg)	Vitamin C (mg)
Sugar (1 tbs)	46	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Honey (1 tbs)	64	0	0	1	0.1	0	11	0	0	0	0	0	0	<1	0
Molasses (1 tbs)	55	0	0	42	1.0	50	300	0.1	0	0	0	0.2	0.1	0	0
Concentrated grape or fruit juice sweetener (1 tbs)	30	0	0	0	0	0	0	0	0	0	0	0	0	0	
Jelly (1 tbs)	49	0	0	1	0	1	12	0	0	0	0	0	0	0	<1
Brown sugar (1 tbs)	54	0	0	8	0.2	3	31	0	0	0	0	0	0	0	0
Cola beverage (12 fl oz)	153	0	0	11	0.1	4	4	0	0	0	0	0	0	0	0
Daily Values	2,000	56	25	1,000	18	400	3,500	15	1,000	1.5	1.7	20	2	400	60

made and is in the form of an iron salt not easily absorbed by the body.

Honey is no better for health than sugars by virtue of being "natural"—honey is chemically almost indistinguishable from sucrose. Honey contains the two monosaccharides, glucose and fructose, in approximately equal amounts. Sucrose contains the same monosaccharides but joined together in the disaccharide form. Spoon for spoon, however, sugar contains fewer calories than honey because the dry crystals of sugar take up more space than the sugars of honey dissolved in its water.

As for concentrated juice sweeteners, these are highly refined and have lost virtually all of the beneficial nutrients and phytochemicals of the original fruit. No form of sugar is any "more healthy" than white sugar, as Table 4-9 shows.

It would be absurd to rely on any sugar for nutrient contributions. A tablespoon of honey (64 calories) does offer 0.1 milligram of iron, but it would take 180 tablespoons of honey—11,500 calories—to provide 100 percent of a young woman's recommended intake of 18 milligrams of iron. The nutrients of honey just don't add up as fast as its calories. Thus, if you choose molasses, brown sugar, or honey, choose them not for their nutrient contributions, but for the pleasure they give.

These tricks can help magnify the sweetness of foods without boosting their calories:

- Serve sweet food warm (heat enhances sweet tastes).
- Add sweet spices such as cinnamon, nutmeg, allspice, or clove.
- Add a tiny pinch of salt; it will make food taste sweeter.
- Try reducing the sugar added to recipes by one-third.
- Select fresh fruits or fruit juice, or those prepared without added sugar.
- Use small amounts of sugar substitutes in place of sucrose.
- Read food labels for clues on sugar content.

Finally, enjoy whatever sugar you do eat. Sweetness is one of life's great sensations, so enjoy it in moderation.

Diet Analysis

PLUS Concepts in Action

Analyze Your Carbohydrate Intake

The purpose of this chapter's exercise is to help you examine the carbohydrate-rich foods in your diet, compare your intakes with recommendations, and help you to obtain the recommended amounts of soluble and insoluble fiber.

1. In the DA+ program, select the Reports tab then select Macronutrient Ranges. Using your three-day diet records, choose Day Two and choose all meals. Generate a report. Did your intake meet the recommendation to consume between 45 percent and 65 percent of total energy calories as carbohydrate?
2. Determine the distribution of carbohydrate among the day's foods. Select Reports, then Source Analysis, and then Carbohydrate from the drop-down box. Generate a separate report for each meal: breakfast, lunch, and dinner. At which meal did you consume the most carbohydrate? Which foods were the greatest contributors?
3. Did your fiber intake fall within the recommended range of intake (25–35 grams)? From the Reports tab select Intake vs. Goals. Choose Day One, all meals, and generate a report. Did you meet your fiber needs?
4. From Reports, select Source Analysis. Using Day Three, choose all meals and generate a report. Which foods provided the greatest amounts of fiber for the day's intake? If you are short on fiber, look at Figure 4-4 (page 114), Figure 4-5 (page 115), and Figure 4-16 (page 137) which suggests fiber-rich foods to increase your intake of both soluble and insoluble fibers.
5. Whole grains provide more than just fiber. From the Track Diet tab, create a new day (do not alter your three-day record). Enter two food items as a snack: 2.5 cups of Fruit Loops cereal and .5 cup granola (these are equal in calories). Select Reports, Source Analysis, and mineral magnesium from the drop-down box. Generate a report for the new snack. Which was the better magnesium source?

MEDIA MENU

CENGAGENOW Throughout this chapter, the CengageNOW logo indicates an opportunity for online self-study, linking you to interactive tutorials and videos based on your level of understanding. Go to **www.cengage.com/sso.**

Learn more about topics like lactose intolerance, tooth decay, diabetes, and artificial sweeteners at **www.healthfinder.gov.**

Search for "sugars" and "fiber" at the International Food Information Council site: **www.foodinsight.org.**

Search the American Diabetes Association website for information about diabetes, including research, prevention, and living with diabetes: **www.diabetes.org.**

Learn more about dental health by searching A-Z Public Topics at **www.ada.org.**

SELF CHECK

Answers to these Self Check questions are in Appendix G.

1. The dietary monosaccharides include:
   A. sucrose, glucose, and lactose
   B. fructose, glucose, and galactose
   C. galactose, maltose, and glucose
   D. glycogen, starch, and fiber
2. The polysaccharide that helps form the supporting structures of plants is:
   A. cellulose
   B. maltose
   C. glycogen
   D. sucrose

3. Digestible carbohydrates are absorbed as _____ through the small intestinal wall and are delivered to the liver, where they are converted to _____.
   A. disaccharides; sucrose
   B. glucose; glycogen
   C. monosaccharides; glucose
   D. galactose; cellulose
4. When blood glucose concentration rises, the pancreas secretes _____, and when blood glucose levels fall, the pancreas secretes _____.
   A. glycogen; insulin
   B. insulin; glucagon
   C. glucagon; glycogen
   D. insulin; fructose
5. When the body uses fat for fuel without the help of carbohydrate, this results in the production of _____.
   A. ketone bodies
   B. glucose
   C. starch
   D. galactose
6. Foods rich in soluble fiber lower blood cholesterol.
   T F
7. Type 1 diabetes is most often controlled by successful weight-loss management.
   T F
8. Around the world, most people are lactose intolerant.
   T F
9. By law, enriched white bread must equal whole-grain bread in nutrient content.
   T F
10. The fiber-rich portion of the wheat kernel is the bran layer.
    T F

CONTROVERSY 4

Are Carbohydrates "Bad" for Health?

LO 4.10

Lately, dietary carbohydrates have been the target of some serious accusations. Popular writers proclaim, sometimes persuasively, that juicy apples, baked potatoes, warm muffins, blueberry pancakes, freshly baked bread, tasty rice or pasta dishes, and other carbohydrate-rich foods are "bad" for health.[1]* In the scientific realm, researchers have been investigating carbohydrates for potential roles in obesity and heart disease.[2] Meanwhile, the current *Dietary Guidelines for Americans* urge people to consume a variety of carbohydrate-rich whole grains, legumes, fruits, vegetables, and milk to support good health. Who's right?

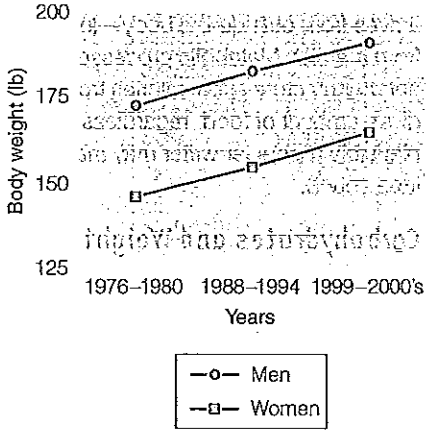
This Controversy investigates some of the accusations launched against carbohydrate-rich foods by the popular media. It also demonstrates how authentic nutrition researchers pursue answers to questions, step-by-step, via scientific inquiry.

ACCUSATION 1: CARBOHYDRATES ARE MAKING US FAT

Over the past several decades, people in the United States have grown dramatically fatter (Figure C4-1).[3] At the same time, their carbohydrate intakes have increased. Does that mean, as some popular writers claim, that carbohydrate-rich foods *cause* obesity? To examine this conclusion, investigators may begin by looking at national nutrient and energy intake data.

FIGURE C4-1

Increases in Adult Body Weight over Time



Carbohydrate Intake and Calorie Trends

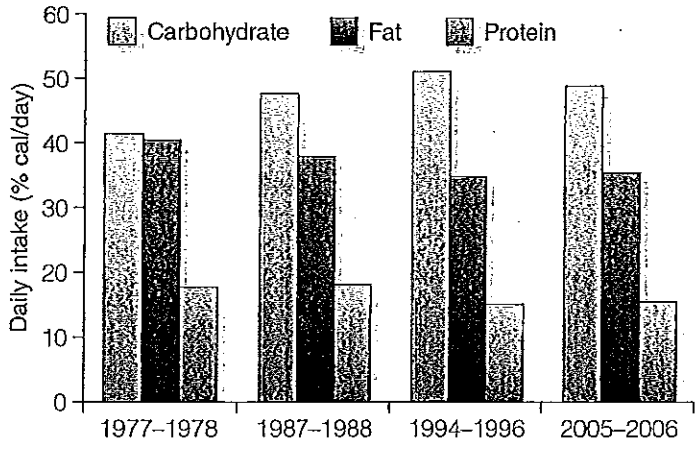
Figure C4-2 presents a summary of energy nutrient intake data over the past three decades. It demonstrates that the percentage of calories from carbohydrates in the U.S. diet increased from 42 percent in the 1970s to 49 percent today.[4] During the same period, the percentage of calories from fat dropped from 41 percent to 34 percent. The percentage of protein intake stayed about the same.

While percentages among energy nutrients in the U.S. diet shifted somewhat, a more significant trend was also taking place: People were consuming many more total calories each day.[5] Figure C4-2 shows that since the 1970s, the average food energy intake has

FIGURE C4-2

Percentages of Calories from Energy Nutrients, United States, 1977–2006

The total daily calories in the U.S. diet are divided into three columns for each time period to reveal the relative contributions of carbohydrate, fat, and protein.



*Reference notes are found in Appendix F.

increased by at least 300 calories per day, with other estimates as high as 500 calories per day.[6] Another factor was also in play: most people were not active enough to use up those extra calories—physical activity levels declined.[7] Not surprisingly, the average body weight for adults over these decades increased by about 20 pounds (see Figure C4-3).

Carbohydrates or Calories?

Intriguingly, carbohydrates provided almost all of the national calorie increase in recent decades. This fact has led to speculation that something about dietary carbohydrate itself, and not the calories it provides, may be to blame for people's weight gain. Plausible-sounding metabolic explanations for a special "fattening power" of carbohydrates have been offered by the popular media.

In the realm of science, epidemiological studies report an *inverse* relationship between carbohydrate intake and body weight.[8] That is, people with higher carbohydrate intakes may have lower body weights. Some of this association, but not all, may be explained by dietary fiber intake, which follows whole food sources of carbohydrate into the diet. Whole food diets favor a healthy body weight.

If carbohydrate itself caused overweight, then people around the world consuming traditional high-carbohydrate rice- or root-based diets, such as the Japanese, Chinese, or many Africans, should have high rates of obesity, diabetes, and heart disease. The reverse is generally true: the world's grain- and root-consuming peoples eating traditional diets most often stay lean even though most of their daily calories derive from carbohydrate. Also, as people in such societies abandon their traditional diets in favor of "Western" style high-fat, high-protein, and high-calorie foods, obesity and chronic disease rates soar. Obesity rates in China, for example, are quickly approaching those of the West.[9] In 1985, less than 2 percent of China's schoolchildren were overweight; by the year 2002, the number was about 17 percent for boys and 10 percent for girls. During the same period, intakes of animal protein jumped from 8 to 25 percent of total calories and fat intakes soared as well.

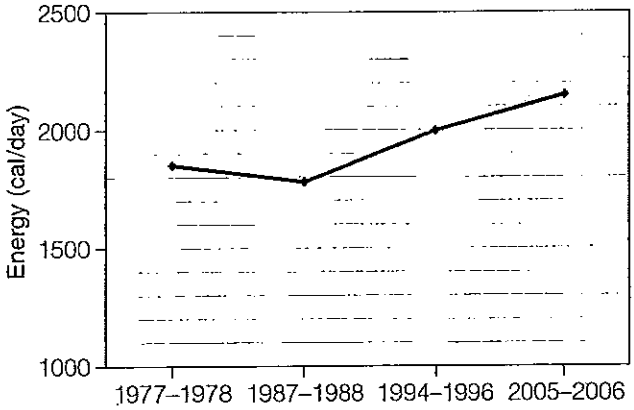
Finally, the first law of thermodynamics comes into play.† Energy (calories) cannot collect as body fat unless it arrives from outside the body—that is, from the diet. Metabolic processes cannot manufacture extra calories from a given amount of food, regardless of how plausible a popular writer may make the idea sound.

Carbohydrates and Weight Loss

Of interest to many people is whether eating a low-carbohydrate weight-loss diet might produce faster or greater weight loss than other diets. It is clear from research that people following low-carbohydrate diets do lose weight, and may even lose a little extra during the first few months of dieting, but the difference disappears over time.[10] Chapter 9 provides details, but the punch line seems to be that, over time, people lose about the same amount of weight on any kind of low-calorie diet.[11] Weight-loss success reflects the degree of adherence to a calorie-restricted diet, and not the proportion of energy nutrients in that diet.

†*The first law of thermodynamics states that energy cannot be created or destroyed.*

FIGURE C4-3 **Daily Energy Intake over Time**



ACCUSATION 2: CARBOHYDRATES CAUSE DIABETES

Diabetes impairs blood glucose regulation following a carbohydrate-containing meal. At one time, people thought that eating carbohydrate *caused* diabetes by "overstraining the pancreas," but now we know that this is not the case. Body fatness is more closely related to diabetes than diet composition is; high rates of diabetes have not been reported in societies where obesity is rare.

Refined Carbohydrates and Diabetes

In some people, however, intakes of certain forms of carbohydrates accompany diabetes development. Particularly among certain Native Americans, a profound increase in the prevalence of diabetes is observed when refined flour and sugars replace whole foods of traditional diets. In addition, evidence from two studies of over 160,000 U.S. women reports an increased diabetes risk in those who drink one or more sugar-sweetened soft drinks each day compared with women consuming less than one per month.[12] Other studies report no link between sugar intake and metabolic markers of diabetes when calorie intakes do not exceed calorie needs, however.

Glycemic Load and Diabetes

Over a decade ago, a study tracking the dietary habits of over 100,000 men and women revealed a positive correlation between diabetes and eating a diet with a high glycemic load based on mashed potatoes, white rice, highly refined cold breakfast cereals, and white bread. However, a subsequent study of this nature did not support this finding. No effect on diabetes risk from such a diet was detected in almost 36,000

women. What this study *did* uncover was a lower incidence of type 2 diabetes and cardiovascular disease in those consuming greater amounts of whole grains and other whole foods, a finding that has been repeated many times.[13]

In summary, whenever whole foods provide most of the carbohydrate in a diet of moderate calories, diabetes is rare. Such evidence does not prove that refined carbohydrates cause diabetes or that whole foods prevent it, however. The apparent protective effect of whole foods might be due to factors other than carbohydrates, such as fiber, other nutrients, or the phytochemicals of whole grains, fruits, and vegetables. In addition, people who tend to their diets by choosing whole grains probably make other healthy choices, such as being physically active, too. Still, refined carbohydrates easily provide excess calories that contribute to body fat stores, and type 2 diabetes risk rises in direct proportion to body fatness.

ACCUSATION 3: ADDED SUGARS CAUSE OBESITY AND ILLNESS

Many vocal carbohydrate opponents point out, rightly, that added sugars (and refined grains) are relatively new in the diet of humankind. Then they conclude that these foods must therefore be responsible for the current high rates of obesity and chronic illnesses. Indeed, many carbohydrate-rich foods that people eat today bear little resemblance to the seeds, grains, fruits, and roots that provided almost all of the carbohydrate in the early human diet. Today, softer, whiter, and sweeter carbohydrate sources predominate.

Trends in Added Sugars

In past centuries, the only concentrated sweetener was honey, a rare addition to the diet. Today, each person in the United States uses up almost three-quarters of a cup (31 teaspoons) of refined sugars added to their foods and beverages each day.[‡] This amount is enough, on average, to provide every man, woman, and child with more than 140 pounds of added sugars per year.[14] Figure C4-4 depicts the dramatic upward trend in available added sugars in the U.S. diet and offers the USDA suggested upper intake limits for added sugars for comparison.[15] Note that the columns in the figure represent sugars in the food supply and do not account for waste, such as the syrup drained from sweet pickles or jam that molds and is tossed out. They also do not account for sweetened imported food products, a fast-growing source of added sugars in the United States.[16] The great majority of these sugars in U.S. foods and beverages are added by manufacturers before consumers purchase them. Most people add little sugar from the sugar bowl at home, so they remain unaware of how much sugar they take in each year.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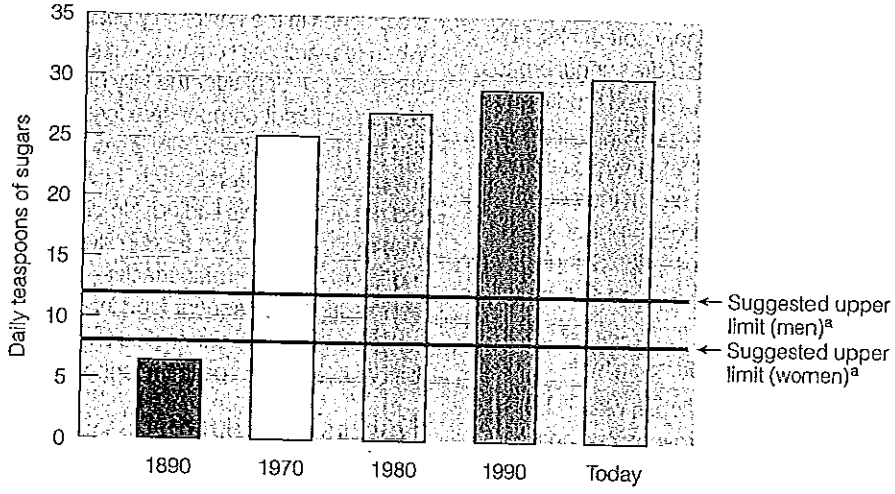
Most people remain unaware of how much added sugar they take in each year.

Added Sugars and Diseases

Data from the world's developing nations seem to clinch the case against added sugars: as a population's income rises, consumption of added sugars increases, and the rates of obesity, diabetes, and related diseases rise, too. Before concluding that sugars must cause health problems, however, scientists also look exhaustively for *other* potential causes occurring simultaneously. For example, newly wealthy peoples do buy and eat more sweets but, as in the China example described earlier, they also choose more fats (particularly oils for frying), animal proteins, fast foods, and refined processed

FIGURE C4-4

Added Sugars: Average U.S. Supply per Person Compared with USDA Prudent Upper Intake Limits



[a]*These USDA suggested upper limits for added sugars reflect one-half of the average discretionary calorie allowance for sedentary men aged 19–30 consuming 2,400 cal/day and sedentary women aged 19–30 consuming 2,000 cal/day. For other people, see Appendix E. The American Heart Association sets a prudent upper limit of 6 tsp of sugar for most women, and 9 tsp for most men.*

Sources: USDA Food Guide; R. K. Johnson and coauthors, Dietary sugars intake and cardiovascular health: A Scientific Statement from the American Heart Association, Circulation *120 (2009): 1011–1020.*

[‡]*This estimate from the USDA Economic Research Service includes all caloric sweeteners in the U.S. human food supply, including cane and beet sugars, corn sweeteners, honey, and syrups.*

foods, all at newly affordable prices.[17] And as they increase their calorie intake, they decrease their physical activity. To say that one of these factors alone—in this case, sugar intake—is causing the world's problems would be naïve. Still, added sugars provide more and more energy to the human diet, so their relationships with health are worth exploring.

ACCUSATION 4: HIGH-FRUCTOSE CORN SYRUP HARMS HEALTH

In 2004, scientists noted that as high-fructose corn syrup (HFCS) replaced sucrose in many foods and beverages, unprecedented U.S. gains in body fatness were burdening the nation's health.[18] Since then, investigators have been testing theories concerning potential roles for HFCS in obesity and disease causation.[19] Their results quickly made the news and became popular topics for writers and speakers. With repetition, the villainy of fructose was exaggerated to the point that consumers adopted unproven hypotheses as common knowledge. Today, some food manufacturers are replacing HFCS with the more familiar sucrose to boost consumer acceptance of their products. Meanwhile, scientists continue to methodically test their ideas, one-by-one, to reveal the effects of HFCS on the body.

The Nature of High-Fructose Corn Syrup

HFCS sweetens sugary soft drinks, fruit drinks, candies, salad dressings, breads, other baked goods, canned foods, and other sweetened foods. Its sweetening power is similar to that of sucrose, and it contributes about half of the added sugars in the U.S. food supply.[20] Food manufacturers choose HFCS in place of sucrose for several reasons.[21] Among them, HFCS:

- is cheaper. The price is stable.
- derives from a reliable, plentiful U.S. crop—corn. Sucrose prices and supplies are affected by political and weather conditions in other cane-growing countries.
- is a ready-to-use liquid. Dry sucrose often must be dissolved in liquid before use.
- remains stable in acidic foods and beverages. Sucrose breaks down in acid.

The decision to sweeten foods with HFCS makes good business sense.

HFCS and Obesity

One question of concern is whether individuals who consume large amounts of HFCS, usually in the form of sugary beverages, weigh more than people who consume less. Overall, findings indicate that people in the United States who consume the most HFCS from sugary sodas, fruit punches, and other sugary beverages do weigh more than people who consume less, and they take in more total calories, too.[22] When results of many such studies are compiled, the data confirm these findings—HFCS consumption and obesity often occur together.[23] This correlation does not prove that HFCS causes obesity, however. Scientists must also find plausible biological mechanisms through which HFCS might have an effect.

Liquid Sugar and Calorie Control

Several such mechanisms involve the body's appetite control system. The first suggests that the body cannot detect calories of liquid sugars and so does not compensate for them with reduced calorie intakes at later meals.[24] To test this idea, some subjects were given jelly beans (solid sugar) before a meal. Later, at mealtime, they ate fewer calories of food—they seemed to compensate for the calories in the earlier jelly bean snack. When researchers substituted liquid sugar as soft drinks for the jelly beans, subjects did not compensate for the calories in the liquid snack—they ate the full meal later on. Later research, however, did not support this finding. No difference was reported between food intake following liquid or solid sugar snacks—both suppressed subsequent food intake.[25] It appears that, regardless of its form, sugar before mealtimes spoils the appetite.

Fructose and Appetite Regulation

A second idea suggests that fructose may impair appetite regulation, possibly by way of insulin or other appetite-regulating signals.[26] Release of insulin causes a shift in the body's appetite-regulating hormones toward appetite suppression.[27] Recall from Chapter 4 that glucose from food stimulates the release of insulin from the pancreas. Fructose, in contrast, does not trigger the release of insulin.[28] (Appetite regulation is described in Chapter 9.) Because fructose ingestion fails to stimulate insulin release, fructose does not suppress the appetite through this mechanism as glucose does.[29] Rats given a solution of glucose, fructose, or sucrose all gain body fatness, but the rats receiving fructose gain the most.[30] Theoretically, then, chronic fructose consumption could lead to greater food intakes, which could contribute to the nation's obesity problem. Although this idea seems plausible, one flaw exists: hardly anyone eats pure fructose. They eat sucrose or HFCS and both of these sugars contain sufficient glucose to stimulate the release of insulin and reduce the appetite accordingly.

Researchers tested the fructose-weight gain theory on monkeys.[31] They fed one group large amounts of pure fructose, while another group received glucose. Some changes in energy balance were observed at several points over the course of the study, but at the end of one year body weights of fructose- and glucose-fed monkeys did not differ. Fructose did not cause excess weight gain, even when monkeys consumed almost half of their daily calories from fructose.

Finally, when overweight or obese human subjects consumed large, equally caloric amounts of fructose or glucose with their regular diets, both sugars caused about the same degree of weight gain.[32] An important difference in the nature of these gains was evident, however. The fructose group gained more of their fat in the abdominal area, and abdominal body fatness elevates the risks of diabetes and heart disease to a greater degree than fat stored elsewhere in the body. While scientifically interesting, these results cannot be applied to the entire U.S. population, many of whom are not obese.

Delicious, Economical, Easily Consumed Calories

All kinds of sugary foods and beverages taste delicious, cost little money, and are constantly available. These factors make

overconsumption likely. Also the liquid HFCS of fruit punches and soft drinks is easy to consume quickly—no chewing required. Few people realize that a typical 16-ounce carbonated soft drink can easily deliver 200 calories, and soda drinkers often drink several at a sitting.

It may be tempting, then, to close the book on HFCS as just another calorie source. One other link between HFCS and obesity has held researchers' attention, however. It concerns subtle shifts in lipid metabolism when body tissues encounter fructose.

Effects of Fructose on Lipid Metabolism

When laboratory animals are fed purified fructose, their metabolism shifts toward fat-making and fat-conserving pathways.[33] The same effect is observed in people who consume large amounts (about a third of daily calories) of purified fructose.[34] Fructose intake causes fats to accumulate in the blood and liver. Instead of being used immediately for energy, the fructose is readily converted into triglycerides by the liver, the form of fat stored by adipose tissue. High fructose intakes may not be necessary to bring on this effect, however: adding a single HFCS-sweetened soft drink at each meal for 10 weeks significantly increases blood triglycerides.[35]

Nutrition scientists conclude that a diet high in fructose could set into motion metabolic activities leading to excess body fatness and a buildup of blood lipids associated with heart disease.[36] In addition, study subjects given fructose had higher concentrations of blood insulin but lower tissue insulin sensitivity, two conditions associated with prediabetes.

Fructose in Foods and HFCS

On hearing these results about fructose and lipid metabolism, diet book writers and others often conclude that the obvious way to avoid and cure obesity, diabetes, or heart disease is to eliminate fructose from the diet. They single out HFCS (after all, its name even *says* "fructose") as an obesity-causing sugar. They urge their readers to avoid the fructose of sucrose and even the natural fructose of fruits and vegetables to avoid the effects of fructose seen in laboratories.

Consumers often believe these ideas because they don't know that foods such as fruits, vegetables, honey, sucrose, and even HFCS provide fructose in about a 50:50 mixture with glucose. The metabolic effects of such mixtures differ substantially from those of the 100 percent fructose compound reported in research (see Figure C4-5). When researchers test HFCS and sucrose against each other, they report virtually identical metabolic effects from these two sweeteners.[37] This is expected, given their similar chemical makeup.

In a notable exception, however, human subjects were fed one of the following: a solution of 100 percent fructose, a 50:50 glucose-to-fructose mixture, HFCS (also about an equal mixture of glucose and fructose), and 100 percent glucose solution. Based on previous results, the researchers expected that fructose would elicit the greatest blood lipid response and glucose the smallest, with other mixtures falling in between. Curiously, blood lipids rose similarly for all subjects except those receiving 100 percent glucose.[38] This evidence warrants further study to clarify the health implications of consuming sugars with a similar makeup.

Conclusions of Experts

In the end, not even fructose can make a person fat when food energy intake does not exceed the body's energy need.[39] The studies in which sugars produce weight gain invariably add sugars to an already calorie-rich diet. Added prudent amounts of sugars may be enjoyed as part of the discretionary calories in a nutritious diet with virtually no risk to health.

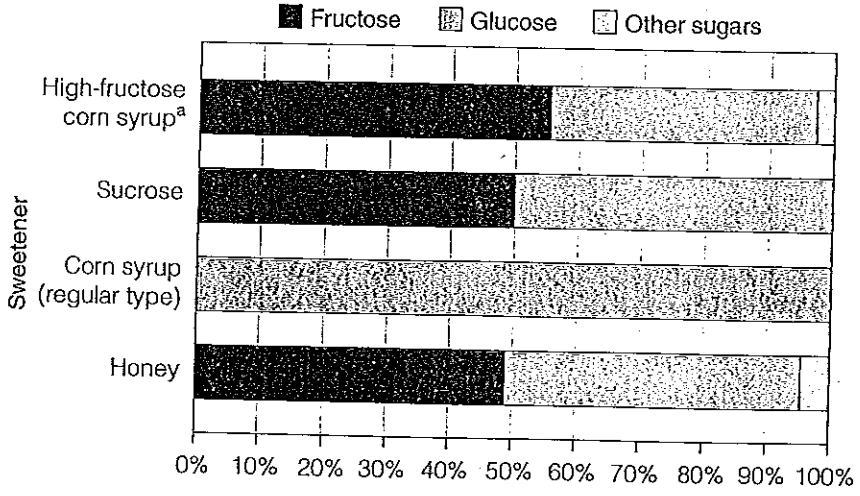
ACCUSATION 5: BLOOD INSULIN IS TO BLAME

If HFCS cannot be blamed for obesity and disease, perhaps other carbohydrates are the villains. Starch, for example, comprised almost entirely of glucose, has been blamed for obesity and illness because it causes the release of insulin into the bloodstream. Among its many roles, insulin facilitates the transport of glucose into the cells, the storage of fatty acids as body fat, and the synthesis of cholesterol. When insulin is present, the body tends to store energy nutrients rather than using them up.[40] Overweight people commonly suffer from insulin resistance—they release excess insulin. Does insulin therefore *cause* their obesity and can a low-glycemic diet reverse it, as some diet books claim?

Claims Made About Insulin

Because insulin promotes storage of body fat, popular writers often assume

FIGURE C4-5 **Glucose and Fructose in Common Added Sugars**



[a]*A typical mixture. Corn syrup purchased for use at home, for example in a pecan pie recipe, is not high-fructose corn syrup; it consists almost entirely of glucose.*

Source: Data from J. S. White, Straight talk about high-fructose corn syrup: What it is and what it ain't, American Journal of Clinical Nutrition *88 (2008): 1716S–1721S.*

that insulin must therefore cause excess body fatness and obesity. They argue that to avoid gains of body fat, people needn't bother controlling discretionary calories or exercising but should simply eat meats, eggs, cheese, salads, and other nonstarchy vegetables and avoid carbohydrates to avoid stimulating the release of insulin. Alternatively, they recommend choosing foods that trigger a reduced insulin response—foods low on the glycemic index scale. Logically, then, less insulin should lead to less storage of body fat, and less body fatness means less type 2 diabetes and a lower risk of heart disease. Keep in mind, however, that logic is not science.

What Nutrition Experts Say About Insulin

When scientists speak on these issues, they agree on this point: insulin regulates carbohydrate and fat storage in the body. However, they disagree that insulin, and not excess calories, causes accumulation of excess body fat.[41]

Do scientists rule insulin to be innocent in causing weight gain, then? Perhaps not entirely. Individual differences in insulin's metabolism may affect how efficiently a person stores food energy. In a 6-year study, people who released normal amounts of insulin following either a high-carbohydrate diet or a low-carbohydrate diet gained about the same amount of weight.[42] But those with insulin resistance gained more weight, especially when they ate a high-carbohydrate diet.

Although insulin disturbances may trigger weight gain, this scientific truth remains: insulin can only assist in the storage of body fat when calories taken in are in excess of need. In all people, weight gain can occur only when the food energy they take in exceeds the energy they use up each day.[43]

CONCLUSION

Investigation into the potential health effects of carbohydrates is ongoing. The idea that the nation's obesity problem might be easily solved by removing an ingredient, HFCS, from the food supply is inviting, but research shows this to be a false hope.[44] Today's larger calorie intakes alone are more than sufficient to explain why people are fatter today than in the past.[45] From the nutritionist's point of view, fad diets that advise people to avoid sugars provided by fruits and vegetables should be ignored. As you will see in later chapters, research overwhelmingly supports consuming 5 to 9 servings of these health-promoting foods.

Enjoying the pleasure of sweets within the discretionary calorie limit is possible in the context of a nutritious diet.[46] However, people who consume many empty calories of daily sugary soft drinks, punches, and other sources of added sugars would do well to replace some of them with water, nonfat milk, vegetable juices, or artificially sweetened beverages and whole foods that are naturally sweet. (Controversies often arise around the use of artificial sweeteners, and Chapter 12 presents the facts.)