CHAPTER 2

Carbohydrates

KEY CONCEPTS

- Carbohydrate foods provide practical energy sources because of their wide availability, relatively low cost, and excellent storage capabilities.
- Carbohydrate structures vary from simple to complex, thus providing both quick and extended energy for the body.
- Dietary fiber, which is an indigestible carbohydrate, serves separately as a regulatory agent within the gastrointestinal tract.

As discussed in Chapter 1, key nutrients in food sustain life and promote health. The unique use of nutrients provides the body with three essential elements for life: (1) energy to do its work; (2) building materials to maintain its form and functions; and (3) control agents to regulate these processes efficiently. These three basic life and health functions of nutrients are closely related, and it is important to remember that no nutrient ever works alone.

This chapter looks specifically at the body's primary fuel source: carbohydrates. Carbohydrates are plentiful in the food supply, and they are an important contribution to a well-balanced diet. Recent controversy surrounding the use, abuse, and misunderstanding of this critical macronutrient should be better interpreted after evaluating its functions within the body.

NATURE OF CARBOHYDRATES

Relation to Energy

Basic Fuel Source

Energy is necessary for life. It is the power that an organism requires to do work. Any energy system must first have a basic fuel supply. In the Earth's energy system, vast energy resources from the sun enable plants, through **photosynthesis**, to transform solar energy into carbohydrate, which is the stored fuel form in plants. The human body can rapidly break down carbohydrates (i.e., sugars and starches), and they provide the major source of energy that is measured in calories.

Throughout this text, the term *energy* is used interchangeably with the terms *calorie, kilocalorie,* and *kcal* (see the definition of *kilocalorie* in Chapter 1). Our bodies need energy to survive. Both involuntary (e.g., heart, lung function) and voluntary actions (e.g., walking, talking) require energy, and that energy is derived from the digestion and metabolism of food.

Energy-Production System

A successful energy system, whether a living organism or a machine, must be able to do the following three things to produce energy from a fuel source:

1. Change the basic fuel to a refined fuel that the machine is designed to use
2. Carry this refined fuel to the places that need it
3. Burn this refined fuel in the special equipment set up at these places

The body easily does these three things more efficiently than any manmade machine. It digests its basic fuel, carbohydrate, thereby releasing glucose. The body then absorbs and, through blood circulation, carries this refined fuel to cells that need it. Glucose is burned in the specific and intricate equipment in these cells, and energy in the

form of adenosine triphosphate is released through the process of cell metabolism. Because the human body can rapidly digest the starches and sugars that are eaten to yield energy, carbohydrates are considered quick-energy foods.

Dietary Importance

Practical reasons also exist for the large quantities of carbohydrates found in diets all over the world. First, carbohydrates are widely available and easily grown (e.g., grains, legumes, vegetables, fruits). In some countries, carbohydrate foods make up almost the entire diet. Second, carbohydrates are relatively low in cost as compared with many other food items. Third, carbohydrate foods are easily stored. They can be kept in dry storage for relatively long periods without spoilage, and modern processing and packaging can extend the shelf life of carbohydrate products for years.

The U.S. Department of Agriculture regularly surveys food intake. These reports indicate that approximately half (49.3%) of the total kilocalories in the typical American diet comes from carbohydrates. The daily intake of grain products by Americans accounts for 39.8% of total carbohydrate kilocalories, and almost as many carbohydrate kilocalories (37.3%) come from added sugars and sweeteners, with the remainder coming from dairy, fruit, and vegetable products.[1] It is worth noting that the consumption of whole grains has increased and the intake of refined sugar has decreased slightly since 1970; this is an overall positive change.

Classes of Carbohydrates

The word *carbohydrate* is derived from the chemical nature of the substance. A carbohydrate is composed of carbon (C), hydrogen (H), and oxygen (O). Its abbreviated name, *CHO,* is the combination of the chemical symbols of its three components. The term ***saccharide*** is used as a carbohydrate class name, and it comes from the Latin word *saccharum,* which means "sugar." Carbohydrates are classified according to the number of sugar (or saccharide) units that make up their structure: *mono*saccharides have one sugar unit; *di*saccharides have two sugar units; and *poly*saccharides have many sugar units. Monosaccharides and disaccharides are small, simple structures of only one- and two-sugar units; thus, they are referred to as ***simple carbohydrates***. However, polysaccharides are large, complex compounds of many saccharide units in long chains; thus, they are called ***complex carbohydrates***. For example, starch, which is the most significant polysaccharide in human nutrition, is composed of many coiled and branching chains in a treelike structure. Each of the multiple branching chains is composed of 24 to 30 units of glucose, which gradually split off during digestion to supply a steady source of energy over time. Table 2-1 summarizes these classes of carbohydrates.

Monosaccharides

The three single sugars in nutrition are glucose, fructose, and galactose. Monosaccharides, which are the building blocks for all carbohydrates, require no digestion. They are quickly absorbed from the intestine into the bloodstream and transported to the liver. Energy demands will determine if the monosaccharides are then used for immediate energy or stored as **glycogen** for later use.

Glucose. The basic single sugar in human metabolism is glucose, which is the form of sugar circulating in the blood. It is the primary fuel for cells. Glucose, a moderately sweet sugar, usually is not found as such in the diet, except in corn syrup or processed food items. The body supply of glucose mainly comes from the digestion of starch. Glucose is also called *dextrose* to denote the structure of the molecule (i.e., six carbons).

Fructose. Fructose is primarily found in fruits (from which it gets its name) and in honey. Although honey is sometimes thought of as a sugar substitute, it is a sugar itself; therefore, it cannot be considered a substitute. The amount of fructose found in fruits depends on the degree of ripeness. As a fruit ripens, some of its stored starch turns to sugar. Fructose is the sweetest of the simple sugars.

photosynthesis the process by which plants that contain chlorophyll are able to manufacture carbohydrate by combining carbon dioxide and water; sunlight is used as energy, and chlorophyll is a catalyst.

saccharide the chemical name for sugar molecules; may occur as single molecules in monosaccharides (glucose, fructose, galactose), two molecules in disaccharides (sucrose, lactose, maltose), or multiple molecules in polysaccharides (starch, dietary fiber, glycogen).

simple carbohydrates sugars with a simple structure of one or two single-sugar (saccharide) units; a monosaccharide is composed of one sugar unit, and a disaccharide is composed of two sugar units.

complex carbohydrates large complex molecules of carbohydrates composed of many sugar units (polysaccharides); the complex forms of dietary carbohydrates are starch, which is digestible and provides a major energy source, and dietary fiber, which is indigestible (humans lack the necessary enzymes) and thus provides important bulk in the diet.

glycogen a complex carbohydrate found in animal tissue that is composed of many glucose units.

TABLE 2-1 SUMMARY OF CARBOHYDRATE CLASSES

Chemical Class Name	Class Members	Sources
Monosaccharides (single sugars, simple carbohydrates)	Glucose (dextrose)	Corn syrup (commonly used in processed foods)
	Fructose	Fruits, honey
	Galactose	Lactose (milk)
Disaccharides (double sugars, simple carbohydrates)	Sucrose	Table sugar (sugar cane, sugar beets)
	Lactose	Milk
	Maltose	Molasses Starch digestion, intermediate Sweetener in food products
Polysaccharides (multiple sugars, complex carbohydrates)	Starch	Grains and grain products (cereal, bread, crackers, baked goods) Rice, corn, bulgur Legumes Potatoes and other vegetables
	Glycogen	Storage form of carbohydrate in animal tissue (not a dietary source)

High-fructose corn syrups, which are manufactured by changing the glucose in cornstarch into fructose, are heavily used in processed food products, canned and frozen fruits, and soft drinks. These syrups are inexpensive sweeteners, and contribute to increased sugar intake in the United States. The per-capita consumption of high-fructose corn syrup increased from 0.12 tsp daily in 1970 to 11.18 tsp daily in 2008[2] (Figure 2-1).

Galactose. Galactose is not usually found as a free monosaccharide in the diet; rather, it is a product of lactose (milk sugar) digestion.

Disaccharides

Disaccharides are simple double sugars that are composed of two single-sugar units linked together. The three disaccharides that are important in human nutrition are sucrose, lactose, and maltose.

Sucrose = Glucose + Fructose
Lactose = Glucose + Galactose
Maltose = Glucose + Glucose

Sucrose. Sucrose is common table sugar. Its two single-sugar units are glucose and fructose. Sucrose is used in the form of granulated, powdered, or brown sugar, and it is made from sugar cane or sugar beets. Molasses, which is a by-product of sugar production, is also a form of sucrose. When people speak of sugar in the diet, they usually mean sucrose.

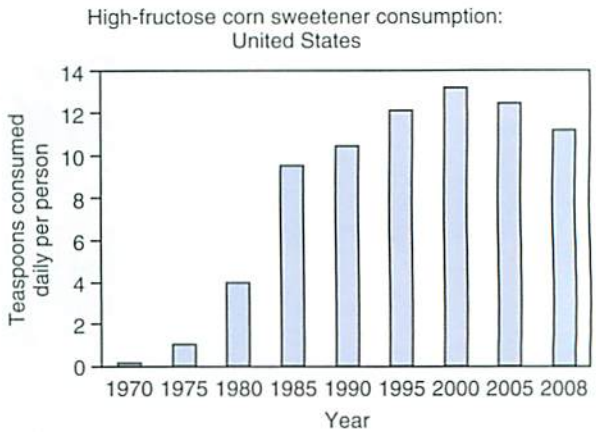

Figure 2-1 High-fructose corn sweetener: per capita consumption adjusted for loss. (Data from the U.S. Department of Agriculture, Economic Research Service. *High fructose corn sweetener [HFCS]: per capita consumption adjusted for loss* (website): www.ers.usda.gov/Data/FoodConsumption/FoodGuideSpreadsheets.htm#sugar. Accessed March 17, 2010.)

Lactose. The sugar in milk, which is formed in mammary glands, is lactose. Its two single-sugar units are

glucose and galactose. Lactose is the only common sugar that is not found in plants. It is less soluble and less sweet than sucrose. Lactose remains in the intestine longer than other sugars, and it encourages the growth of certain useful bacteria. Cow's milk contains 4.8% lactose, and human milk contains 7% lactose. Because lactose promotes the absorption of calcium and phosphorus, the presence of all three nutrients in milk is a fortunate circumstance.

Maltose. Maltose is not usually found as such in the diet. It is derived within the body from the intermediate digestive breakdown of starch. Because starch is made up entirely of many single-glucose units, the two single-sugar units that compose maltose are both glucose. Synthetically derived maltose is used as a sweetener in various processed foods.

Polysaccharides

Polysaccharides are complex carbohydrates that are composed of many single-sugar units. The important polysaccharides in nutrition include starch, glycogen, and dietary fiber.

Starch. Starches are by far the most significant polysaccharides in the diet. They are found in grains, legumes, and other vegetables and in some fruits in minute amounts. Starches are more complex in structure than simple sugars, so they break down more slowly and supply energy over a longer period of time. For starch to be used more promptly by the body, the outer membrane can be broken down by grinding or cooking. Cooking starch improves its flavor and also softens and ruptures the starch cells, thereby making digestion easier. Starch mixtures thicken when cooked, because the portion that encases the starch granules has a gel-like quality that thickens the starch mixture in the same way that pectin causes jelly to set.

Starch is the most important dietary carbohydrate worldwide. The Dietary Reference Intakes (DRIs; see Chapter 1) recommend that 45% to 65% of total kilocalories consumed come from carbohydrates, with a greater portion of that intake coming from complex carbohydrates.[3] For countries in which starch is the staple food, carbohydrates make up an even higher proportion of the diet. The major food sources of starch (Figure 2-2) include grains in the form of cereal, pasta, crackers, bread, and other baked goods; legumes in the form of beans and peas; potatoes, rice, corn, and bulgur; and other vegetables, especially of the root variety.

The term *whole grain* is used for food products such as flours, breads, or cereals that are produced from unrefined grain. Unrefined grains retain the outer bran layers, the inner germ, and the endosperm (Figure 2-3) and thus their nutrients (i.e., dietary fiber, vitamins, and minerals). *Enriched grains* are refined grain products to which some

Figure 2-2 Complex carbohydrate foods. (Copyright JupiterImages Corp.)

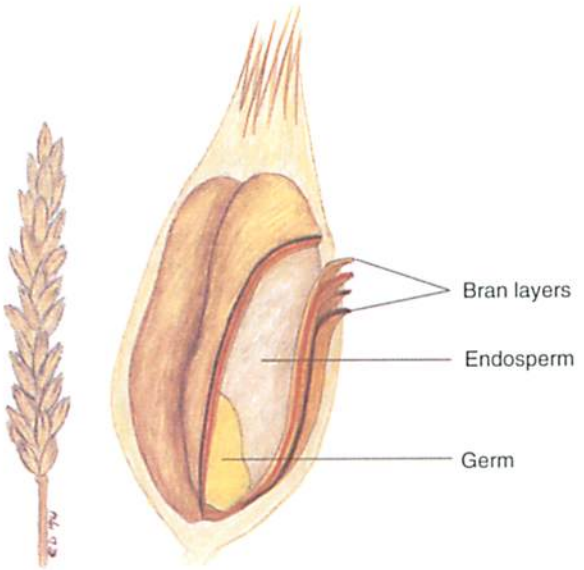

Figure 2-3 Kernel of wheat showing bran layers, endosperm, and germ. (Courtesy Eileen Draper.)

nutrients that were removed during the refining process—usually minerals (e.g., iron) and vitamins (e.g., A, C, D, thiamin, riboflavin, niacin)—have been added back. Ready-to-eat breakfast cereals usually contain additional nutrients such as vitamins D, E, B_6, and folic acid as well as the minerals phosphorus, magnesium, and zinc. These cereals, which are a favorite breakfast item for children, have become a major source of vitamin and mineral intake in the United States.

Glycogen. Glycogen is not a significant source of carbohydrate in the diet. Rather, it is a carbohydrate that is formed within the body's tissues, and it is crucial to the body's metabolism and energy balance. Glycogen is found in the liver and muscles, where it is constantly recycled (i.e., broken down to form glucose for immediate energy needs and synthesized for storage). These small stores of glycogen help to sustain normal blood glucose during short-term fasting periods (e.g., sleep), and they provide immediate fuel for muscle action. These reserves also protect cells from depressed metabolic function and injury. The process of blood glucose regulation with regard to glycogen breakdown is discussed in greater detail in Chapter 20.

Dietary Fiber. Human beings lack the necessary enzymes to digest dietary fiber; therefore, these polysaccharides do not have a direct energy value like other carbohydrates. However, their inability to be digested makes them important dietary assets. Increasing attention has focused on the beneficial relationship between fiber and disease prevention (especially cardiovascular disease and gastrointestinal problems) as well as the management of diabetes.[4-7]

BOX 2-1 SUMMARY OF SOLUBLE AND INSOLUBLE FIBERS

Insoluble
Cellulose
Most hemicelluloses
Lignin

Soluble
Gums
Mucilages
Algal polysaccharides
Most pectins

As a means of simplification, dietary fiber is usually divided into two groups on the basis of solubility. Cellulose, lignin, and most hemicelluloses are not soluble in water. The rest of the dietary fibers (i.e., most pectins and other polysaccharides [e.g., gums, mucilages]) are water soluble. These two classes of dietary fiber are listed in Box 2-1. The looser physical structure and greater water-holding capacity of gums, mucilages, pectins, and algal polysaccharides (i.e., those derived from seaweed) partly account for their greater water solubility. Recommendations for specific types of fiber to consume often are based on the water-solubility distinction. Soluble fiber is noted for its ability to bind bile acids and ultimately lower blood cholesterol levels. Alternatively, insoluble fiber is recommended for relief from constipation. The types of dietary fiber that are important in human nutrition are described later in this chapter.

Cellulose. Cellulose is the chief component of cell walls in plants. It remains undigested in the gastrointestinal tract, and it adds important bulk to the diet. This bulk helps to move the food mass along, it stimulates normal muscle action in the intestine, and it forms feces for the elimination of waste products. The main sources of cellulose are the stems and leaves of vegetables and the coverings of seeds and grains. Within the same area of the plant, phosphorus is stored in the form of phytic acid; this compound is undigested in humans because of the lack of a necessary enzyme (phytase). Phytic acid is a strong **chelator** of important minerals (see the Drug-Nutrient Interaction box, "Phytic Acid and Mineral Absorption").

Lignin. Lignin, which is the only noncarbohydrate type of dietary fiber, is a large compound that forms the

chelator a ligand that binds to a metal to form a metal complex.

DRUG-NUTRIENT INTERACTION

PHYTIC ACID AND MINERAL ABSORPTION

Some compounds that are naturally found in food bind minerals, thereby making them unavailable for absorption. Phytic acid is one such compound, and it is found in legumes, wheat bran, and seeds. Iron also is naturally found in these foods, but, because of the phytic acid interference, as little as 2% of the available iron is absorbed.

A diet that consists of high-fiber foods that contain phytic acid and a low intake of iron-rich foods (e.g., meat, poultry) may exacerbate iron deficiency. This can especially be a problem in the developing world.[1]

In the United States and other developed nations, iron deficiency is rarely caused by this alone. However, iron deficiency is still common among pregnant and premenopausal women. If the anemia is severe enough, a physician may prescribe an iron supplement. The intake of foods that contain high amounts of phytic acid with the supplement would inhibit iron absorption just as it would if the iron were part of the food.

Phytic acid binds to other minerals that have a similar charge as iron, including calcium, magnesium, and zinc. Calcium supplements are often prescribed for those who may be losing bone mass (e.g., postmenopausal women) or for those who do not get enough calcium in the diet (e.g., teens, the elderly). Food sources of phytic acid that are eaten with calcium supplements may inhibit absorption. When recommending that patients take an iron or calcium supplement, also advise them to take the supplement with foods that do not contain phytate.

Sara Harcourt

1. World Health Organization; Centers for Disease Control and Prevention; de Benoist B, McLean E, Egli I, Cogswell M, editors. *Worldwide prevalence of anaemia 1993-2005: WHO Global Database on Anaemia* (website): http://whqlibdoc.who.int/publications/2008/9789241596657_eng.pdf. Accessed August 29, 2011.

TABLE 2-2 SUMMARY OF DIETARY FIBER CLASSES

Dietary Fiber Class	Source	Function
Cellulose	Main cell wall constituent of plants (stalks and leaves of vegetables; outer coverings of seeds, such as are found in whole grains)	Holds water; reduces elevated colonic intraluminal pressure
Noncellulose polysaccharides		Slow gastric emptying; provide fermentable material for colonic bacteria with the production of gas and volatile fatty acids; bind bile acids and cholesterol
Gums and mucilages	Secretions of plants and seeds (oats, legumes, barley)	
Algal polysaccharides	Algae, seaweeds	
Pectin substances	Intercellular plant material (fruit)	
Hemicellulose	Cell-wall plant material (bran, whole grains)	Holds water and increases stool bulk; reduces elevated colonic pressure; binds bile acids
Lignin	Woody part of plants (broccoli stems; fruits with edible seeds, such as strawberries and flaxseeds)	Antioxidant; binds bile acids, cholesterol, and metals

woody part of certain plants. It binds the cellulose fibers in plants, thereby giving added strength and stiffness to plant cell walls. Although it is an insoluble fiber, it also combines with bile acids and cholesterol in the human intestine to prevent their absorption.

Noncellulose Polysaccharides. Hemicellulose, pectins, gums, mucilages, and algal substances are noncellulose polysaccharides. They absorb water and swell to a larger bulk, thus slowing the emptying of the food mass from the stomach, binding bile acids (including cholesterol)[8] in the intestine, and preventing spastic colon pressure by providing bulk for normal muscle action. Noncellulose polysaccharides also provide fermentation material on which colon bacteria can work.

Table 2-2 provides a summary of these dietary fiber classes along with the sources and functions of each.

In general, the food groups that provide needed dietary fiber include whole grains, legumes, vegetables, and fruits with as much of their skin remaining as possible. Whole grains provide a special natural "package" of both the complex carbohydrate starch and the fiber in its coating. In addition, whole grains contain an abundance of

vitamins and minerals (see the Clinical Applications box, "Case Study: Identifying Carbohydrates and Fiber").

Many health organizations have recommended increasing the intake of complex carbohydrates in general and dietary fiber in particular (see the For Further Focus box, "Fiber: What's All the Fuss About?").[3,9] The Food and Nutrition Board of the Institute of Medicine has always indicated that a desirable fiber intake should not be exclusively achieved by adding concentrated fiber supplements to the diet. Instead, the recommendations are to eat a high-fiber diet that is rich in whole grains, fruits, vegetables, and legumes, which also provide essential vitamins and minerals. The recommended daily intake of fiber for men and women who are 50 years old or younger is 38 and 25 g/day, respectively. The DRIs are reduced to 30 and 21 g/day for men and women who are older than 50 years of age.[3] This intake requires the consistent use of whole grains, legumes, vegetables, fruits, seeds, and nuts. Unfortunately, the average American does not consume the recommended servings of whole grains, vegetables, and fruit on a daily basis. In fact, results from the National Health and Nutrition Examination Survey (NHANES) revealed that only 40% of Americans meet the recommended servings of fruits and vegetables per day.[10] Another study found that only 8% of the U.S. population consumes the recommended three servings per day of whole grains.[11] The dietary fiber content of some commonly used foods is provided in Table 2-3 and Appendix B.

As with many things in nutrition, too much of a good thing also can be problematic. Sudden increases in fiber intake can result in uncomfortable gas, bloating, and constipation. Fiber intake should be gradually increased (along with water intake) to an appropriate amount for the individual. In addition, excessive amounts of dietary fiber can trap (by chelation) small amounts of minerals and prevent their absorption in the gastrointestinal tract. This function of fiber is beneficial when trapping or binding bile acids, but it may compromise nutritional status if fiber intake greatly exceeds the recommendations to the point of reducing mineral absorption.

CLINICAL APPLICATIONS

CASE STUDY: IDENTIFYING CARBOHYDRATES AND FIBER

A patient comes to you for dietary analysis. He is trying to eat a diet that is consistent with the dietary guidelines of 45% to 65% carbohydrate and 38 g of dietary fiber per day. On the basis of the 1-day diet record that he provides you, answer the questions that follow regarding his dietary analysis.

Breakfast:
- 2 cups Cheerios
- 1.25 cups skim milk
- 1 medium banana
- 16 oz coffee with 1 Tbsp sugar and 2 Tbsp whole-milk creamer

Lunch:
- Turkey sandwich (2 slices whole-wheat bread, 3 oz lean turkey, 1 oz cheddar cheese, 1 slice tomato, 2 lettuce leaves, 2 tsp yellow mustard, and ½ Tbsp mayonnaise)
- 1 oz pretzels
- 1½ cups mixed green salad with 2 Tbsp crushed pecans and 2 Tbsp fat-free Italian dressing
- 20 oz water

Snack:
- 1 medium apple
- 1 package peanut-butter crackers (6 crackers)

Dinner:
- 4 oz grilled chicken breast
- ½ cup green beans
- ¾ cup mashed potatoes made with skim milk and butter
- ½ cup roasted red peppers
- 1 whole-wheat roll
- 16 oz sweet tea

Questions for Analysis
1. Identify all of the foods that contain carbohydrates.
2. With the use of the dietary analysis CD-ROM included with this book or the Choose MyPlate Food Tracker available at www.choosemyplate.gov, analyze this 1-day diet to determine the following:
   a. How many total grams of carbohydrate did this individual consume?
   b. How many grams of sugar did he consume?
   c. How many grams of soluble and total fiber did he consume?
   d. What was the percentage of total calories from carbohydrates?
3. Did this individual meet the dietary guidelines for the percentage of calories from carbohydrates and grams of fiber on this day?
4. What additional recommendations would you make for improvement?

evolve Please refer to this text's Evolve Web site for answers to Case Study.

FOR FURTHER FOCUS

FIBER: WHAT'S ALL THE FUSS ABOUT?

The National Institutes of Health and the World Health Organization—along with almost all other health-related agencies in the world—have been promoting the intake of fiber for years. The benefits have been defined in several clinical trials related to a variety of chronic illnesses.[1-4]

However, the average fiber intake in a typical American diet remains substantially lower than the current recommendations. Scientists are confident that consuming adequate amounts of fiber imparts the following health benefits:

- It lowers blood cholesterol levels.
- It promotes normal bowel function and prevents constipation.
- It increases satiety, which helps with the prevention of obesity.
- It protects against colon cancer.
- It slows glucose absorption, thereby reducing blood glucose spikes and insulin secretion.
- It prevents and helps to manage diverticulosis.

Health professionals can assist members of the public with evaluating their fiber intake by educating and encouraging the use of food labels. Food labels list the total dietary fiber found in each serving of food. Manufacturers may also voluntarily list the specific type of fiber (i.e., soluble or insoluble). Increases in dietary fiber intake should be made gradually, with extra attention paid to fluid intake. A sudden boost in dietary fiber can lead to uncomfortable bloating, gas, and cramping; this can be avoided by making small changes over time and by including an appropriate fluid intake of 8 glasses of water per day.

1. Behall KM, Scholfield DJ, Hallfrisch J. Whole-grain diets reduce blood pressure in mildly hypercholesterolemic men and women. *J Am Diet Assoc.* 2006;106(9):1445-1449.
2. Bijkerk CJ, de Wit NJ, Muris JW, et al. Soluble or insoluble fibre in irritable bowel syndrome in primary care? Randomised placebo controlled trial. *BMJ.* 2009;339:b3154.
3. Van Horn L, McCoin M, Kris-Etherton PM, et al. The evidence for dietary prevention and treatment of cardiovascular disease. *J Am Diet Assoc.* 2008;108(2):287-331.
4. Ventura E, Davis J, Byrd-Williams C, et al. Reduction in risk factors for type 2 diabetes mellitus in response to a low-sugar, high-fiber dietary intervention in overweight Latino adolescents. *Arch Pediatr Adolesc Med.* 2009;163(4):320-327.

Other Sweeteners

Sugar alcohols and alternative sweeteners often are used as a sugar replacements. Sweeteners that contribute to total calorie intake (e.g., sugar alcohols) are considered *nutritive* sweeteners. *Nonnutritive sweeteners* or *alternative sweeteners* are sugar substitutes that do not have any caloric value.

Nutritive Sweeteners. The sugar alcohols **sorbitol**, mannitol, and xylitol are the alcohol forms of sucrose, mannose, and xylose, respectively. Sugar alcohols provide 2 to 3 kcal/g as compared with other carbohydrates, which provide 4 kcal/g. The most well-known sugar alcohol is sorbitol, which has been widely used as a sucrose substitute in various foods, candies, chewing gum, and beverages. Both glucose and sugar alcohols are absorbed in the small intestine. However, the sugar alcohols are absorbed more slowly and do not increase the blood sugar as rapidly as glucose. Therefore, sugar alcohols are often used in products that are intended for individuals who cannot tolerate a high blood sugar level (e.g., those with diabetes). The downside of using excessive amounts of sugar alcohols in food products is that the slowed digestion may result in osmotic diarrhea. The advantage of using a sugar alcohol to replace sugar is a lowered risk of dental caries, because oral bacteria cannot use the alcohol for fuel.

Nonnutritive Sweeteners. Nonnutritive sweeteners are specifically manufactured to be used as alternative or artificial sweeteners in food products. Because

sugar alcohols nutritive sweeteners that provide 2 to 3 kcal/g; examples include sorbitol, mannitol, and xylitol; these are produced in food-industry laboratories for use as sweeteners in candies, chewing gum, beverages, and other foods.

sorbitol a sugar alcohol that is often used as a nutritive sugar substitute; it is named for where it was discovered in nature, in ripe berries of the *Sorbus aucuparia* tree; it also occurs in small quantities in various other berries, cherries, plums, and pears.

TABLE 2-3 DIETARY FIBER AND CALORIC VALUE FOR SELECTED FOODS

Food	Serving Size	Dietary Fiber (g)	Kilocalories
Breads and Cereals			
All-Bran	⅓ cup	13	75
Complete Oat Bran	¾ cup	4	105
Complete Wheat Bran	¾ cup	5	92
Cracklin' Oat Bran	¾ cup	6.4	225
Fiber One	½ cup	14.4	60
Oatmeal	1 cup	4	138
Popcorn, air popped	1 cup	1.2	30
Raisin Bran	½ cup	3.5	94
100% Bran	⅓ cup	8.3	83
Shredded Wheat'N Bran	⅔ cup	4	98
Whole-wheat bread	1 slice	2	69
Fruit			
Apple, raw, with skin	1 medium (2¾ inches in diameter)	3.7	81
Apricot	1 medium	0.7	17
Banana	1 medium (7 to 8 inches long)	2.8	108
Blueberries	½ cup	2	40
Cherries	½ cup	0.8	26
Dates, dried	1	0.6	23
Grapefruit	½ cup of pieces	1.25	38
Orange	1 medium (2½ inches in diameter)	3.1	61
Peach	1 medium (2½ inches in diameter)	2	42
Prunes, dried	1	0.6	20
Raisins, seedless	½ cup (not packed)	3	217
Strawberries	½ cup sliced	1.9	25
Legumes			
Black beans	½ cup	7.5	113
Garbanzo beans	½ cup	6.2	134
Kidney beans	½ cup	5.6	112
Lima beans	½ cup	6.5	108
Vegetables			
Asparagus, cooked	½ cup	1.4	21
Black-eyed peas	½ cup	4.1	80
Broccoli, cooked	½ cup	2.3	22
Carrots, raw strips	½ cup	1.8	26
Cauliflower, cooked	½ cup	1.7	14
Corn	½ cup	2.2	88
Green beans (snap beans), cooked	½ cup	2	22
Green peas	½ cup	4.4	67
Potato, baked, with skin	1 medium (2¼ to 3¼ inches in diameter)	3.8	160
Sweet potato, baked, with skin	1 medium (2 × 5 inches)	3.4	117
Tomato, raw, chopped	½ cup	1	19

Data from the U.S. Department of Agriculture, Agricultural Research Service, Nutrient Data Laboratory. *USDA national nutrient database for standard reference* (website): www.nal.usda.gov/fnic/foodcomp/search/. Accessed August 10 2010.

nonnutritive sweeteners do not provide any kilocalories, they present the sweet taste without contributing to an individual's total energy intake. People typically associate these sweeteners with diet foods. The alternative sweeteners that are most commonly used in the United States are acesulfame-K, aspartame, neotame, saccharin, and sucralose. Nonnutritive sweeteners are much sweeter than sucrose; therefore, extremely small quantities can be used to produce the same sweet taste. Table 2-4 provides a summary of artificial sweeteners and their relative sweetness value as compared with table sugar.

FUNCTIONS OF CARBOHYDRATES

Primary Energy Function

Basic Fuel Supply

The main function of carbohydrates is to provide fuel for the body. Carbohydrates burn in the body at the rate of 4 kcal/g; thus, the fuel factor of carbohydrates is 4. Carbohydrates furnish readily available energy that is needed for physical activities as well as for the work of body cells. Fat also serves as a source of fuel for the body, but the

TABLE 2-4 SWEETNESS OF SUGARS AND ARTIFICIAL SWEETENERS

Substance	Sweetness Value
Sugar or Sugar Product	
Levulose, fructose	173
Invert sugar*	130
Sucrose	100
Glucose	74
Sorbitol	60
Mannitol	50
Galactose	32
Maltose	32
Lactose	16
Artificial Sweeteners	
Cyclamate (banned in the United States)	30
Aspartame (NutraSweet and Equal)†	180
Acesulfame-K (Sunette and Sweet One)	200
Stevia (Enliten, Stevia, Truvia)	250 to 300
Saccharin (Sweet'N Low and Sugar Twin)	300
Sucralose (Splenda)	600
Neotame	7000 to 13,000

*Inverted sugar is sucrose (table sugar) that has been broken down into equal parts fructose and glucose.
†Nutritive (i.e., has calories).
Revised from Mahan LK, Escott-Stump S. *Krause's food & nutrition therapy*. 12th ed. Philadelphia: Saunders; 2008.

body only needs a small amount of dietary fat to supply the essential fatty acids (see Chapter 3).

Reserve Fuel Supply

The total amount of carbohydrate in the body, including both stored glycogen and blood sugar, is relatively small. Healthy, well-nourished adults store approximately 100 g of glycogen in the liver, which is about 8% of the liver mass weight. On average, 300 to 400 g of glycogen can be stored in the muscle, which is about 1% to 2% of the muscle mass weight. Glycogen in the liver is primarily reserved to maintain blood glucose levels and to ensure brain function. Without refueling, the total amount of available glucose in the muscle only provides enough energy for 1 to 2 hours of aerobic activity at 66% maximum capacity. Therefore, to maintain a normal blood glucose level and to prevent a breakdown of fat and protein in tissue, individuals must eat carbohydrate foods regularly to meet energy demands.

Special Tissue Functions

Carbohydrates also serve special functions in many body tissues and organs.

Liver. Glycogen reserves in the liver provide a constant exchange with the body's overall energy balance system. These reserves protect cells from depressed metabolic function and resulting injury.

Protein and Fat. Carbohydrates help to regulate both protein and fat metabolism. If dietary carbohydrate is sufficient to meet general body energy needs, protein does not have to be broken down to supply energy. This protein-sparing action of carbohydrate protects protein for its major roles in tissue growth and maintenance; these are crucial functions for which other macronutrients cannot serve as a substitute. Likewise, with sufficient carbohydrate for energy, fat is not needed to supply large amounts of energy. This is significant, because a rapid breakdown of fat may result in the production of ketones, which are products of incomplete fat oxidation in the cells. Ketones are strong acids. The condition of acidosis or ketosis upsets the normal acid–base balance of the body and may result in cellular damage in severe cases. This protective action of carbohydrate is called its *anti-ketogenic effect.*

Central Nervous System. Constant carbohydrate intake and reserves are necessary for the proper functioning of the central nervous system. The master center of the central nervous system, the brain, has no stored supply of glucose; therefore, it is especially dependent on a minute-to-minute supply of glucose from the blood. Sustained and profound shock from low blood sugar may cause brain damage and can result in coma or death.

FOOD SOURCES OF CARBOHYDRATES

Starches

Starch is the most important carbohydrate in a balanced diet. Whole grain starches such as rice, wheat, corn, and potatoes provide important sources of fiber and other nutrients. Table 2-5 outlines the carbohydrate content of commonly consumed foods.

Sugars

Sugar per se is not necessarily a villain. After all, the form of carbohydrate that is found in fruit is a disaccharide or simple sugar. The difference between this type of sugar and the sugar in candy is that fruit also provides fiber, water, and vitamins. The health problem with regard to added sugar (e.g., sweets, desserts, candy, soda) lies in the large quantities of "empty calories" that many people consume, often to the exclusion of other important foods. The average American consumes approximately 28.7 tsp of added sugar per day (460 kcal).[12] As with most things, moderation is the key.

TABLE 2-5 CARBOHYDRATE CONTENT OF SELECT FOODS

Food Source	Serving Size	Carbohydrate (g)	Total Kilocalories
Concentrated Sweets			
Sugar:			
Granulated	1 tsp	4.2	16
Powdered	1 tsp	2.49	10
Brown	1 tsp, packed	4.48	17
Maple	1 tsp	2.73	11
Honey	1 Tbsp	17.3	64
Syrup:			
High-fructose corn	1 Tbsp	14.44	53
Maple	1 Tbsp	13.42	52
Jam and preserves	1 Tbsp	13.77	56
Carbonated beverage, cola	12 oz	35.18	136
Candy:			
Skittles	1 package (2.17 oz)	56.28	251
Starburst fruit chews	1 package (2.07 oz)	48.72	241
Twizzlers	4 pieces from an 8 oz package	35.88	158
Baked goods:			
Brownie	1 square (1 oz)	18.12	115
Butter cookie	1 medium (1 oz)	19.53	132
Doughnut, glazed	1 medium (3-inch diameter)	22.86	192
Fruit			
Apple, with skin	1 medium (2¼-inch diameter)	19.06	72
Banana	1 medium (7.5 inches long)	26.95	105
Cherries, sweet, raw	15 cherries	16.33	64
Orange	1 medium (2½-inch diameter)	15.39	62
Pineapple	1 slice (3½-inch diameter × ¾-inch thick)	10.6	40
Strawberries	10 medium (1¼-inch diameter)	9.22	38
Dried fruit, mixed (prune, apricot, pear)	1 package (5.5 oz)	93.85	356
Vegetables			
Beans, kidney, cooked	½ cup	19.34	109
Carrots, raw	½ cup chopped, raw	6.13	26
Corn, sweet, yellow, cooked	½ cup, drained	20.59	89
Lettuce, green leaf, raw	1 cup shredded	1	5
Potato, with skin, baked	1 medium (2¼- to 3¼-inch diameter)	36.59	161
Squash, summer	½ cup cooked slices	3.88	18
Tomatoes, red, raw	½ medium (2¾-inch diameter)	2.4	11
Dairy Products			
Milk:			
Skim	1 cup	12.15	88
2%	1 cup	13.5	138
Whole	1 cup	11.03	146

Continued

TABLE 2-5 CARBOHYDRATE CONTENT OF SELECT FOODS—cont'd

Food Source	Serving Size	Carbohydrate (g)	Total Kilocalories
Cheese:			
Cheddar	½ cup, shredded	0.72	228
Cottage, 2% milk fat	½ cup	4.1	102
Grain Products			
Bread:			
Wheat	1 slice	11.8	65
White	1 slice	12.6	66
Rye	1 slice	15.46	83
Cereal (dry):			
Corn flakes	1 cup	24.28	101
Rice, puffed	1 cup	12.57	56
Wheat, shredded, presweetened	1 cup	43.58	183
Cereal (cooked):			
Grits, corn, cooked with water	1 cup	31.15	143
Oatmeal, cooked with water	1 cup	25.27	147
Wheat, cooked with water	1 cup	32.96	160
Crackers, saltines	5	10.72	65
Pasta, cooked	1 cup	39.07	176
Rice:			
Brown	½ cup, cooked	22.92	109
White	½ cup, cooked	26.59	121

Data from the U.S. Department of Agriculture, Agricultural Research Service, Nutrient Data Laboratory. *USDA national nutrient database for standard reference* (website): www.nal.usda.gov/fnic/foodcomp/search/. Accessed August 10 2010.

See the For Further Focus box, "Carbohydrate Complication," for a brief discussion of two controversial hot topics in mass-media coverage of nutrition, the glycemic index and "net carbs."

DIGESTION OF CARBOHYDRATES

Mouth

The digestion of carbohydrate foods, starches, and sugars begins in the mouth and progresses through the successive parts of the gastrointestinal tract, and it is accomplished by two types of actions: (1) mechanical or muscle functions that break the food mass into smaller particles; and (2) chemical processes in which specific **enzymes** break down the food nutrients into still smaller usable metabolic products. The chewing of food, which is called *mastication*, breaks food into fine particles and mixes it with saliva. During this process, the salivary enzyme salivary amylase (also called *ptyalin*) is secreted by the parotid glands, which lie under each ear at the back of the jaw. Salivary amylase acts on starch to begin its breakdown into dextrins (i.e., intermediate starch breakdown products) and disaccharides (primarily maltose). Carbohydrates eaten in the form of monosaccharides travel to the stomach and small intestines for absorption without further digestion.

Stomach

Wavelike contractions of the stomach muscles continue the mechanical digestive process. This action, called *peristalsis*, further mixes food particles with gastric secretions to facilitate chemical digestion. The gastric secretions contain no specific enzymes for the breakdown of carbohydrates. Gastric secretions do include hydrochloric acid, which inhibits the action of salivary amylase. However,

enzymes the proteins produced in the body that digest or change nutrients in specific chemical reactions without being changed themselves during the process, so their action is that of a catalyst; digestive enzymes in gastrointestinal secretions act on food substances to break them down into simpler compounds. (An enzyme usually is named after the substance [i.e., substrate] on which it acts, with the common word ending of *-ase;* for example, sucrase is the specific enzyme for sucrose, which it breaks down into glucose and fructose.)

FOR FURTHER FOCUS

CARBOHYDRATE COMPLICATION

Glycemic Index

The glycemic index (GI), which was developed by researchers at the University of Toronto in 1987, was thought to be an ideal tool for controlling blood glucose levels, specifically for individuals with diabetes. However, the use of this tool has been controversial throughout the past decade.

How it Works

The GI ranks foods according to how fast blood glucose levels rise after consuming a specific amount (50 g) as compared with a reference food such as white bread or pure glucose. Foods that produce a higher peak in blood sugar within 2 hours of eating them are given a higher GI ranking. Thus, low GI foods do not produce high blood glucose spikes and are favorable. In addition, low GI foods are generally high in fiber.

Complications of Use

The primary reason why this tool is controversial is because of its high variability. The GI of a food can vary significantly in the following ways:

- From person to person
- With the quantity of food eaten
- From one time of day to another
- When a food is eaten alone versus when it is eaten with other foods
- Depending on the ripeness, variety, cooking method used, degree of processing, and site of origin

The GI of a food also does not indicate the nutritious quality of the food. For example, ice cream has a lower GI value than pineapple.

Benefits of Consistent Use

Despite the limitations, a recent meta-analysis of 45 peer-reviewed publications concluded that individuals who were consuming a low-GI diet had favorable health markers for conditions including obesity, diabetes mellitus, and risk factors for coronary heart disease.[1] In a separate publication, authors supported the use of low-GI diets over high-protein diets for long-term weight loss as a result of the associated overall health benefits and disease prevention.[2] The Academy of Nutrition and Dietetics continues to recommend that people with diabetes monitor their total grams of carbohydrates and use the GI to fine-tune their food choices.

Net Carbs

Food manufacturers invented a category of carbohydrates called "net carbs" as a marketing tactic to capitalize on the low-carbohydrate diet craze. The U.S. Food and Drug Administration regulates all information provided in the Nutrition Facts label, including total carbohydrates, dietary fiber, and sugars, and it does not acknowledge or approve of the "net carb" category.

The concept was developed during the height of carbohydrate-phobic diets. Food manufacturers reasoned that, because dietary fiber and sugar alcohols have lower GI values, these carbohydrates can simply be subtracted from the total carbohydrates in a food serving. For example, a food may have 30 g of total carbohydrates with 18 g of sugar alcohols and 3 g of fiber, thereby leaving 9 "net carbs"; these are sometimes also referred to as "impact carbs" or "active carbs."

Problems With the "Net Carb" Theory

- Sugar alcohols do have calories and can raise blood sugar.
- The excessive use of sugar alcohols in foods has not been studied, but this type of labeling encourages manufacturers to increase the use of products such as sorbitol to lower their "net carb" claim.
- Excess intake of sugar alcohols can cause diarrhea.
- The idea of zero "net carbs" does not explain the fact that the food still has calories.

The bottom line is that the U.S. Food and Drug Administration maintains that, for weight management, no substitute exists for the formula of "calories in must equal calories out." Total calories count more than the quantity—or lack thereof—of high-GI carbohydrates, low-GI carbohydrates, or "net carbs."

1. Livesey G, Taylor R, Hulshof T, Howlett J. Glycemic response and health—a systematic review and meta-analysis: the database, study characteristics, and macronutrient intakes. *Am J Clin Nutr*. 2008;87(1):223S-236S.
2. Brand-Miller J, McMillan-Price J, Steinbeck K, Caterson I. Dietary glycemic index: health implications. *J Am Coll Nutr*. 2009;28(Suppl):446S-449S.

before the food completely mixes with the acidic stomach secretions, up to 20% to 30% of the starch may have been changed to maltose. Muscle action continues to mix the food mass and then moves the food to the lower part of the stomach. Here, the food mass is a thick and creamy chyme, ready for its controlled emptying through the pyloric valve and into the duodenum, which is the first portion of the small intestine.

Small Intestine

Peristalsis continues to help with digestion in the small intestine by mixing and moving chyme along the length of the organ. The chemical digestion of carbohydrate is completed in the small intestine by specific enzymes from both the pancreas and the intestine.

CULTURAL CONSIDERATIONS

ETHNICITY AND LACTOSE INTOLERANCE

Lactose intolerance or malabsorption results when the enzyme that is necessary for lactose digestion is absent or deficient from the brush border cells of the small intestine. This condition is known as *hypolactasia.* If the disaccharide lactose cannot be hydrolyzed into its respective monosaccharides (i.e., glucose and galactose), then the unabsorbed sugar attracts excess fluid into the gut. Lactose then entering the large intestine can be partially metabolized by normal bacteria found in the colon, thereby producing large amounts of gas and discomfort.

About 10% of the American population experiences lactose intolerance. However, within the United States, several ethnic groups—African Americans, Native Americans, Hispanic Americans, and Asian Americans—have significantly higher rates of lactose intolerance as compared with Americans of Northern European descent.[1] Some subgroups, such as Native Americans, report a prevalence of up to 100% lactose intolerance, and the prevalence of this condition among African Americans is approximately 75%.

Individuals with lactose intolerance can usually tolerate some low-lactose milk products, such as cheese. Lactose intolerance is not an allergy, and most affected individuals can handle varying levels of lactose in their diet. The amount tolerated varies and should be explored by gradually introducing small amounts of lactose-containing foods into the diet while keeping note of any side effects. Generally, in most people, the equivalent of 8 oz of milk is tolerated before symptoms arise. The strong genetic link to lactose intolerance indicates that it is not likely a drastic change will occur in response to dietary lactose over a lifetime. However, many individuals do experience slight changes. Most people become more intolerant with age, whereas others are able to gradually accept more.

1. National Institutes of Health, National Institute of Diabetes and Digestive and Kidney Diseases, National Digestive Diseases Clearinghouse. *Lactose intolerance* (website): http://digestive.niddk.nih.gov/ddiseases/pubs/lactoseintolerance. Accessed August 29, 2011.

Pancreatic Secretions

Secretions from the pancreas enter the duodenum through the common bile duct. These secretions contain the starch enzyme pancreatic amylase for the continued breakdown of starch into disaccharides and monosaccharides.

Intestinal Secretions

Enzymes from the **brush border** (i.e., microvilli) of the intestinal tract contain three disaccharidases: sucrase, lactase, and maltase. These specific enzymes act on their respective disaccharides to render the monosaccharides—glucose, galactose, and fructose—ready for absorption directly into the **portal** blood circulation.

Lactose intolerance, which is the inability to break lactose down into its monosaccharide units, results from a deficiency of lactase. Symptoms include bloating, gas, abdominal pain, and diarrhea. Lactose intolerance affects approximately 75% of adults worldwide, with a much higher prevalence in certain countries and ethnic groups (see the Cultural Considerations box, "Ethnicity and Lactose Intolerance").

A summary of the major aspects of carbohydrate digestion through the successive parts of the gastrointestinal tract is shown in Figure 2-4. The overall process of the absorption and metabolism of all energy-yielding nutrients (i.e., carbohydrate, fat, and protein) is discussed in Chapter 5.

RECOMMENDATIONS FOR DIETARY CARBOHYDRATE

Dietary Reference Intakes

Energy needs are listed as total kilocalories, and these amounts include caloric intake from fat and protein as well as carbohydrate. According to the most recent DRIs, 45% to 65% of an adult's total caloric intake should come from carbohydrate foods.[3] This translates to 225 to 325 g of carbohydrates for a 2000-kcal/day diet. The recommended fiber intake can be achieved by choosing carbohydrate foods such as whole-grain cereals, legumes, vegetables, and fruits, which also provide vitamins and minerals. In addition, the DRIs recommend limiting added sugar to no

brush border the cells that are located on the microvilli within the lining of the intestinal tract; the microvilli are tiny hair-like projections that protrude from the mucosal cells that help to increase surface area for the digestion and absorption of nutrients.

portal an entrance or gateway; for example, the portal blood circulation designates the entry of blood vessels from the intestines into the liver; it carries nutrients for liver metabolism, and it then drains into the body's main systemic circulation to deliver metabolic products to body cells.

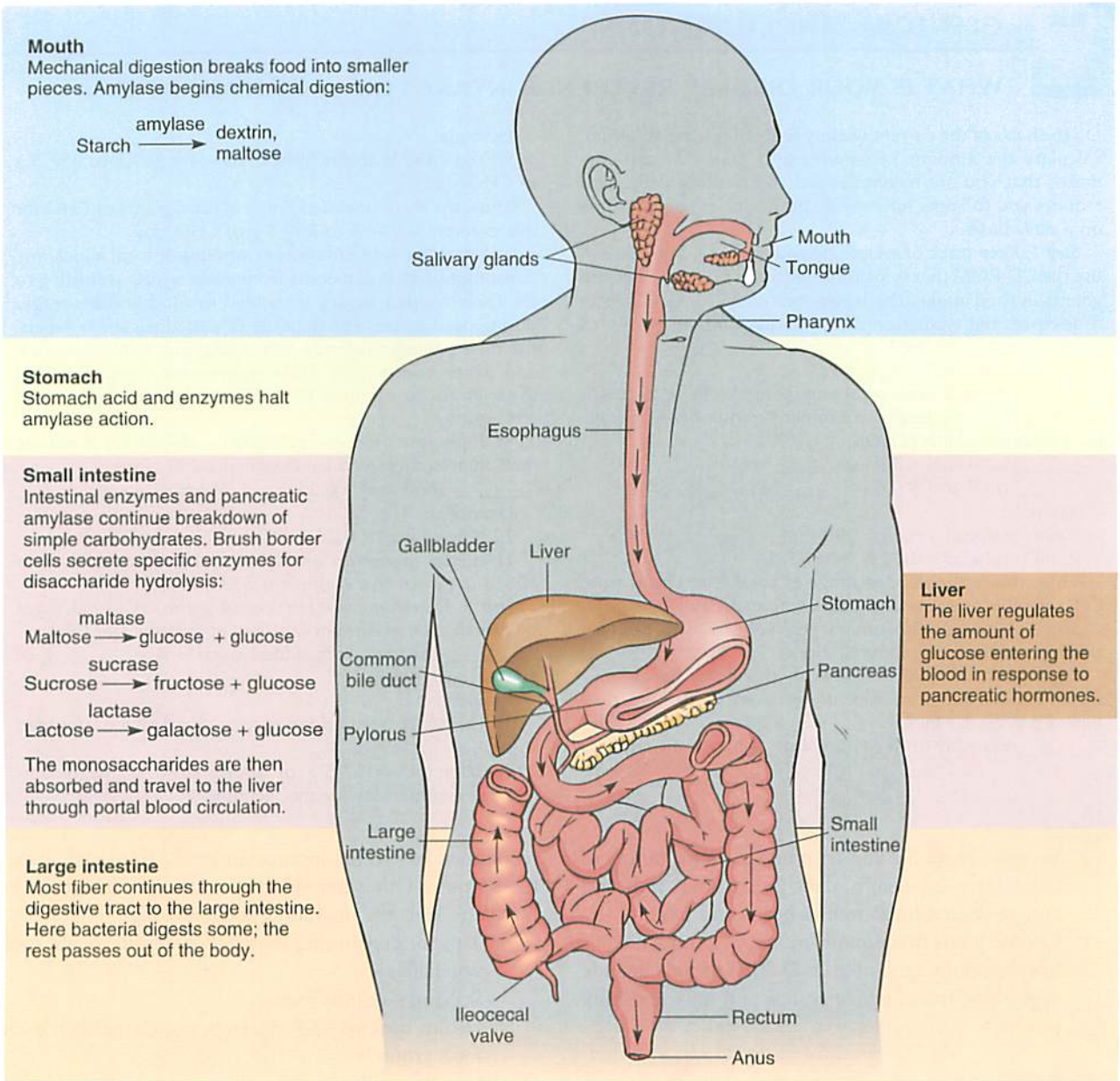

Figure 2-4 Summary of carbohydrate digestion. (Courtesy Rolin Graphics.)

more than 25% of the total calories consumed. See the Clinical Applications box entitled "What Is Your Dietary Reference Intake for Carbohydrates?" to calculate specific carbohydrate recommendations.

Dietary Guidelines for Americans

The *Dietary Guidelines for Americans* are general guidelines for the promotion of health; therefore, they do not specifically outline calorie consumption or where those kilocalories should come from (refer to Figure 1-4). Instead, the *Guidelines* advise individuals to do the following with regard to carbohydrate-rich foods[9]:

- Reduce the intake of calories from added sugars.
- Limit the consumption of foods that contain refined grains, especially refined grain foods that contain solid fats, added sugars, and sodium.
- Consume at least half of all grains as whole grains. Increase whole-grain intake by replacing refined grains with whole grains.

CLINICAL APPLICATIONS

WHAT IS YOUR DIETARY REFERENCE INTAKE FOR CARBOHYDRATES?

On the basis of the current Dietary Reference Intakes (DRIs), calculate the amount of calories and grams of carbohydrates that you are recommended to consume daily. This requires you to know how many total calories you consume on a daily basis.

Step 1: Keep track of everything you eat for 1 day. You can use the CD-ROM that is included with this book to calculate your daily food intake. This is your *total energy intake.* (Chapter 6 discusses the evaluation of total energy intake relative to weight and activity needs.)

Total energy intake = ____ kcal.

Step 2: Multiply your total energy intake by 45% (0.45) and 65% (0.65) to get the recommended number of *kilocalories from carbohydrates (CHO).*

_____ total kcal × 0.45 = _____ kcal

_____ total kcal × 0.65 = _____ kcal

Example:

2200 total kcal × 0.45 = 990 kcal

2200 total kcal × 0.65 = 1430 kcal

Thus, the recommended range of total kilocalories from CHO for this example is 990 to 1430 kcal/day

Step 3: Determine how many *grams of CHO* you need on the basis of these recommendations.

Each gram of CHO has 4 kcal; therefore, divide your recommended range of kilocalories from CHO (as determined previously) by 4.

_____ kcal/day from CHO ÷ 4 = _____ g of CHO/day

Example:

990 to 1430 kcal/day from CHO ÷ 4 = 247.5 to 357.5 g of CHO/day

Thus, the recommended range of total grams of CHO for this example is 247.5 to 357.5 g of CHO/day.

Step 4: What is the maximum amount of total kilocalorie consumption that can come from *added sugars,* according to the DRIs? Added sugars are added to food and beverages during production. The majority of added sugars in American diets come from candy, soft drinks, fruit drinks, pastries, and other sweets. The DRIs recommend limiting added sugar intake to no more than 25% of the total kilocalories consumed.

Multiply your total energy intake by 25% (0.25) to get the maximum number of *kilocalories from added sugars.*

_____ total kcal × 0.25 = _____ kcal

Example:

2200 total kcal × 0.25 = 550 kcal

Thus, the maximum amount of total kilocalories from added sugar for this example is 550 kcal/day.

Step 5: Determine the number of grams of added sugar by dividing the maximum kcal/day of added sugar by 4.

_____ kcal/day from added sugar ÷ 4 = _____ g of added sugar/day

Example:

550 kcal/day from added sugar ÷ 4 = 137.5 g of added sugar/day

Therefore, the 137.5 g of added sugar is the recommended *limit* per day for this example.

- Increase vegetable and fruit intake. Eat a variety of vegetables, especially dark-green and red and orange vegetables as well as beans and peas.
- Choose foods that provide more potassium, dietary fiber, calcium, and vitamin D. These foods include vegetables, fruits, whole grains, and milk and milk products.

MyPlate

The MyPlate food guidance system provides recommendations that are specific to age, gender, height, weight, and physical activity when reported as part of the MyPlate plan (see Figure 1-3), which is available online at www.choosemyplate.gov. After this basic information is entered, the system will produce a plan with recommendations for appropriate intake from each of the food groups. Other helpful information can be found on the plan's Web site, including the following[13]:

- Tips for consuming more whole grains, fruits, and vegetables
- Serving size information
- Health benefits and nutrients associated with each food group
- Sample menus

In addition, the MyPlate Tracker is an assessment tool that allows the user to enter his or her own menu for an evaluation of diet quality. This is a great resource for feedback about dietary sources of carbohydrate, including the consumption of fiber, whole grains, fruits, vegetables, and added sugars.

SUMMARY

- The primary source of energy for most of the world's population is carbohydrate foods. These foods are from widely distributed plant sources, such as grains, legumes, vegetables, and fruits. For the most part, these food products can be stored easily and are relatively low in cost.

SUMMARY—cont'd

- Two basic types of carbohydrates supply energy: simple and complex. Simple carbohydrates are single- and double-sugar units (i.e., monosaccharides and disaccharides, respectively). Because simple carbohydrates are easy to digest and absorb, they provide quick energy. Complex carbohydrates (i.e., polysaccharides) are composed of many sugar units. They break down more slowly and thus provide sustained energy over a longer period.
- Dietary fiber is a complex carbohydrate that is not digestible by humans. It mainly occurs as the structural parts of plants, and it provides important bulk in the diet, affects nutrient absorption, and benefits health.
- Carbohydrate digestion starts briefly in the mouth with the initial action of salivary amylase to begin digesting starch into smaller units. No enzyme for starch digestion is present in the stomach, but muscle action continues to mix the food mass and move it to the small intestine, where pancreatic amylase continues the chemical digestion. Final starch and disaccharide digestion occurs in the small intestine with the action of sucrase, lactase, and maltase to produce single-sugar units of glucose, fructose, and galactose. These monosaccharides are then absorbed into the portal blood circulation to the liver.

CRITICAL THINKING QUESTIONS

1. Why are carbohydrates the predominant type of food in the world's diets? Give some basic examples of these carbohydrate foods.
2. How would you describe each of the main classes of carbohydrates in terms of general nature, functions, and main food sources to an individual who comes to you for advice about a no- or low-carbohydrate diet?
3. Compare starches and sugars as basic fuel. Why are complex carbohydrates a significant part of a healthy diet? What are the recommendations regarding the use of sugars in such a diet? Why?
4. Describe the types and functions of dietary fiber. What are the main food sources? How would you recommend increasing dietary fiber consumption, and how much per day would you recommend for an adult?
5. What is glycogen? Why is it a vital tissue carbohydrate?

CHAPTER CHALLENGE QUESTIONS

True-False

Write the correct statement for each statement that is false.

1. *True or False:* Carbohydrates are composed of carbon, hydrogen, oxygen, and nitrogen.
2. *True or False:* Starch is the main source of carbohydrate in the diet.
3. *True or False:* Lactose is a very sweet simple monosaccharide that is found in a number of foods.
4. *True or False:* Glucose is the form of sugar that circulates in the blood.
5. *True or False:* Modern food processing and refinement have reduced dietary fiber.
6. *True or False:* Glycogen is an important long-term storage form of energy, because large amounts are stored in the liver and muscles.

Multiple Choice

1. Which of the following carbohydrate foods provides energy the quickest?
   a. Slice of bread
   b. Oat-bran muffin
   c. Milk
   d. Orange juice
2. A quickly available but limited form of energy is stored in the liver by conversion of glucose to
   a. glycerol.
   b. glycogen.
   c. protein.
   d. fat.
3. The current DRIs recommend that _____ of a person's total daily caloric intake come from carbohydrate sources.
   a. 5% to 15%
   b. 20% to 35%
   c. 35% to 50%
   d. 45% to 65%

4. Which of the following is not a monosaccharide?
   a. Lactose
   b. Glucose
   c. Galactose
   d. Fructose
5. The disaccharide sucrose is hydrolyzed to the monosaccharides glucose and
   a. galactose.
   b. glucose.
   c. fructose.
   d. starch.
6. Which type of fiber would be specifically beneficial for someone with elevated blood cholesterol levels?
   a. Soluble
   b. Insoluble

Evolve Please refer to the Students' Resource section of this text's Evolve Web site for additional study resources.

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12. U.S. Department of Agriculture, Economic Research Service. *Average daily per capita servings from the U.S. food supply, adjusted for spoilage and other waste* (website): www.ers.usda.gov/Data/FoodConsumption/FoodGuideSpreadsheets.htm. Accessed March 17, 2010.
13. U.S. Department of Agriculture, Center for Nutrition Policy and Promotion. *USDA's myplate home page* (website): www.choosemyplate.gov. Accessed August 29, 2011.

FURTHER READING AND RESOURCES

The following organizations are valuable resources for nutrition and health-related information.

Centers for Disease Control and Prevention. www.cdc.gov

Continuum Health Partners. Fiber content chart: www.slrhc.org/healthinfo/dietaryfiber/fibercontentchart.html

International Food Information Council Foundation. www.ific.org

U.S. Department of Health and Human Services. www.dhhs.gov

Whole Grains Council. www.wholegrainscouncil.org

Livesey G, Taylor R, Hulshof T, Howlett J. Glycemic response and health—a systematic review and meta-analysis: relations between dietary glycemic properties and health outcomes. *Am J Clin Nutr.* 2008;87(1):258S-268S.

The authors discuss the collective findings of 45 publications regarding the usefulness of adhering to a low glycemic index diet.

Brinkworth GD, Noakes M, Buckley JD, et al. Long-term effects of a very-low-carbohydrate weight loss diet compared with an isocaloric low-fat diet after 12 mo. *Am J Clin Nutr.* 2009;90(1):23-32.

Wycherley TP, Brinkworth GD, Keogh JB, et al. Long-term effects of weight loss with a very low carbohydrate and low fat diet on vascular function in overweight and obese patients. *J Intern Med.* 2010;267(5):452-461.

Carbohydrates are the topic of much debate in weight loss programs. Traditional weight loss programs focus on low-fat diets. However, more recent diets are centered on low levels of carbohydrate consumption. These studies examine the long-term effects of a low-carbohydrate diet as compared with a traditional low-fat diet with regard to cardiovascular risk factors.