CHAPTER 3 Carbohydrates

Key Questions Addressed

- What's the big deal about carbohydrates?
- What are carbohydrates?
- How are carbohydrates classified?
- What functions do carbohydrates serve in the body?
- How can carbohydrates affect overall health?
- How much carbohydrates should be consumed daily?
- What are the various sources of dietary carbohydrates?
- What are the glycemic index and glycemic load, and how can they be used in sports nutrition?
- How are carbohydrates utilized during exercise?
- What type, how much, and when should carbohydrates be consumed before exercise?
- What type, how much, and when should carbohydrates be consumed during exercise?
- What type, how much, and when should carbohydrates be consumed after exercise?

You Are the Nutrition Coach

Meggan is a 15-year-old soccer player. She is very athletic, plays midfielder, and is noted for her speed and endurance. She has been trying to lose a few pounds to achieve a more comfortable playing weight, and therefore has decreased her carbohydrate intake from 65% of her total daily caloric intake to 40%. Lately she has been feeling fatigued in the middle of her 2- to 3-hour practices and weekend games, which is affecting her performance. Meggan's coach has suggested that she bring a water bottle filled with a sports drink to their next practice. However, Meggan dislikes the taste of sports drinks and decides to find an alternative. She enjoys juices of any kind; therefore, the following Saturday she fills her water bottle with orange juice and drinks diligently throughout practice. Halfway through practice, instead of feeling tired, she is feeling nauseous and has intestinal cramping.

Questions

- What are the possible causes of Meggan's earlier-than-usual fatigue?
- What dietary suggestions might you give to Meggan to get her back to peak sport performance?

What's the big deal about carbohydrates?

Extensive research on the importance of carbohydrates in the diet has been conducted since the 1970s. There is little doubt that this macronutrient is critical to a healthy diet and crucial for optimal athletic performance. The popularity of distance sports such as triathlons, marathons, and distance cycling has sparked even more interest in carbohydrates within the scientific community and dietary supplement industry. The challenge for athletes is to consume the best sources and establish ideal practices for carbohydrate intake to improve sport performance. Athletes and active individuals are becoming increasingly exposed to both facts and misconceptions regarding the role of carbohydrates; thus sports nutrition professionals need to have a clear understanding of carbohydrates and their dietary and performance-related roles. Most individuals know that dietary carbohydrates are an energy source for the body, but they do not understand how important a role carbohydrates actually play, particularly for sports and exercise activities. Furthermore, many athletes do not have an appreciation for the fact that adequate intake of carbohydrates is also crucial for recovery from exercise and maintenance of carbohydrate stores in the body. Finally, many people do not understand the impact of the various types of carbohydrate foods and the timing of their intake in regard to exercise and sport performance. The purpose of this chapter is to clarify the understanding of this "master fuel."

What are carbohydrates?

Carbohydrates are a class of organic molecules consisting of a carbon (C) backbone with attached oxygen (O) and hydrogen (H) atoms. *Carbo* means "carbon" and *hydrate* means "water," or H_2O, thus giving a hint as to how these molecules are formed.[1] The simplest of carbohydrates in terms of molecular structure, the **simple sugars**, exist in arrangements of one or two molecules.

The arrangement and number of carbon molecules dictate the type of simple sugar. The chemical formula for these simple sugars is $C_nH_{2n}O_n$, where *n* equals a number from three to seven. For example, the most important simple sugar for the human body is glucose. It has six carbons in its chemical structure, and thus its formula is $C_6H_{12}O_6$. In addition to glucose, there are literally hundreds of other simple sugars that exist in nature. However, glucose and a few other simple sugars are the most important to the human body because they can be digested, absorbed, and utilized for energy.

simple sugars Another name for simple carbohydrates. These are sugars that exist as single sugar molecules (i.e., monosaccharides) or two linked simple sugar molecules (i.e., disaccharides).

Glucose and most of the other types of carbohydrates that exist in nature are synthesized by plants in a process known as **photosynthesis** (see Figure 3.1). The energy required to construct a carbohydrate comes from the sun. The sun's light energy is captured by plants and used to combine carbon dioxide (CO_2) from the air and water (H_2O) from the soil to create simple sugars. The simple sugars are linked together to make **complex carbohydrates**, such as starch and glycogen. Starch (found in plant cells) and glycogen (found in animal cells) are complex carbohydrates that are stored inside cells and used for energy when needed. Starch and glycogen are nothing more than glucose molecules linked together in chains of various lengths and configurations (see Figure 3.2).

photosynthesis An energy-requiring process in which plants capture light energy from the sun and use the energy to combine carbon dioxide and water to form carbohydrates.

complex carbohydrate A carbohydrate composed of three or more linked simple sugar molecules.

How are carbohydrates classified?

There are several types of carbohydrates that can be classified in different ways. The most common way to classify carbohydrates is using the terms *simple* and *complex*. The different simple and complex carbohydrates are listed in **Table 3.1**. The **simple carbohydrates** are made up of only one or two sugar molecules linked together, whereas complex carbohydrates are composed of longer and more complex chains of sugars.

What are simple sugars?

Simple sugars are a classification of carbohydrates that includes monosaccharides and disaccharides. A monosaccharide is nothing more than a single molecule of sugar. Many different types of monosaccharides exist in nature; however, the three simple sugars that serve as nutrients to humans are glucose, fructose, and galactose.

Glucose is the most abundant simple carbohydrate found in nature (see Figure 3.3). It rarely exists as a monosaccharide in food

simple carbohydrate A form of carbohydrate that exists as a monosaccharide or disaccharide.

glucose One of the most commonly occurring simple sugars in nature. It is the carbohydrate that humans rely upon for cellular energy.

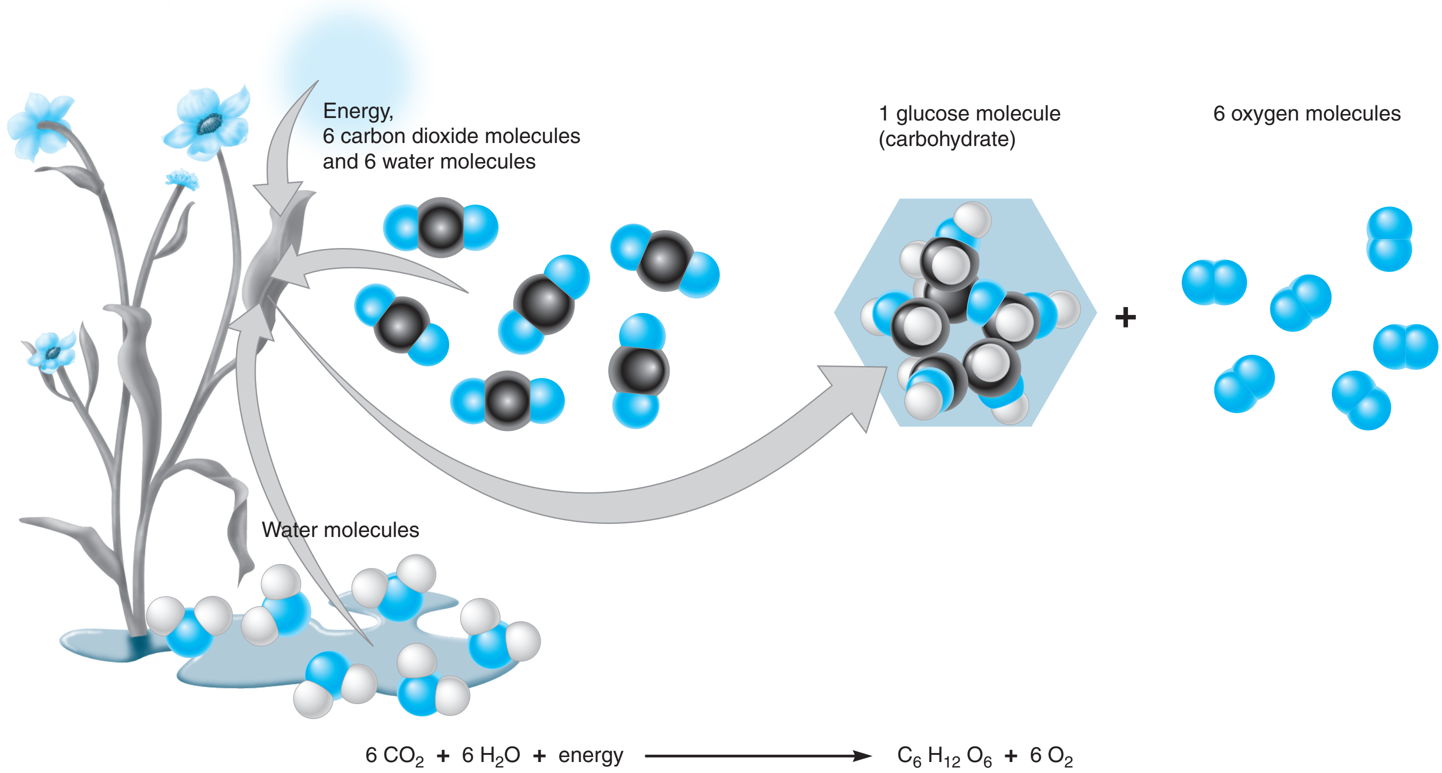

Figure 3.1 Photosynthesis. Plants release oxygen as they use water, carbon dioxide, and energy from the sun to make carbohydrate (glucose) molecules.

but is joined with other sugars to form disaccharides and other complex carbohydrates. In the body, glucose supplies energy to cells. The blood glucose level in the body is closely regulated to ensure that adequate energy is available to vital cells and organs at all times. The brain uses glucose exclusively except in times of starvation, when glucose is scarce. **Galactose** (see Figure 3.3) is rarely found alone in nature or in foods. It is most commonly linked with glucose, forming the disaccharide lactose, or milk sugar.

Fructose (see Figure 3.3) has the sweetest taste of the monosaccharides. It occurs naturally in fruits and some vegetables and provides the sweet taste. Honey is approximately half fructose and half glucose. A common sweetener containing fructose is high fructose corn syrup, which is added to sweeten many soft drinks, candies, jellies, and desserts.

Disaccharides, also considered to be simple carbohydrates, are made of two simple sugars (*di* means "two") that are linked (see Figure 3.4). Examples of disaccharides are sucrose (fructose + glucose), lactose (glucose + galactose), and maltose (glucose + glucose).

galactose A simple sugar found in milk.

fructose A simple sugar known for its sweet taste that is commonly found in fruits.

Sucrose is commonly referred to as table sugar and is composed of one glucose and one fructose molecule. Sucrose is manufactured using extraction processes from sugar beets and sugar cane to produce granulated sugar and powdered sugar. When a food label lists sugar as the first ingredient, the term refers to sucrose. Sucrose and other common nutritive sweeteners that can be found on food labels are listed in **Table 3.2**. **Lactose** is commonly known as milk sugar and is composed of one molecule of glucose and one molecule of galactose. Lactose gives milk and other dairy products their sweet taste. Some individuals are intolerant to lactose. As a result, milk and other dairy products cause gastric upset because these people lack or have reduced levels of the enzyme necessary to digest and absorb the lactose sugars. Another disaccharide, **maltose** is composed of two glucose molecules. It seldom occurs naturally in foods, but forms whenever long molecules of starch are broken down. In the human body, digestive

sucrose A commonly consumed disaccharide also known as table sugar. It is composed of linked glucose and fructose molecules.

lactose The disaccharide found in milk that is composed of the simple sugars glucose and galactose.

maltose A disaccharide made up of two linked molecules of glucose.

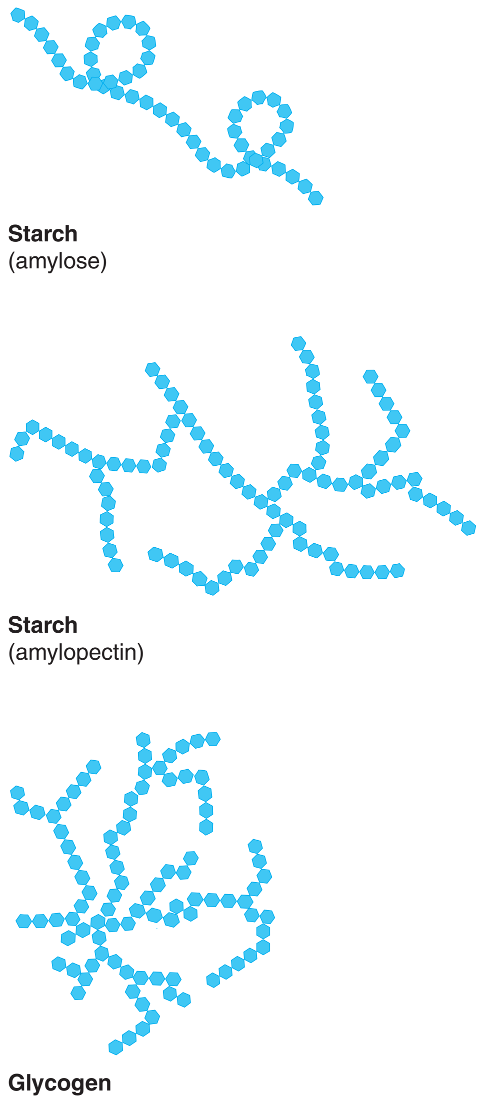

Figure 3.2 Structure of starch and glycogen. Plants contain two main types of starch: amylose and amylopectin. Animals store glucose as glycogen.

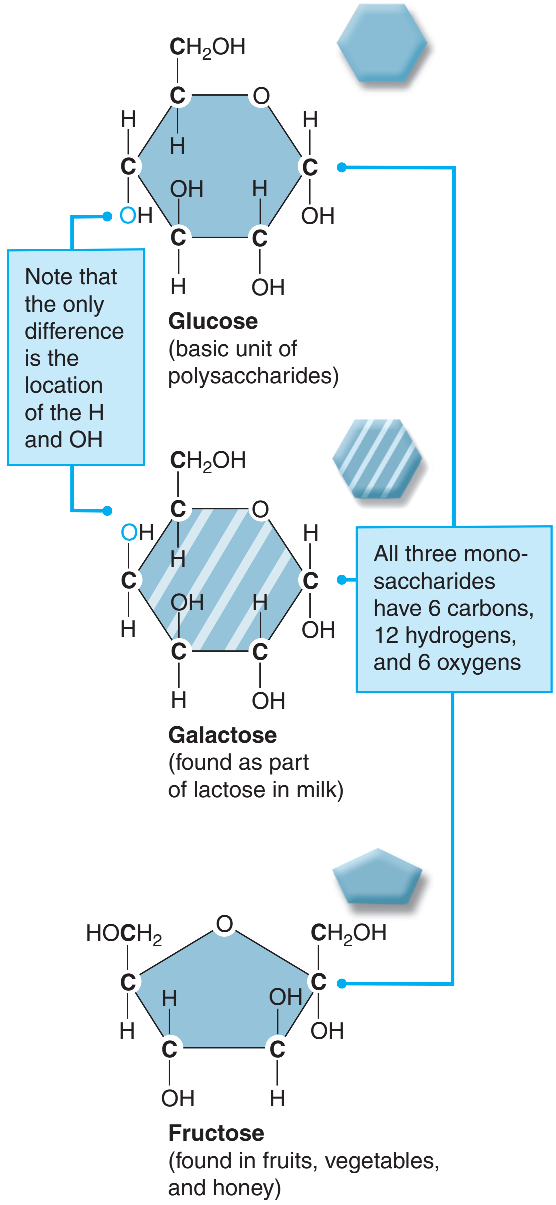

Figure 3.3 Structure of glucose, fructose, and galactose. Glucose and galactose are six-sided structures; fructose is a five-sided structure.

TABLE 3.1 Carbohydrate Classifications and Common Examples

Simple Carbohydrates		Complex Carbohydrates	
Monosaccharides	*Disaccharides*	*Oligosaccharides*	*Polysaccharides*
Glucose	Sucrose	Maltodextrin	Fiber
Fructose	Lactose	High fructose corn syrup	Starch
Galactose	Maltose	Corn syrup	

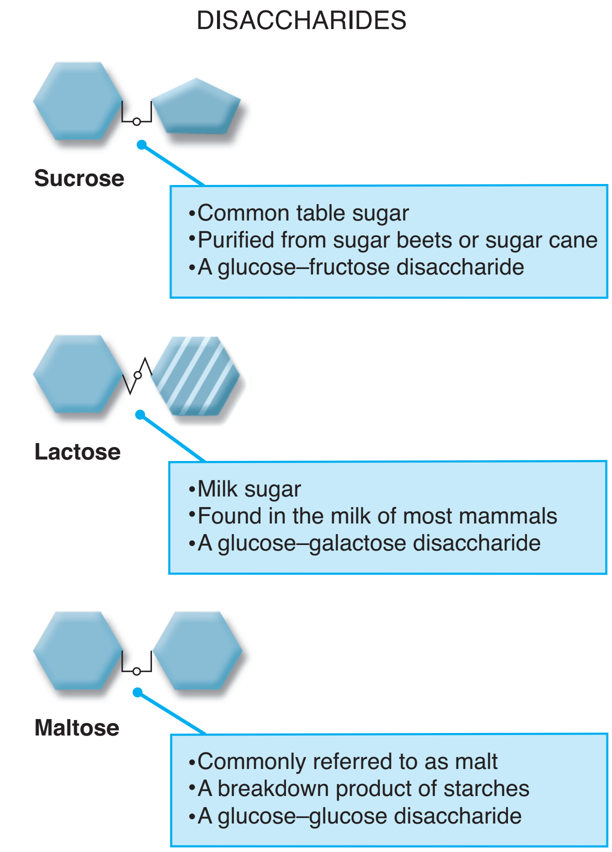

Figure 3.4 Structure of disaccharides. The three monosaccharides pair up in different combinations to form the three disaccharides.

TABLE 3.2 Common Nutritive Sweeteners in Foods

Sucrose	Corn Syrup
Corn sweetener	Dextrin
High fructose corn syrup	Concentrated fruit juice
Molasses	Maple syrup
Malt	Cane sugar
Honey	Maltose
Dextrose	Fructose
Sugar	Confectioner's sugar
Brown sugar	Turbinado sugar

enzymes begin to break starch down into maltose in the mouth. Although a sugar, maltose is very bland tasting.

What are complex carbohydrates?

The complex carbohydrates found in foods are starches and fiber (see **Table 3.3**). Glycogen is the storage form of carbohydrates in the body and is considered a complex carbohydrate because of its similarity in structure to starch (see Figure 3.2). Complex carbohydrates are composed of many sugar molecules linked in often very long and complicated carbon chains. Carbohydrates that are composed of short chains of 3 to 10 linked sugars are known as oligosaccharides. Examples of oligosaccharides are the maltodextrins, corn syrup, and high fructose corn syrup. Polysaccharides are complex carbohydrates composed of even longer chains of 11 or more sugars. Polysaccharides can be straight chains of linked sugars or can be highly branched (see Figure 3.2). The molecular structure of a polysaccharide determines how soluble it is in water, how easy it is to digest, and how it behaves when heated.

Starches are polysaccharides and serve as a major source of carbohydrates in our diet. Food sources rich in starch include grains, legumes, potatoes, and yams (see Figure Figure 3.5). Starches give foods some of their sticky or moist properties.

TABLE 3.3 High-Carbohydrate Foods

High in Complex Carbohydrates	High in Simple Carbohydrates
• Bagels	**Naturally Present**
• Cereals	• Fruits
• Corn	• Fruit juices
• Crackers	• Plain nonfat yogurt
• Legumes	• Skim milk
• Peas	**Added**
• Popcorn	• Angel food cake
• Potatoes	• Candy
• Rice Cakes	• Cookies
• Squash	• Frosting
• Tortillas	• Gelatin
	• High-sugar breakfast cereals
	• Jams
	• Jellies
	• Sherbet
	• Soft drinks
	• Sweetened nonfat yogurt
	• Syrups

Figure 3.5 Food sources of starch. A variety of grain products, potatoes, and legumes are good sources of starch.

Glycogen, also called animal starch, is the storage form of carbohydrate in animals.[2] Glycogen is not found in plants. It is composed of long, highly branched chains of glucose molecules (see Figure 3.2). Stored glycogen in humans can be rapidly broken down into single glucose molecules for use by cells for energy.

Dietary fiber, yet another complex carbohydrate, is found in plant cell walls and inside plant cells. All plant foods contain some fiber of varying types. Most fiber is indigestible by the body, and therefore provides no caloric or carbohydrate value when consumed. There are two types of fiber, which are classified based on their solubility in water: soluble and insoluble. **Soluble fibers** are found primarily in oats, barley, legumes (dried beans, peas, lentils), and some fruits and vegetables. **Insoluble fiber** sources are primarily whole grain products, nuts, seeds, and some vegetables. Consuming foods that contain both soluble and insoluble fiber can help prevent high cholesterol and diverticular disease, regulate blood glucose levels, and help prevent and/or treat constipation. A high-fiber diet also produces an increased satiety level that may aid in weight loss over time by reducing hunger, and thus ultimately decreasing caloric intake. Current recommendations for fiber intake are 25 grams and 21 grams per day for women aged 19–50 and older than 50, respectively, and 38 grams and 30 grams per day for men aged 19–50 and older than 50, respectively.[3] These recommendations are based on the fiber intake required to reduce the risk of cardiovascular disease. Unfortunately, the average American consumes only 10–20 grams of fiber per day.[4] **Table 3.4** lists the fiber content of common foods.

The Food and Nutrition Board, part of a panel convened to evaluate the Dietary Reference Intakes on fiber, proposed new definitions for **dietary fiber**, **functional fiber**, and **total fiber**.[3] These updated definitions evolved from a need to have consistent nutrition

Fortifying *Your Nutrition Knowledge*

Experience the Digestion of a Starch to a Sugar

Chew a saltine cracker until it tastes sweet. The digestive enzymes in saliva break down the long chains of sugar molecules to produce glucose and maltose, thus making the cracker eventually taste sweet.

gaining the performance edge

Glycogen is the storage form of carbohydrates in muscle cells. It is a readily available source of energy for muscle and is critical for fueling performance in endurance, strength/power, and team sports.

soluble fiber A type of indigestible plant carbohydrate that dissolves in water. Soluble fiber has been shown to help lower blood cholesterol levels in some individuals. Sources of soluble fiber are oats, barley, legumes, and some fruits and vegetables.

insoluble fiber A type of nondigestible plant carbohydrate that does not dissolve in water. Insoluble fiber sources are primarily whole grain products, nuts, seeds, and some vegetables.

dietary fiber A complex carbohydrate obtained from plant sources that is not digestible by humans. Although dietary fiber provides no energy for cellular activity, it does help maintain a healthy digestive system, lower blood cholesterol levels, and regulate blood glucose levels.

functional fiber Isolated, nondigestible carbohydrates that have beneficial physiological effects in humans.

total fiber The sum of dietary and functional fiber.

TABLE 3.4 Fiber Content of Common Foods

Food	Amount	Flber (g)
Apple	1 medium	4.4
Pear	1 medium	4.0
Banana	1 medium	2.0
Broccoli	1/2 cup	2.6
Corn	1/2 cup	3.0
Carrots	2 medium	3.4
Green beans	1/2 cup	2.7
Beans (black, pinto, etc.)	1/2 cup	9.7
Whole wheat bread	1 slice	3.0[1]
Oatmeal	1 cup cooked	4.0
Bran flakes	1 cup	5.0
Popcorn	1 cup	1.0

[1]Fiber content of bread and other baked goods varies greatly depending on the brand.

Sources: Data from U.S. Department of Agriculture, Agricultural Research Service, 2012. USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory home page. Available at: http://www.ars.usda.gov/ba/bhnrc/ndl.

labeling regarding fiber because of the creation of new products that behave like fiber but do not meet the former traditional definition of fiber. Many of these new food products have potential health benefits, yet they do not meet the previous U.S. definitions for fiber based on analytical methods.[3] The new definitions for fiber include:

- *Dietary fiber:* Consists of nondigestible carbohydrates and lignins that are intrinsic and intact in plants. Examples include cellulose, hemicellulose, pectin, gums, beta-glucans, fibers found in oat and wheat bran, plant carbohydrates, and lignins.
- *Functional fiber:* Consists of isolated, nondigestible carbohydrates that have beneficial physiological effects in humans. Examples include resistant starch, pectin, gums, animal carbohydrates (chitin and chitosan), and commercially produced carbohydrates such as resistant starch, polyols, inulin, and undigested dextrins.
- *Total fiber:* The sum of dietary and functional fiber.

These definitions are not likely to alter the recommended intake levels, but will more clearly define the sources of fiber and the specific potential for health benefits when consumed. Fiber remains intact in the gut and is exposed to the normal bacteria present in the large intestine. Bacteria aid the digestive process, and as bacterial metabolism occurs it produces gas as a by-product. Fiber, when consumed in excess, can cause bloating and flatulence that can be uncomfortable to athletes during training and competition. In addition, undigested fiber increases stool mass and volume and attracts water into the large intestine. The added weight, feeling of heaviness, and possible complications with diarrhea or constipation are dependent upon water intake and can contribute to uncomfortable workouts and competitions for athletes. Some athletes choose to limit high-fiber foods in their diet for several hours or up to 1 day prior to heavy training or competitions to avoid potential intestinal discomfort. However, because of fiber's health-promoting effects, high-fiber foods should not be completely avoided, and athletes should make an effort to include carbohydrates containing fiber on a regular basis.

gaining the performance edge

Limiting high-fiber foods starting several hours to 1 day prior to competition can help avoid feelings of heaviness, bloating, and/or intestinal discomfort.

Are artificial sweeteners carbohydrates? Are they beneficial or harmful?

As their name indicates, artificial sweeteners provide sweetness to foods but not at the expense of calories. Artificial sweeteners can actually be hundreds of times sweeter than sucrose (see **Table 3.5**). Some artificial

TABLE 3.5 Sugars and Artificial Sweeteners

Name	Sweetness (relative to sucrose)	ADI (mg/kg/day)	Trade Name	Appropriate for Cooking/Baking
Sucrose	1.0			Yes
Maltose	0.4			Not commonly used
Fructose	1.73			Yes
Tagatose	0.92	Not specified		Yes
Sorbitol	0.6	Not specified		Not commonly used
Xylitol	0.9	Not specified		Not commonly used
Mannitol	0.5	Not specified		Not commonly used
Acesulfame K	130–200	15 mg/kg	Sunett; Sweet One	Yes
Aspartame	200	50 mg/kg	Nutrasweet; Equal	No
Saccharin	300	5 mg/kg	Sweet'N Low; Sugar Twin	Yes
Sucralose	600	5 mg/kg	Splenda	Yes
Cyclamate	30	11 mg/kg		Yes
Stevia	250–450	2 mg/kg	Truvia; Purevia; Sweetleaf	Yes
Neotame	7000–13,000	18 mg/kg		Yes

Sources: Data from American Dietetic Association. Position of the American Dietetic Association: Use of nutritive and nonnutritive sweeteners. *J Am Diet Assoc*. 1998;98;580–587; and Bray GA, Nielsen SJ, Popkin BM. Consumption of high-fructose corn syrup in beverages may play a role in the epidemic of obesity. *Am J Clin Nutr*. 2004;79;537–543.

sweeteners are derived from carbohydrates, modified with alterations to their molecular structure, making them less digestible and thereby yielding fewer calories when eaten. Other artificial sweeteners, such as aspartame, are not carbohydrates at all and may be derived from amino acids. Because they contain few or no calories, their value in producing better-tasting low-calorie foods and providing sweetness without calories is quite beneficial to those on restricted diets or trying to lose weight. Individuals with diabetes or insulin sensitivity can also enjoy sweetened foods without consuming excess sugars and calories.

Artificial sweeteners are regulated in the United States by the FDA. Some are on the **Generally Recognized as Safe (GRAS)** list regulated by the FDA, and others are considered food additives. Food additives must be approved for use in food products by the FDA before entering the food supply. The FDA approves and regulates the safety limit of food additives and sets **acceptable daily intakes (ADIs)**. The ADI is the estimated amount per kilogram of body weight that a person can consume every day over a lifetime without risk.[4] The ADI is conservative and is set at an amount approximately 100 times less than the minimum level at which observed adverse effects occurred in animal studies. Artificial sweeteners such as aspartame, saccharin, acesulfame K, and sucralose have all obtained FDA approval for use in food products. However, some researchers and practitioners remain concerned about the safety of sugar substitutes. Because of the inconsistent results from research studies on the long-term safety of artificial sweetener consumption, intake should be kept to a minimum.

Saccharin was the first of the commercially produced artificial sweeteners; it hit the market in the early 1960s. The safety of saccharin became an issue when it was determined that laboratory rats consuming saccharin had a higher incidence of bladder cancer than rats that did not consume saccharin. In 1991, the FDA withdrew its proposed ban on saccharin and now considers it to be a safe food additive for use in foods and beverages, cosmetics, gums,

Generally Recognized as Safe (GRAS) Substances that have not been conclusively proven to be safe but are generally accepted by experts as being safe for human consumption and therefore can be added to foods by manufacturers.

acceptable daily intake (ADI) The FDA-established safety limit for food additives and artificial sweeteners. The ADI is set at approximately 100 times below the level required for toxic or adverse effects.

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and candies. Aspartame and acesulfame K are two other common artificial sweeteners that have been approved for use as tabletop sweeteners and use in heat-stable foods such as diet sodas, puddings, gelatins, candies, and gum.

Sucralose and tagatose are relatively new additions to the list of artificial sweeteners. Sucralose is a chemically altered form of sucrose that is manipulated by substituting the sucrose hydroxyl group with chlorine. This produces an intense sweetness—about 600 times sweeter than sucrose.[5] Tagatose attained GRAS status in 2002 and is a low-calorie, full-bulk natural sugar that is 92% as sweet as sucrose.[6] It contains a caloric value of 1.5 kcal/g because only about 15–20% of the product is absorbed in the small intestine. Tagatose provides sensory and textural qualities similar to sugar in many foods, adding to its versatility in the development of new food products with lower calories without a reduction in palatability.

Sugar alcohols, also known as **polyols**, are dissimilar to regular sugars and sugar substitutes because they are digested and absorbed differently. They are found naturally in plants such as berries and other fruits and some vegetables, but they also are produced for commercial use. Sugar alcohols such as xylitol, sorbitol, and mannitol are nutritive sweeteners (contain some calories) and often are added to sweeten products such as mints, candy, and gum. They are not as easily digested or absorbed by the body and therefore contain fewer calories (one-half to one-third fewer) than sugar. The incomplete absorption does not allow for direct metabolism that would provide the usual 4 calories per gram of carbohydrate.[7] Depending on the type or brand, sugar alcohols generally contain 1.5–3.0 calories per gram. Because sugar alcohols do contain calories, they can have some effect on glucose levels, and if eaten in large amounts can increase blood glucose levels.

All sugar alcohols are regulated by the GRAS list or as food additives. Sugar alcohols must be listed on food labels if a nutrient claim is made, such as "sugar-free" or "reduced sugar." Sugar alcohols are listed on the ingredient list and on the nutrition facts section of the label. Excessive intake of sugar alcohols can have a laxative effect and may cause diarrhea.[7] Food products that contain sugar alcohols can put a warning on the label stating, "excess consumption of this product may have a laxative effect." Athletes trying to reduce caloric or carbohydrate intake may consume foods that contain sugar alcohols as artificial sweeteners. However, because of the laxative effect, athletes may need to reduce the amount and type of artificial sweeteners consumed prior to exercise.

polyols A class of food sweeteners that are found naturally in some plants but are not easily digested and thus yield fewer calories. Polyols, also known as sugar alcohols, include xylitol, sorbitol, and mannitol and often are added to sweeten products such as mints, candy, and gum.

There are benefits to using all of the varieties of artificial sweeteners in foods. They provide a sweet taste and several have bulking properties, while contributing fewer calories than sugars. They do not promote tooth decay, and consumption of gum and mints sweetened with sugar substitutes instead of sugars can be beneficial to dental health. Consumers need to be aware, however, that foods containing sugar substitutes and those promoted as "low carbohydrate" are not necessarily low calorie. This misconception may lead to overconsumption of foods with sugar substitutes and therefore an increased overall calorie intake.

gaining the performance edge

Artificial sweeteners can be used by athletes wishing to control body weight; however, because of the laxative effect of some sweeteners, athletes may need to reduce the amount and type of artificial sweeteners consumed prior to competition.

What functions do carbohydrates serve in the body?

Carbohydrates serve several important roles in the body, many of which are critical to optimal sport performance. Carbohydrates are the most important source of energy for the body. Although fat stores supply a large quantity of energy, carbohydrates must be present to metabolize fats at the rapid rates needed to support the caloric demands of exercise and sport competition. Furthermore, the higher the intensity of the activity, the greater the reliance of the body on carbohydrates. In fact, carbohydrates are the only macronutrient that can provide energy for anaerobic activities such as sprinting. Adequate carbohydrate intake also helps spare muscle tissue. If an athlete's carbohydrate intake is low, his or her body will turn to the breakdown of muscle protein to make up for the deficit in needed carbohydrates. Finally, carbohydrates are the primary energy source

gaining the performance edge

Cutting carbohydrates from an athlete's diet leads to "performance suicide." Carbohydrates are the "master fuel" for all sports.

Fortifying *Your Nutrition Knowledge*

What Does "Low Carb" Mean?

The FDA regulation for nutrient content claims allows manufacturers to highlight and make health-related claims on their food labels regarding certain nutrients or dietary substances in their products. However, the FDA permits only specified nutrients or substances to have these nutrient content claims. The FDA has not established a set of values for descriptors identifying carbohydrates. Food manufacturers can put quantitative statements on labels such as "6 grams of carbohydrates" as long as they are factual. However, they cannot make a statement such as "only 6 grams of carbohydrates" because that implies the food is a carbohydrate-reduced or low-carbohydrate food. If the label "characterizes" the level of a nutrient, then it is considered a nutrient content claim. Therefore, a claim of "low carbohydrate" cannot be used on food labels because it characterizes the amount of carbohydrates in that food.

Although there are no official definitions of low carbohydrate, the FDA is gathering evidence and will potentially develop a statement outlining carbohydrate food-labeling guidelines. Guidelines are likely to be similar to those established for such terms as "low fat," "reduced fat," or "reduced sugar." These will list the number of grams of carbohydrates to be considered "low" and probably will include definitions of reduced carbohydrates as well.

for the nervous system. Nerve cells do not store carbohydrates like muscle cells do; their source for carbohydrates is the bloodstream. When blood glucose levels fall, nerve cell function suffers, which can have a dramatic effect on exercise and sport performance.

How can carbohydrates affect overall health?

It is widely recognized that a diet moderate to high in carbohydrates is important for optimal daily training, high energy levels, and overall good health. Carbohydrate-rich foods contain not only energy for working muscles, but also nutrients required for proper body functioning, such as fiber, vitamins and minerals, and various **phytochemicals**.

phytochemicals A large class of biologically active plant chemicals that have been found to play a role in the maintenance of human health.

What role does fiber play in health?

Fiber is a complex carbohydrate that the body cannot digest or absorb. Most fibers are made up of long chains of sugar units and thus are classified as polysaccharides. However, unlike starch, fiber polysaccharides cannot be broken down by human digestive enzymes into small enough units for the body to absorb. Thus, fiber, with the exception of some resistant starches, does not contribute energy to the body as do other digestible carbohydrates. Even though it is a minimal energy source, fiber promotes good health in many ways.

When we eat plant foods, the indigestible fiber portion adds bulk to the intestinal contents. It does so by attracting water into the intestines, some of which is absorbed by the fiber itself, causing it to expand. The greater the bulk of the intestinal contents, the greater the peristaltic actions of the smooth muscles in the intestinal walls and the faster the passage of foods through the digestive system. The water drawn in by the fiber also helps soften the stools for easy passage out of the system. If fiber intake is low, there is less water and less intestinal bulk, which results in stools that are small and hard, and that pass more slowly through the length of the intestines. Constipation and hemorrhoids can occur more readily when stools are hard and when fiber intake is low. Constipation produces an uncomfortable full feeling, often with gas, and is particularly uncomfortable during exercise.

Active individuals who eat adequate fiber and consume adequate fluids will have fewer problems with constipation than those who do not exercise. Physical exercise not only strengthens the muscles used during exercise, but also tends to produce a healthier GI tract that moves food and fluids efficiently and quickly through the system. This is just another example of the importance of combining exercise with good nutrition.

Choosing foods rich in fiber may help reduce the risk of some types of cancers. The link between fiber and colon cancer has received much attention recently. Controversy exists in the research as to whether fiber has a positive or a neutral effect on the risk for colon cancer. Some studies support a positive correlation between high fiber intakes and colon cancer risk reduction,[8,9] whereas others do not support this finding.[10–12] The theory behind fiber's potential ability to decrease colon cancer risk is that the higher bulk of insoluble fibers may "dilute" toxins in the intestinal tract plus speed the passage of toxins out of the body. This decreased transit time may reduce the amount of contact between potential cancer-causing agents and the intestinal mucosal cells. More research, especially studies that control for type of fiber and food intake, needs to be conducted to determine whether there is a direct correlation between high fiber intake and a lowered incidence of colon cancer. Regardless of future findings, eating a diet rich in complex carbohydrates, including fruits, vegetables, whole grains, and legumes, provides a healthful diet and can aid in the prevention of many other disease conditions (see Figure 3.6).

Soluble fiber appears to play a significant role in reducing the risk of heart disease. Several studies have shown that diets high in soluble fiber decrease blood cholesterol levels. Soluble fiber may help reduce serum cholesterol levels by binding bile acids in the GI tract, thus preventing their reabsorption. This is significant because bile acids are made from cholesterol in the liver and are secreted into the intestinal tract to aid with fat absorption. In addition, short-chain fatty acids, produced from bacterial fermentation of fiber in the large intestine, may inhibit cholesterol synthesis.

Foods rich in complex carbohydrates may indirectly help with weight loss or maintenance of a healthy weight. Fruits, vegetables, whole grains, and starchy legumes are usually low in total fat and calories. A diet that contains adequate portions of these lower calorie foods may replace higher calorie foods, thus producing a caloric deficit. Because of their bulk, these foods provide a feeling of fullness that lasts longer when compared with less complex carbohydrate foods. High-fiber foods take longer to digest and absorb; thus the full feeling lasts longer, and individuals may eat less often.

Food for Thought 3.1

Daily Carbohydrates and Fiber for Athletes

In this exercise, you will analyze a 1-day meal plan and discuss the health benefits of appropriate carbohydrate intake.

Figure 3.6 Food sources of fiber. Whole grains are a good source of fiber.

What role do simple sugars have in health?

In contrast to the benefits of high complex carbohydrate and fiber intake, simple carbohydrates—specifically refined sugars—may have some negative health consequences. Highly sugared foods and those that are sticky and stay in the mouth longer may produce more dental caries (cavities). Sugar, sugared soda, and fruit drinks (especially when sipped slowly throughout the day); crackers; and chewy candies that get caught in teeth have a greater likelihood of producing cavities than do less sticky, sweet foods. Bacteria in the mouth react with sugar and produce acids. These acids erode the tooth enamel and produce cavities. Choosing low-sugar foods and rinsing the mouth after eating sugary or sticky foods can help reduce the risk of dental caries.

Recently, sugar, specifically in the form of high fructose corn syrup (HFCS), has been purported to be one of the reasons for the rise in obesity and related disease rates in the United States.[13,14] Much of the research has focused on the correlation between increased consumption of sodas and other sugar-sweetened beverages containing HFCS and weight gain.[15–17] However, not all studies have shown a direct link, especially in humans.[18] A proposed metabolic theory explaining the mechanism by which fructose causes weight gain is through the suppression of insulin and leptin production.[13,19] More research is needed to elucidate a cause and effect relationship as well as to develop associated intake recommendations.

From a practical standpoint, weight gain may be associated with the consumption of high-sugar foods as a result of the typical high calorie value of these items. However, it may not be simply the sugar that makes the foods high calorie. Many sweet foods contain significant amounts of fat as well. All carbohydrates, simple sugars or complex, contain 4 calories per gram. Fats contain 9 calories per gram. Foods such as cookies, cakes, ice cream, and many chocolate candies contain both simple sugars and fat. The fat often contributes as many (or more) calories to these products as sugars do.

Sugar and foods made with significant amounts of sugar are often low in total nutrients, lack fiber, and are calorie dense. Choosing these foods regularly makes it difficult to meet individual needs for vitamins, minerals, and other nutrients because they can take the place of nutrient-dense foods. This, combined with a higher incidence of dental caries, the caloric density of high-sugar foods contributing to weight problems, and the low amount of fiber found in individuals consuming a high-sugar diet, suggests that reducing refined sugar intake in foods and beverages is the best option for better health.

How much carbohydrates should be consumed daily?

The quantity of carbohydrate needed on a daily basis varies among athletes based on several factors, including current body weight, total energy needs, the specific metabolic demands of their sport, and their stage of training or competition schedule. The primary role of carbohydrates is to provide energy to cells, particularly the brain, which is the only carbohydrate-dependent organ in the body. The RDA for carbohydrates recommends at least 130 grams per day for adults and children, based on the average minimum amount of glucose utilized by the brain.[20] The Acceptable Macronutrient Distribution Range (AMDR) for carbohydrates for males and females age 9 and older is 45–65% of daily calories.[20]

What is the relationship between current body weight and carbohydrate intake?

Carbohydrate needs can be determined based on current body weight. Six to 10 grams of carbohydrate per kilogram of body weight is a general recommendation for calculating daily carbohydrate needs for athletes.[21] It should noted that an even wider range (i.e., 3–12 g/kg) has been suggested in certain instances.[22,23] Clearly, individual carbohydrate needs can vary greatly. Using the general recommendation of 6–10 g/kg, an athlete who weighs 60 kg would require 360–600 grams of carbohydrates per day. The large range in recommendations allows for changes in exercise intensity, environmental conditions, and personal preferences, as well as type and quantity of daily physical activity. **Table 3.6** provides suggested daily carbohydrate intake recommendations for a variety of activity levels.

How can carbohydrate needs be determined based on a percentage of total calories?

The recommended range of 45–65% of calories coming from carbohydrates is quite large. The level of carbohydrate in this range can be chosen for each individual based on medical conditions, training regimen, and personal food preferences.

TABLE 3.6 Daily Carbohydrate Intake Recommendations for Various Types of Athletes

Type of Athlete	Training Frequency (days/week)	Training Intensity	Training Duration (hours/day)	Daily Carbohydrate Intake Range (g/kg)
Recreational	3 to 4	Light to moderate	<1.0	3–6
Competitive	5 to 6	Moderate	1.0–2.0	6–8
Competitive	6 to 7	Moderate to high	2.0–4.0	8–10
Ultra-endurance	6 to 7	Moderate to high	>4.0	10–12

This range provides enough carbohydrates for the general population to maintain energy levels. For athletes, the higher end of this percentage range is usually recommended. As training volume increases, or for endurance athletes preparing and tapering for competition, the percentage of calories from carbohydrates can increase beyond the recommended range to as high as 70–75%. For recreational athletes or individuals with certain medical conditions, such as diabetes, carbohydrate intake at the middle to low end of the range is typically appropriate.

The following provides an example of how to calculate carbohydrate needs based on a percentage of total calories:

Assume a recreational athlete requires 2500 calories daily and 55% of total calories from carbohydrates:

1. *Calculate the number of total calories contributed by carbohydrates based on the goal percentage:* 2500 × 0.55 (55% of calories from carbohydrates) = 1375 calories from carbohydrates.
2. *Convert calories from carbohydrates to grams of carbohydrates daily:* 1375 calories ÷ 4 calories/gram = 344 grams of carbohydrates daily (see **Training Table 3.1**).

Training Table 3.1: Sample Meal Plan Providing 340–350 Grams of Carbohydrate

Food/Beverage	Grams of Carbohydrate
Breakfast	
1½ cups of raisin bran cereal	62
1 cup skim milk	12
1 cup sliced strawberries	11
Lunch	
Grilled cheese sandwich	28
2 cups of vegetable soup	24
10 saltine crackers	20
Pear	26
Dinner	
1½ cups of spaghetti with marinara sauce	70
+ 3 oz ground turkey	0
1 cup mixed vegetables	15
2 cups skim milk	24
1 cup frozen yogurt with ⅓ cup mixed nuts	54
Total Carbohydrate Intake	**346 grams**

It is important to calculate and compare the grams of carbohydrates based on both current body weight and the percentage of calories coming from carbohydrates. It can be misleading to follow only one formula or the other. For example, a 70 kg middle-distance runner who consumes 4000 calories per day, of which 50% are carbohydrate calories, will consume approximately 500 grams of carbohydrates. At 70 kg, 500 grams is approximately 7 grams of carbohydrates per kilogram of body weight. If the quantity of carbohydrates was evaluated solely on the percentage of total calories contributed by carbohydrates, it might be perceived as falling on the low end of the recommendations. However, 7 grams of carbohydrate per kilogram of body weight falls well within the 6–10 g/kg recommendation, and therefore both guidelines are met.

Another important consideration is to calculate the percentage of calories contributed by carbohydrates and compare it to daily protein and fat needs. In cases such as weight loss, total calories may be restricted slightly and therefore carbohydrate estimates based on current body weight may launch the percentage from carbohydrates into the 75–85% range. This high percentage makes it challenging, if not impossible, to include adequate levels of proteins and fats in the daily meal plan without exceeding total calorie needs. It is important to always balance carbohydrate, protein, and fat needs relative to total calorie estimates to ensure that athletes are properly fueled while meeting their goals of weight loss, maintenance, or gain.

Recommendations as high as 70–75% have been suggested as optimal for some athletes, especially during long-duration and high-intensity training sessions and competitive events.[21] Athletes competing in the Race Across America, a nonstop cycling race from coast to coast, may consume as much as 70–80% of their calories from carbohydrates during the event.

What impact does the stage of training or competition schedule have on carbohydrate intake?

For most athletes, carbohydrate needs will increase slightly as training volume increases or when approaching a competition. In general, during the off-season or recovery periods total calorie needs may be lower, and therefore total carbohydrate needs will also decline. As preseason conditioning begins and training volume and intensity are on the rise, carbo-

Fortifying

Your Nutrition Knowledge

Heather's Experience as the Dietitian for Team 70+ in the Race Across America

The Race Across America is a nonstop cycling event from the West Coast to the East Coast of the United States. I had the pleasure of planning and executing the nutrition plan for the 70+ Team—a four-man team of athletes over the age of 70—in August of 1996.

We met as a team in April of that year to begin planning. During this meeting, I gathered background information on each individual—their food likes and dislikes, the type of beverages and food usually consumed during cycling, estimates of their sweat rates, food allergies and intolerances, medications, and much more. Between April and August, I calculated the daily energy, carbohydrate, protein, and fat needs for all four riders. The estimates were based on the system of two riders performing an 8-hour shift: riding 1 hour, and resting for 1 hour in the van following the riders. The average distance and time ridden in 1 day, based on an estimate of the riders pedaling at 15 mph, was 60–90 miles, or 4 to 6 hours a day. The average total calorie needs for the riders was approximately 5000–5500 calories a day, with at least 65% of the total calories coming from carbohydrate.

I devised a daily regimen that included several meals, many snacks, and lots of fluid. Meals were eaten during a rider's 8-hour shift off, in which the riders would be delivered to the roaming motor home following the team. In the motor home, the riders would eat a solid meal, get a massage, and sleep. Snacks were consumed during the rider's rest hour in the van during his 8-hour shift. Fluids were consumed throughout the day, with a focus on sports drinks while cycling. The meals consisted of high-carbohydrate, moderate-protein foods including items such as spinach lasagna, turkey chili, and yogurt and cheese stuffed potatoes. As the week progressed, the riders' tastes changed, requiring slight modifications to the menu items. The most requested food combination was baked potatoes with raisins, salt, and milk. I would have never guessed that this combination would be so appealing!

The men ate a wide variety of foods throughout the week, supplying a perfect balance of carbohydrate, protein, fat, and fluids. Through daily food records, weigh-ins before and after shifts, and monitoring urine color and quantity, I ensured that the men stayed energized and hydrated. The 70+ Team completed the race in 9 days, 2 hours, and 27 minutes. This achievement granted them the recognition of the first team of men 70 years and older to ever successfully finish the Race Across America.

gaining the performance edge

Carbohydrate needs are determined based on a variety of factors, including total body weight, percentage of total calories, stage of training, and individual health conditions. Consider all of these factors when advising athletes on an appropriate level of daily carbohydrate intake.

hydrate needs will increase. During the competitive season, carbohydrate needs remain high in preparation for hard workouts or events. Later in this chapter, the concept of carbohydrate loading, or supercompensation, which involves increasing the intake of carbohydrates in the days leading up to a competition, is discussed.

Some athletes, such as body builders, maintain a moderate amount of carbohydrate intake during training but decrease carbohydrate intake in the days and weeks leading up to a competition, to create a more lean or "cut" look.

What are the various sources of dietary carbohydrates?

Carbohydrates are found within each food group of the MyPlate food guidance system. The richest sources of carbohydrates are found in the grains, fruits, and vegetables. Most dairy/alternative products, as well as beans, legumes, and nuts from the protein foods group, provide moderate amounts of carbohydrates.

Training Table 3.2: Incorporating Carbohydrate-Rich Whole Grains into Meals/Snacks

- Cook a mixture of old-fashioned oatmeal and bulgur wheat with skim or soy milk and top with dried fruit and nuts.
- Toast whole wheat, spelt, or millet bread and top with peanut butter.
- Stir-fry lean meats or tofu with vegetables and serve over brown rice, whole wheat couscous, or wheat berries.
- Make a complete meal with a dish of whole wheat pasta, garbanzo beans, and roasted/steamed vegetables mixed lightly with olive oil and Italian seasonings.

Sweets, desserts, and sodas—part of the empty calories allowed in the new MyPlate system—provide carbohydrates mainly in the form of simple sugars. Even though carbohydrates are found universally within each food group, it is imperative that athletes choose the most nutrient-dense options within each category for optimal performance and health.

What are the best carbohydrate choices within the grains group?

Most of the foods found in the grains section of MyPlate are excellent sources of complex carbohydrates, fiber, and B vitamins (see **Training Table 3.2**). The key is to choose whole grain products that are more nutrient dense and sustain energy longer than refined carbohydrates. **Table 3.7** lists a variety of healthy whole grain options to choose most often, as well as refined starches to be incorporated sparingly.

TABLE 3.7 The Goodness of Whole Grains

Whole Grains to Choose Often	Refined Grains to Choose Sparingly
Whole wheat bread	White bread
Whole grain cereals	High-sugar cereals
Brown rice	White rice
Whole wheat pasta	White pasta
Barley	Crackers
Bulgur wheat	Croissants
Oatmeal	
Quinoa	
Spelt berries	
Wheat pita bread	
Wheat berries	
Whole grain tortillas	
Whole wheat couscous	

What are the best carbohydrate choices within the fruit and vegetable groups?

In addition to carbohydrates, fruits and vegetables are ideal for athletes because they contain:

- Soluble and insoluble fiber.
- Vitamin C, potassium, and beta carotene.
- A variety of antioxidants and phytochemicals.
- Fewer calories than other carbohydrate sources, for those attempting to lose weight.

Fruits and vegetables can be consumed in many forms (see **Training Table 3.3**). There are benefits and drawbacks to each form: fresh, frozen, canned, dried, and juices. **Table 3.8** outlines the reasons to choose or not to choose each form for a variety of different situations and preferences.

What are the best carbohydrate choices within the dairy/alternative group?

Dairy/alternative foods and beverages provide a convenient mix of carbohydrates and proteins (see

Training Table 3.3: Incorporating Carbohydrate-Rich Fruits and Vegetables into Meals/Snacks

- Keep fresh fruit on hand for quick snacks and complements to breakfast, lunch, or dinner.
- Freeze slightly overripe fruits to blend into smoothies (see Soccer Smoothie recipe) made with other ingredients such as milk, yogurt, peanut butter, or juices.
- Add sautéed vegetables to spaghetti sauce or canned soups.
- Purchase precut vegetables for snacks, stir-fry, salads, or stews.

Soccer Smoothie

1 frozen banana*
8 oz skim or soy milk
1 scoop chocolate-flavored protein powder
1–2 tbsp peanut butter
Place all ingredients in a blender and mix until smooth.
* Peel overripe banana, place in a plastic bag, and freeze overnight beforehand.
Serving Size: 2 cups (Recipe makes one serving)
Calories: 373 kcals
Protein: 32 grams
Carbohydrates: 44 grams
Fat: 10 grams

TABLE 3.8 Pros and Cons of Various Forms of Fruits and Vegetables

Form	Benefits	Drawbacks	When to Include in the Meal Plan
Fresh	Can be enjoyed raw or cooked. Retains nutrients if eaten soon after purchasing. Very flavorful.	Spoils within 7 to 14 days of purchase. Produce shipped from other countries may lose some nutritional value between being harvested and served at the table.	Any time! Raw fruits and vegetables are perfect for snacking. Fruits and vegetables should compose about one-third to one-half of each meal.
Frozen	Frozen soon after harvesting, thus retaining most nutrients. Can be stored in the freezer for 3 to 6 months for convenience and availability year-round.	May not be sustainable for dishes calling for fresh fruits/vegetables or in salads.	Fruits can be used in smoothies or thawed and eaten with yogurt or cereals. Vegetables make quick meals by thawing and heating thoroughly on the stove or in the microwave. Perfect for soups, stews, lasagna, and casseroles.
Canned	Canned soon after harvesting, thus retaining most nutrients. Can be stored for 6 to 12 months for convenience and availability year-round. Do not have to be refrigerated.	Fruits may be canned with added sugars. Look for fruits canned in their own juice. Vegetables are typically canned with sodium or other preservatives. Rinse canned vegetables before serving.	Canned fruits are perfect to keep in a desk drawer or in the car for a quick, easy snack, any time. Canned vegetables can be used for any dish calling for cooked vegetables, or added to sauces, soups, or stews for a vegetable boost.
Dried	Do not require refrigeration. Can be stored for 6 to 12 months or more. Concentrated source of calories.	May not be appropriate for all recipes. High in calories for a small amount of food compared to fresh fruits and vegetables; therefore, may not be the best form for individuals attempting to lose weight.	Add to nuts for a trail mix snack. Keep on hand for a fruit source when fresh fruits are not available. Great for traveling.
Juices	Quick and easy source of fruits and vegetables. Concentrated source of vitamins and minerals compared to whole fruits and vegetables.	Contains significantly more calories per serving than fresh fruits and vegetables. Minimal to no fiber is found in juices.	Ideal for after exercise, providing a dose of fluids, carbohydrates, potassium, vitamin C, and other nutrients. For some, a small amount of juice before exercise settles well and supplies fluid and carbohydrates to sustain effort during exercise.

Training Table 3.4). Most choices from this group are good sources of calcium. Milk is unique because it is an excellent source of calcium as well as vitamin D. Calcium and vitamin D are essential nutrients, especially to athletes participating in weight-bearing sports, providing strength and structure to bones. Dairy foods are produced from a variety of sources, most commonly from the milk of cows. Soy and other grain-derived milk, yogurt, and cheese products are an excellent alternative for those choosing to avoid animal products or for individuals who struggle with lactose intolerance. The soy/grain

Training Table 3.4: Incorporating Carbohydrate-Rich Dairy/Alternatives into Meals/Snacks

- Top yogurt with oatmeal, nuts, or dried fruit for a midday snack or light breakfast.
- Layer fresh fruit, yogurt, and granola in a tall glass for a yogurt parfait.
- Use milk to make hot cereals, tomato soup, or hot chocolate.
- Thinly slice or shred cheese for salads, chili, and sandwiches.

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Athletes should be educated on the benefits and drawbacks of different forms of fruits and vegetables. However, the bottom line is to encourage athletes to eat more fruits and vegetables, in any form they find convenient!

products tend to be low in saturated fat, have no cholesterol, and provide a good source of carbohydrates and proteins. However, the plant sources of dairy alternative products are typically not naturally high in calcium and vitamin D; therefore, look at the Nutrition Facts panel on each dairy alternative product to ensure that it has been fortified with these nutrients.

What are the best carbohydrate choices within the protein foods group?

Beans, lentils, nuts, seeds, and soy products are included in the protein foods group and are excellent sources of carbohydrates (see **Training Table 3.5**). These foods are also a good source of protein, iron, zinc, and fiber. Beef, chicken, fish, eggs, and other animal meats do not contain carbohydrates.

Training Table 3.5: Incorporating Carbohydrate-Rich Protein Foods into Meals/Snacks

- Use extra-firm tofu for spaghetti sauce or casseroles.
- Keep canned beans on hand to toss into salads or pasta dishes.
- Make hummus (see Handball Hummus recipe) from garbanzo, cannellini, or black beans for a quick sandwich spread or dip for vegetables.
- Spread peanut butter on whole grain bread, bagels, or crackers.

Handball Hummus

1 15 oz can of garbanzo beans, drained; reserve liquid
1–2 tbsp liquid from the can of garbanzo beans
1–2 tbsp tahini (sesame seed paste)
1–2 tbsp lemon juice
1 tsp ground cumin
1/2 tsp ground coriander
1/4 tsp ground black pepper
Place all ingredients in a food processor. Blend until smooth. Serve with pita bread, raw vegetables, or as a sandwich spread.
Serving Size: 1/4 cup (Recipe makes eight servings)
Calories: 110 kcals
Protein: 5 grams
Carbohydrates: 16 grams
Fat: 3 grams

Can foods containing simple sugars or artificial sweeteners be used as a source of carbohydrates?

Some sugary or sweet foods can serve as sources of carbohydrates (see **Training Table 3.6**). Candies, desserts, jellies, and regular sodas contain carbohydrates in the form of simple sugars but are otherwise void of nutrient value. These foods complement other foods to make meals and snacks more flavorful and enjoyable. Sweets and sodas do not need to be permanently excluded from the diet but should be used sparingly. Diet sodas, desserts, and snacks replace sugar with artificial sweeteners, thus providing minimal or no carbohydrates. Diet foods can be incorporated into a healthy diet, but should also be used sparingly to make room for carbohydrate-rich and nutrient-dense foods.

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Dietary carbohydrates can be obtained from a variety of foods throughout the MyPlate food guidance system. Each food group provides a unique blend of carbohydrates and other nutrients. Athletes should focus on the most nutrient-dense carbohydrate sources, including whole grains, fruits, vegetables, low-fat dairy/alternatives, beans/legumes, and nuts.

What are the glycemic index and glycemic load, and how can they be used in sports nutrition?

There has been much interest in both the lay and scientific literature about the glycemic index of foods. In the quest for the optimal diet for sport performance, researchers have been discovering information about the different types of carbohydrate foods and the timing of these foods that may be beneficial to athletes. The glycemic index and the glycemic load can provide guidance to athletes to help them make appropriate carbohydrate choices. These concepts, combined with other solid nutrition practices, have

Training Table 3.6: Incorporating Moderate Amounts of Carbohydrate-Rich Sweets into Meals/Snacks

- Use 1–2 teaspoons of jelly on toasted whole grain bread or muffins.
- Enjoy 1–2 small cookies with milk as a bedtime snack.
- Bake oatmeal cookies with a few chocolate chips.
- Savor a bite-sized candy bar instead of a full-size bar after a meal.

glycemic index (GI) An index for classifying carbohydrate foods based on how quickly they are digested and absorbed into the bloodstream. The more quickly blood glucose rises after ingestion, the higher the glycemic index.

the potential to improve sport performance.

The glycemic index (GI) indicates how much a certain food raises blood glucose levels when consumed in isolation. The index is calculated by measuring the incremental area under the blood glucose curve following ingestion of a test food that provides 50 grams of carbohydrates, compared with the area under the curve following an equal carbohydrate intake from a reference food.[24] Glucose and white bread are most often used as the food standard, given a GI value of 100, to which all other foods are compared. Accordingly, a GI of 70 indicates that consuming 50 grams of the food in question provides an increase of blood glucose 70% as great as that for ingesting 50 grams of pure glucose.[25] GI testing occurs after an overnight fast. The GI ranking of specific foods is based on the measurement of the blood glucose response 2 hours after the sample food is ingested. Information in **Table 3.9** is excerpted from Foster-Powell et al.'s extensive compilation of data on the GI of foods.[26] Their research, published between 1981 and 2001, contained nearly 1300 entries of more than 750 different types of foods. Table 3.9 provides a small sample of foods that have had GI testing completed.

TABLE 3.9 Glycemic Index and Glycemic Load of Common Foods

Food	Glycemic Index (glucose = 100)	Glycemic Index (white bread = 100)	Glycemic Index Category*	Serving Size (g)	g CHO/ Serving	Glycemic Load
White bread, Wonder Bread	73 ± 2	105 ± 3	High	30	14	10
White rice, boiled	64 ± 7	91 ± 9	High	150	36	23
Couscous	65 ± 4	93 ± 6	High	150	35	23
Gatorade	78 ± 13	111	High	250 mL	15	12
Ice cream	61 ± 7	87 ± 10	High	50	13	8
Sweet potato	61 ± 7	87 ± 10	High	150	28	17
Baked potato, russet	85 ± 12	121 ± 16	High	150	30	26
Cranberry juice cocktail	68 ± 3	97	High	250 mL	36	24
Grapenuts	71 ± 4	102 ± 6	High	30	21	15
Cornflakes	81 ± 3	116 ± 5	High	30	26	21
Blueberry muffin	59	84 ± 8	High	57	29	17
Power bar	56 ± 3	79 ± 4	Med	65	42	24
Honey	55 ± 5	78 ± 7	Med	25	18	10
White rice, long grain	56 ± 2	80 ± 3	Med	150	41	23
Coca-Cola	58 ± 5	83 ± 7	Med	250 mL	26	16
Sweet corn	54 ± 4	78 ± 6	Med	80	17	9
Carrot	47 ± 16	68 ± 23	Med	80	6	3
New potato	57 ± 7	81 ± 10	Med	150	21	12
Banana	52 ± 4	74 ± 5	Med	120	24	12
Orange juice	50 ± 4	71 ± 5	Med	250 mL	26	13
Chickpeas	28 ± 6	39 ± 8	Low	150	30	8
Kidney beans	28 ± 4	39 ± 6	Low	150	25	7
Xylitol	8 ± 1	11 ± 1	Low	10	10	1
Lentils	29 ± 1	41 ± 1	Low	150	18	5
Chocolate cake, frosted	38 ± 3	54	Low	111	52	20
Fructose	19 ± 2	27 ± 4	Low	10	10	2
Tomato juice	38 ± 4	54	Low	250 mL	9	4
Skim milk	32 ± 5	46	Low	250 mL	13	4
Smoothie, raspberry	33 ± 9	48 ± 13	Low	250 mL	41	14
Apple	38 ± 2	52 ± 3	Low	120	15	6

*Category = High (>85); Medium (60–85); Low (<60) using GI white bread = 100.

Source: Adapted from Foster-Powell K, Holt SHA, Brand-Miller JC. International table of glycemic index and glycemic load values. *Am J Clin Nutr*. 2002;76:5–56.

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Unfortunately, the GI of individual carbohydrate foods cannot be determined based simply on their classification as a mono-, di-, or polysaccharide. Similarly, it is too simplistic to instruct people to eat more complex carbohydrates than simple carbohydrates to help keep glycemic response low. Fiber, protein, and fat content, along with other factors, can affect the GI of carbohydrate foods (see Table 3.10). The GI of foods appears to be much more complex than initially thought and is not an easy way to categorize food. As a result, its use in daily dietary practice is of little practical value. However, it is an additional way to obtain information about the carbohydrate content of foods. The GI, when used in conjunction with food-labeling information and food preferences, can be an effective way to help athletes make healthy carbohydrate choices.

What is glycemic load?

The concept of glycemic load was introduced in 1997 to determine whether the overall glycemic effect of a diet, not just the carbohydrate content, is related to disease risk.[27] Researchers defined dietary glycemic load as the product of the GI of food and the amount of carbohydrates in a serving. Therefore, an individual food that has an established GI and a known amount of carbohydrates in the serving size tested can also have a glycemic load number. Table 3.9 contains both the glycemic index and glycemic load values for selected foods. By summing the glycemic load of individual foods consumed throughout one day, the overall glycemic load of the whole diet can be calculated.[28] Thus, glycemic load looks at the impact of carbohydrate consumption, taking the GI into consideration.

glycemic load A way of assessing the overall glycemic effect of a diet based on both the glycemic index and the number of carbohydrates provided per serving for each food ingested.

Glycemic Load = (GI × carbohydrate content per serving)/100

Brand-Miller and colleagues studied 30 lean, healthy volunteers to test the assumptions that (1) portions of different foods calculated to the same glycemic load produce similar blood glucose responses and (2) stepwise increases in glycemic load produce proportionate increases in both glycemia and insulinemia.[28] The subjects were split into two groups to research these two assumptions separately.

In the first study, 10 different food portions having the same glycemic index as one slice of white bread (GI of 70, 15 grams of carbohydrates) or a glycemic load of 10.5 were compared. Ten subjects consumed each food portion on different occasions

TABLE 3.10 Factors Affecting the Glycemic Index of Foods

Factor	Explanation
Type of carbohydrate	The glycemic index of individual carbohydrate foods cannot be determined based simply on their classification as simple (i.e., mono- or disaccharides) or complex (i.e., polysaccharides) because some complex carbohydrates have higher glycemic indexes than simple ones.
Fiber content	Typically, high fiber content lowers the glycemic index of a food.
Fiber type	Soluble fiber tends to lower the glycemic index of a food more so than insoluble fiber.
Protein content	The higher the protein content of a carbohydrate food or meal, the lower the glycemic index.
Fat content	The higher the fat content of a carbohydrate food or meal, the lower the glycemic index.
Form of the food (i.e., liquid versus solid)	Liquid sources of carbohydrates tend to have higher glycemic indexes than solid foods of similar carbohydrate makeup.
Timing of the meal	The time since the last meal can affect the glycemic index of carbohydrate foods.
Food combinations	Combining a high-carbohydrate food with other foods greatly alters the glycemic index of the food compared to if it were eaten alone. Typically, mixing carbohydrate sources with foods containing proteins and fats lowers the glycemic index. Consuming different carbohydrate foods at the same time also can affect the glycemic index compared to if the carbohydrate food had been eaten singularly.
Amount of carbohydrate consumed	The glycemic index of a carbohydrate source can be altered by the quantity of carbohydrate ingested (i.e., glycemic load).

in random order several days apart. The test foods were selected to provide a wide range of carbohydrate content and glycemic index. The foods tested were white bread, rice, spaghetti, cornflakes, yogurt, jellybeans, bananas, lentils, baked beans, and orange juice. The glucose responses to 9 out of 10 foods fed at the same glycemic load as one slice of white bread did not differ. However, lentils resulted in an unexpectedly lower response than the other foods.

The second study used the other 20 volunteers who consumed two sets of five foods, one of which was white bread, to determine dose–response relationships for four variables: subject, dose, food, and order. The foods in the two different sets in this study were the same as those in the first study. Increasing the glycemic load (dose level) affected the glucose response within both sets of food and also had a significant influence on insulin response. The authors suggest that these findings provide the first evidence of the physiological validity of the glycemic load concept because, with one exception (lentils), the 10 foods fed at the same glycemic load as one slice of white bread produced relatively similar glycemic responses. Stepwise increases in glycemic load (from the GI equivalent of one to six slices of bread, regardless of food source) gave predictable increases in glycemia and insulinemia. These findings are relevant to the assumption that the overall glycemic and insulinemic effect of a diet can be calculated from the GI and the amount of carbohydrates per serving.

The authors of this combined study noted that glycemic load remains controversial because it is a mathematical calculation based on an already controversial approach to classifying foods, the GI. However, much more research into the GI has been done since then, and many more foods have been tested and assigned a GI value. So, despite its controversial beginnings, the GI is now widely recognized as a reliable, physiologically based classification of foods according to their postprandial glycemic effects.[26] In fact, the 2005 Dietary Reference Intake (DRI) report on macronutrients extensively refers to the glycemic index because many studies have been conducted using this classification system.[20]

As mentioned, the glycemic load can be calculated for any food that has a GI value. However, there are many influences that affect individual responses to the glycemic load, including factors that could slow carbohydrate absorption, the total glycemic load of a meal or several meals throughout the day, and the differences in single serving sizes that people typically consume that may be very different from the portions tested to establish a GI for individual foods. The glycemic load data should be used cautiously to account for these variances, and health professionals and researchers should calculate their own glycemic load based on the types of foods and portion sizes consumed.

Does glycemic kinetics affect the glycemic index?

Closer study into the glycemic effects of foods indicates that the GI values of specific foods may not be just an indication of how quickly the carbohydrate source is digested and absorbed into the bloodstream. Emerging research into glucose kinetics reveals that glucose levels in the blood are dependent not only on the rate of appearance of glucose from the gut, but also on the rate of disappearance based on uptake by cells. Schenk et al.[29] compared the effects of low- and high-glycemic breakfast cereals on blood glucose levels, blood insulin levels, and glucose uptake rates for 3 hours after ingestion. Six healthy males consumed high-GI cornflakes (CF) and low-GI bran cereal (BC) containing 50 grams of carbohydrates on separate days. After ingestion, the plasma glucose concentration was significantly lower for BC (low GI) than CF (high GI). In fact, the GI for CF was more than twice that for BC. Although on first blush this finding seems to support the fact that high-GI foods release glucose more quickly into the blood, glucose kinetic measures of glucose appearance rates did not support this. The appearance rate of glucose into the bloodstream was not different between the high- and low-GI cereals. However, a difference was found in the plasma insulin levels and glucose uptake rates. It is interesting to note that insulin levels in the blood were actually 76% higher and glucose uptake rates were 31% higher after ingestion of the low-GI BC compared to the high-GI CF cereal, thus the reason for the lower GI. These findings indicate that GI values are not merely an indicator of how quickly different carbohydrates are digested and released from the gut into the bloodstream. Whether the glucose kinetics of the cereal foods used in this study are representative of other carbohydrate foods is unknown, and other studies will have to be performed. However, it is important for sports nutrition professionals to be aware of growing developments regarding the GI, what it means, and how it can be used. Knowledge of the current ambiguities regarding the GI will prevent overuse or abuse of the index in sports and will, it is hoped, prevent the abandoning of sound dietary advice for athletes.

How does the glycemic index relate to exercise?

The extensive amount of information about the GI has led researchers to test whether the GI of foods is helpful to active individuals. Because carbohydrates are a primary fuel for athletes, especially during high-intensity or long-duration exercise, it has been suggested that manipulating the diet using GI information may improve sport performance. The goal of using the GI is to optimize carbohydrate availability before, during, and after exercise.

Preexercise meals with a low GI may be best for athletes. When DeMarco et al. compared trained cyclists who had either a high-GI or low-GI meal prior to a 2-hour cycling bout and exercise to exhaustion, the low-GI group had higher glucose levels at 120 minutes and cycled significantly longer in the exhaustion test.[30] Other researchers have studied the effects of the consumption of a single low-GI food on long-duration exercise and have found similar results.[31–33] Recent studies reporting an enhanced performance after consuming a low-GI meal often attribute the gains to an increase in fat oxidation compared to the consumption of a high-GI meal.[34,35] However, not all research has been able to establish a direct link between metabolic changes caused by a low-GI meal and increased work output or time to exhaustion during performance tests.[32,36,37] More information is needed before precise recommendations regarding the GI of preexercise meals for athletes can be formulated.

During exercise, muscles depend on the quick delivery of ingested carbohydrates for the continuation of high-intensity or long-duration efforts. Therefore, carbohydrate-rich foods and/or sports drinks of moderate to high GI are the most appropriate. Consuming low-GI foods during exercise may lead to decreased performance and early cessation of exercise.

After exercise, the focus is placed on nutrition for optimal recovery. Carbohydrate consumption immediately after exercise is critical for glycogen replenishment. Consumption of medium- and high-GI foods can help athletes replenish carbohydrate stores as quickly as possible. It has been suggested that athletes should consume 50–100 grams of high-GI carbohydrates immediately following intense, glycogen-depleting exercise.[38] Although studies have supported this recommendation, it appears that differences in recovery are found primarily in the 6 to 24 hours following exercise.[39] After 24 hours, glycogen replenishment from low- and high-GI meals may be similar.[40]

Using the GI of foods to help athletes improve sport performance appears to have some merit. However, there are also some limitations. Most GI studies have been conducted using human subjects who are not exercise trained. The responses to GI in trained versus untrained individuals could be very different. In general, trained individuals have more muscle mass and are more insulin sensitive than are untrained individuals. In addition, not all research reports a direct correlation between the GI of foods consumed before, during, and after exercise and enhanced athletic performance.[41]

Not all foods have been tested and ranked in the GI system. Many factors affect the GI and can ultimately influence the glucose and subsequent insulin response in the bloodstream. Glycemic load and glycemic kinetics are newer concepts that may in the future help to determine more clearly how different foods, timing of meals, and the amount of carbohydrates affect the glucose response.

In practical terms, a variety of low-, moderate-, and high-GI foods contain a variety of nutrients, soluble and insoluble fiber, and phytochemicals that are beneficial to the body. Educating athletes about these health benefits, while incorporating recommendations on carbohydrate intake for sport performance, will help athletes stay healthy and perform optimally.

How are carbohydrates utilized during exercise?

Whether an athlete is engaging in long-duration endurance activities, intermittent exercise, or short-duration, high-intensity power sports, carbohydrates are needed to supply fuel to the muscles and brain. In regard to oxygen consumption, carbohydrates produce energy in a more efficient manner than fats or proteins. Athletes who eat lower levels of carbohydrates find that workouts become harder to complete, mental focus is more difficult, energy levels drop, and muscles feel fatigued.

The body prefers to use carbohydrates as fuel during exercise. Depending on the intensity of the exercise, carbohydrates may be broken down for energy via aerobic or anaerobic means. At low to moderate exercise levels, carbohydrates are primarily aerobically metabolized for energy. Each glucose molecule passes through glycolysis, where it is broken down to pyruvate. From there the pyruvate is converted to acetyl coenzyme A (CoA) and enters into the citric acid cycle. The citric acid cycle strips

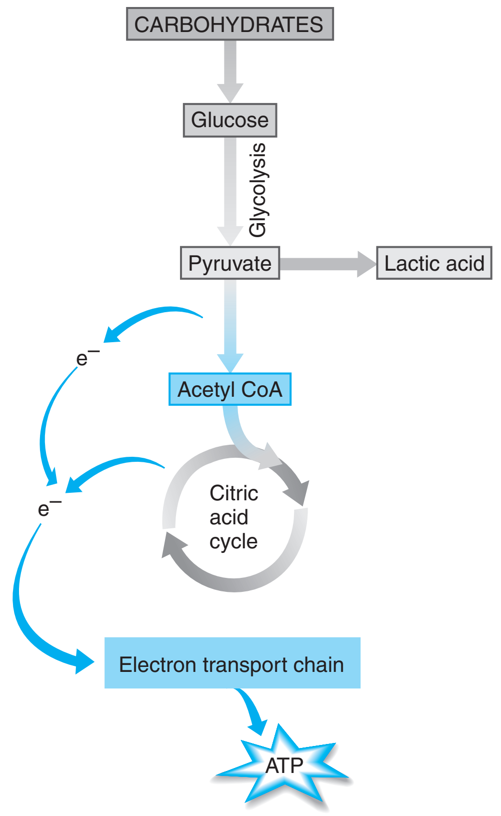

Figure 3.7 Carbohydrate metabolic pathways. The citric acid cycle strips hydrogen from the carbon structure of the acetyl CoA, leaving the carbon atoms to bind with oxygen to form CO_2. The hydrogen is then carried to the electron transport chain, where it is used to create energy in the form of ATP.

hydrogens off the carbon structure of the acetyl CoA, leaving the carbon atoms to bind with oxygen to form CO_2. The hydrogens are carried to the electron transport chain, where they are used to create energy in the form ATP. In the process of transferring hydrogens, water is formed (see Figure 3.7).

At rest and during low exercise intensities (< 20% of aerobic capacity), fatty acids play a major role in energy production along with carbohydrates. However, when exercise intensities increase to 40–60% of VO_2max, carbohydrates become the major source of energy. The point at which carbohydrates take over as the primary energy source is called the **crossover point**.[42] As depicted in Figure 3.8, activities to the left of the crossover point rely primarily on fats for energy. Endurance training causes adaptations in the body that cause the crossover point to move to the right. In other words, trained endurance athletes can exercise or perform at

crossover point The point on an increasing continuum of exercise intensity where fats and carbohydrates each contribute 50% of the needed energy and beyond which carbohydrates become the predominant energy source.

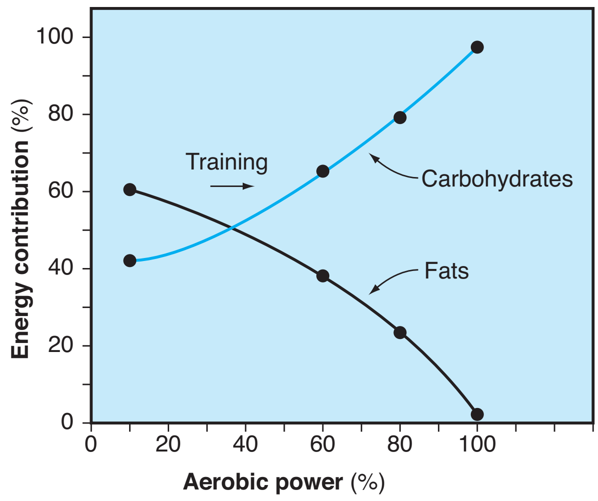

Figure 3.8 Carbohydrate and fat utilization at varying intensities of exercise. The point at which carbohydrates take over as the primary energy source is called the crossover point. Endurance training can shift the crossover point to the right.
Sources: Adapted from Brooks GA, Mercier J. Balance of carbohydrate and lipid utilization during exercise: the "crossover" concept. *J Appl Physiol.* 1994;76(6):2253–2261. American Physiology Society.

higher intensities and rely more on fats than carbohydrates for energy than untrained individuals. This is important because the body's carbohydrate stores are limited, and when the muscles deplete their glycogen stores, they fatigue. Because endurance training increases the body's ability to use fats for energy, it helps to spare glycogen and thus delays fatigue, which improves endurance performance.

During the most intense activities, such as an all-out sprint, carbohydrates are the only macronutrient that can be metabolized fast enough to provide energy. The energy comes from the anaerobic breakdown of glucose to lactic acid (see Figure 3.7). This metabolic pathway is capable of producing energy very rapidly and thus can supply the energy needed in activities that require rapid production of ATP. Because most sports require bursts of intense activity that draw energy from anaerobic metabolism, restricting carbohydrates from an athlete's diet is tantamount to performance suicide.

How much carbohydrate is stored within the body?

As previously discussed, carbohydrates are stored in the body as glycogen. Unfortunately, compared to fats, the other major source of energy in the body, very little glycogen is stored. The body may be able to store a total of only 400–600 grams of carbohydrates in the liver and muscle.[43] This amounts to about 1600–2400 kcal (4 kcal per gram of carbohydrate) depending on body size, time of day, and dietary intake. Although 1600–2400 kcals sounds like a lot, it should be noted that only about 400–500 kcals are actually directly available to be used for maintaining blood glucose levels. The remaining 1200–1900 calories from glycogen are found in the muscle cells, which are very stingy about sharing their glycogen. In other words, muscle cells are not capable of releasing stored glucose directly into the bloodstream. Unlike in liver cells, which can release glucose back into the blood to help to maintain glucose levels between meals, once glucose is taken into the muscle cell, it cannot be directly released back into the bloodstream. Therefore, once the liver is depleted of glycogen, blood glucose levels begin to decrease. Conversely, fat cells, known as **adipocytes**, store an estimated 90,000 kcals of energy and are capable of sharing their stored energy with the rest of the body. Because carbohydrates are such an important fuel for the exercising muscle and so little is stored in the body, individuals need to be aware of ways to improve both circulating and storage forms of carbohydrates for success during training and competition.

adipocyte A single fat cell.

Why are carbohydrates an efficient fuel source?

Carbohydrates are a good source of rapid energy for several reasons. One reason is that carbohydrates are actually stored in the muscle cells themselves. This means they are readily available to provide energy at the very outset of exercise, unlike most fats, which are stored at remote sites in the body and must be delivered via the bloodstream.

Another reason carbohydrates are such an efficient fuel is that they can provide energy for a short period of time without the need for oxygen. To get energy for exercise or sports from fats, our cells must have oxygen. Without adequate amounts of oxygen being delivered to the muscles, fats and, to a lesser extent, proteins cannot produce enough energy to support intense exercise. Fortunately, not only are carbohydrates readily available for energy, but also muscle cells can break down carbohydrates for energy without oxygen being present. This is known as anaerobic metabolism.

Finally, when carbohydrates are broken down in the presence of adequate oxygen, because of the chemical makeup of carbohydrates compared to fats, less oxygen is needed. A person's aerobic exercise rate is limited by how fast oxygen can be delivered to muscle cells, so it is better to rely on carbohydrates because less oxygen is needed.

Does carbohydrate intake enhance performance?

There is no question about the importance of carbohydrates in sport performance. In fact, athletes who practice a diet that restricts carbohydrates for a long period of time are severely hindering their preparation for and performance in their sport. A review of the earlier section on the role of carbohydrates gives hints to this fact. Regardless of the sport or its energy requirements, a positive mental attitude and energetic approach to training are required on an ongoing basis if improved sport performance is the goal. Depleted muscle glycogen levels and low blood glucose levels lead to loss of mental focus, feelings of weakness, and thus ineffective training.

Does carbohydrate intake delay fatigue?

The answer to this question is a resounding yes, if the fatigue is the type experienced by many endurance athletes. As noted earlier in this chapter (see the section "What functions do carbohydrates serve in the body?"), carbohydrates, namely glucose, are an important source of energy during exercise. Because carbohydrates are an important energy source, the body stores them as glycogen in the liver and muscles. Liver glycogen is important for maintaining blood glucose levels between meals and during exercise, thereby providing a relatively constant supply of energy to muscles and other tissues. The muscle glycogen stores serve as readily available energy sources for muscle during activity. Exercise and/or diet can greatly affect glycogen levels (see Figure 3.9). A diet high in carbohydrates can lead

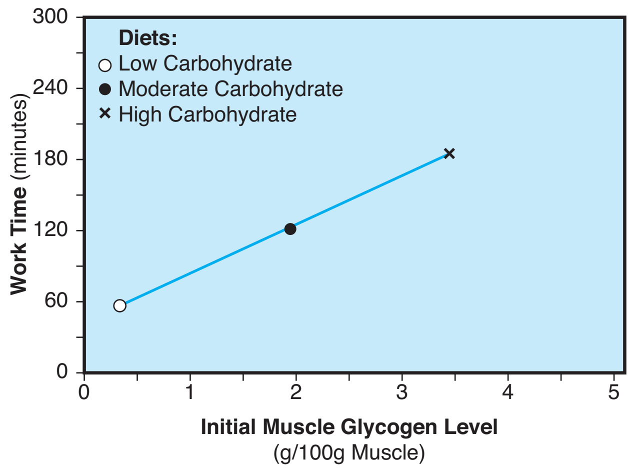

Figure 3.9 Diet composition, muscle glycogen levels, and time to fatigue. The muscle glycogen stores serve as readily available energy sources for muscle during activity. Exercise and/or diet can greatly affect glycogen levels.
Source: Data from Astrand PO. Diet and athletic performance. *Federation Proc.* 1967;26:1772–1777.

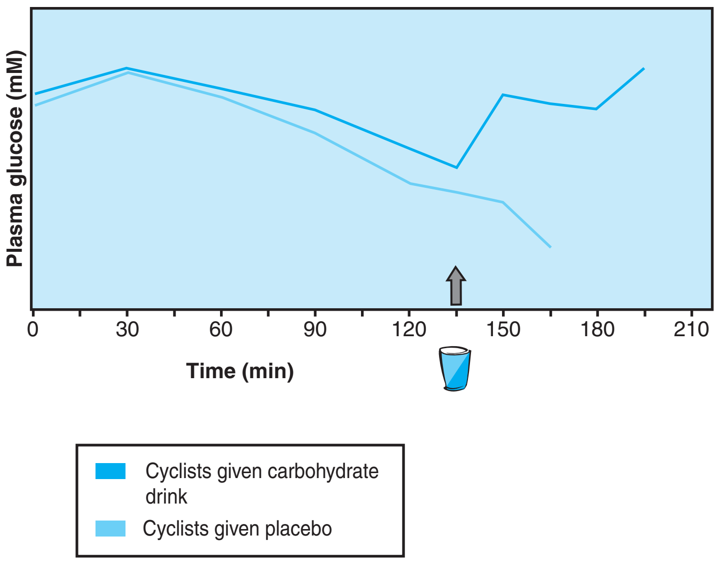

Figure 3.10 Carbohydrate sports drinks and performance. Blood glucose levels begin to fall below resting levels after 90 minutes. Subjects who consumed carbohydrate drinks (135 minutes) had dramatically increased blood glucose levels, whereas levels continued to decrease in subjects fed a placebo. *Source:* : Reproduced from Coggan AR, Coyle EF. Metabolism and performance following carbohydrate ingestion late in exercise. *Med Sci Sports and Exerc.* 1989;21(1):59–65. Reprinted with permission from Wolters Kluwer.

to increased glycogen stores in both the liver and the muscle, whereas one that is low in carbohydrates can decrease glycogen levels. Depletion of glycogen stores at either of these locations can negatively affect performance. Figure 3.9 clearly indicates that the carbohydrate composition of a diet affects initial muscle glycogen levels and that high glycogen levels can significantly increase the amount of time until exhaustion in an exercising athlete. In fact, this is the main reason why carbohydrate loading is practiced by endurance athletes in the days leading up to an event. It is not that extra glycogen in the muscle cells makes endurance athletes faster; it just enables them to maintain their race pace for a longer period of time, which translates into faster race times.

Ingestion of carbohydrates during activity is also critical for delaying fatigue in endurance sports.[44] Over time, the liver's glycogen stores begin to decrease because of the increased demand for glucose. As the liver's glycogen stores near depletion, its ability to maintain blood glucose levels decreases and work output diminishes. If exercise persists after liver glycogen is depleted, muscles will continue to use available blood glucose for energy. Eventually, blood glucose levels will fall below normal levels, causing hypoglycemia (low blood sugar). Signs and symptoms of low blood glucose include hunger, dizziness, shakiness, headache, and irritability. If carbohydrate intake remains insufficient and glucose levels continue to drop, unconsciousness, coma, and death can result.

As shown in Figure 3.10, after about 90 minutes of exercise, which corresponds to the amount of time it takes to severely diminish liver glycogen stores, blood levels of glucose begin to fall below resting levels (i.e., Time = 0 minutes). However, when a glucose polymer drink was ingested at minute 135, blood glucose increased to levels comparable to those earlier in the exercise session. Helping the body to maintain blood glucose levels through carbohydrate ingestion during exercise can, in turn, translate into sustained effort and thus enhanced performance.[44] Figure 3.10 clearly demonstrates the importance of consuming carbohydrates during activity and its impact on blood glucose.

Power sports are those that require very short bursts of intense activity. The most extreme examples of power sports are shot put, discus, Olympic weightlifting, and the 100-meter sprint. In power sports, reliance on stored glycogen for energy is very low, and thus glycogen depletion in regard to performance is not necessarily of concern. However, a strong argument can be made for the impact carbohydrates have on the preparation (i.e., the intense training required) for the sport competition. Diets low in carbohydrates combined with frequent intense training can, over time, diminish muscle and liver glycogen levels and lower blood glucose levels. Low blood glucose decreases overall energy level, motivation to train, and the mental focus needed for high-intensity training. In addition, decreased muscle glycogen levels can lead to feelings of chronic fatigue and thus decreased training intensity levels. The end result is suboptimal sport preparation, and thus poor competition performance.

What type, how much, and when should carbohydrates be consumed before exercise?

To perform optimally, adequate amounts of carbohydrates need to be supplied to the body prior to exercise. The source, quantity, and timing of the carbohydrates ingested can lead either to a high-energy, high-performance exercise session or to a feeling of staleness and fatigue. Proper nutrition before exercise focuses on the quantity and type of food consumed in the days leading up to a workout or event. Also of importance is the timing between

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Listen and learn about athletes' food/beverage likes and dislikes. Encourage them to experiment with a variety of carbohydrate-rich meals, snacks, and sports beverages during training to determine the best option for optimal performance on race day.

eating and exercise. The key to optimal nutrition before, as well as during and after, exercise is individualization. Each person has likes and dislikes, tolerances and intolerances. There is not one "best" pregame meal, sports beverage, or postexercise snack. However, by following a few guidelines and lots of experimentation, athletes can determine the nutrition plan that best fits their sport and lifestyle.

What should an athlete eat on the days leading up to an important training session or competition?

It is widely recognized that exercise performance will be enhanced when preceded by several days of a high-carbohydrate diet. It is critical to consume adequate amounts of carbohydrates in the days, as well as the hours, leading up to an exercise session or competition to maximize energy levels and performance.

As mentioned previously, research has shown that by increasing glycogen stores prior to exercise, athletes can increase the time to fatigue and enhance performance during prolonged, strenuous exercise (see Figure 3.9). The term **carbohydrate loading** has traditionally referred to the process of muscle glycogen supersaturation and has been shown to increase glycogen levels above normal, thus allowing athletes to perform longer before fatiguing. For example, the glycogen content of skeletal muscle in an untrained individual, consuming a balanced diet, is typically around 80 mmol/kg of muscle wet weight. An adaptation of regular exercise training is the ability for muscles to store more glycogen. Therefore, trained individuals generally have muscle glycogen levels of ~125 mmol/kg. However, during tapering and carbohydrate loading, when exercise is decreased so that less glycogen is used on a daily basis and carbohydrate intake is simultaneously increased, glycogen stores can be boosted to levels of 175–200 mmol/kg of muscle wet weight.[45]

carbohydrate loading A high-carbohydrate dietary plan commonly used by endurance athletes that is designed to engorge muscle cells with glycogen.

The concept of carbohydrate loading was first investigated by Bergstrom and colleagues in the late 1960s.[46] Although he found his 6-day regime to be effective at packing the muscle cells with up to two times their normal glycogen concentration, the two exhaustive exercise bouts and the first 3 days of low carbohydrate ingestion were found to be physically and mentally taxing to the athletes. Since then several modified versions of the original (i.e., classical 6-day protocol) have been developed with the intent of making it easier on the athlete and thereby avoiding the unwanted side effects (e.g., muscle soreness, fatigue, poor mental attitude). See **Table 3.11** for details on a few of the modified carbohydrate-loading regimes.

Much of what is known about carbohydrate loading has been derived from studies involving male subjects. It is interesting to note that studies involving carbohydrate loading in females have yielded equivocal results. It appears that for effective carbohydrate loading to occur in females close attention must be paid to the total energy intake, level of carbohydrate intake, and phase of the menstrual cycle.[47] Female athletes who increased their normal total energy intake by 34%, and at the same time maintained a carbohydrate intake of 75% of total calories, demonstrated muscle glycogen increases comparable to males.[48] It has also been reported that carbohydrate loading is more effective during the luteal phase rather than the follicular phase of the menstrual cycle. The difference in the glycogen loading within the cells seems to be related to the differences in hormonal levels that exist between the menstrual phases.[49] In fact it has been reported that women taking oral contraceptives may have an advantage when it comes to carbohydrate loading due to the muting of hormonal differences between the menstrual phases.[47,50]

An athlete must take into consideration that temporary water weight gain may occur with carbohydrate loading. Muscles store 3 grams of water for every 1 gram of carbohydrate. Some individuals find that the extra water weight contributes to a bloated feeling and a sense of stiffness, which may negatively affect performance. Instead, "loading" the muscles with carbohydrates can be viewed as a daily component of training. If an athlete consumes 55–70% of total calories from carbohydrates daily, muscles may be consistently "topped off," therefore not requiring an alteration to normal eating immediately prior to an event.

What should an athlete eat in the hours leading up to an important training session or competition?

The 24 hours leading up to an important training session or competition are a critical time for carbohydrate-rich meals. By understanding the

TABLE 3.11 Methods of Carbohydrate (CHO) Loading

CHO Loading Regimen	Requires Exhaustive Exercise or Glycogen Depletion	Exercise Protocol	Diet Details	Reference
Classic 6-day	Yes	Day 1 involves an exhaustive bout of exercise; days 2 and 3 involve moderate submaximal exercise; day 4 involves another exhaustive exercise bout; no exercise on days 5 and 6.	First 3 days low-CHO diet (~15% total calories); next 3 days high-CHO diet (~70% total calories)	Bergstrom et al.[a]
6-day	No	First 3 days involve intense submaximal exercise of decreasing duration. Day 1 involves 90 minutes exercise; days 2 and 3 require 40 minutes of exercise. Next 2 days only 20 minutes of submaximal exercise. Last day no exercise.	First 3 days mixed diet (~50% CHO); next 3 days high CHO (~70% of total calories)	Sherman et al.[b]
Classic 3-day	Yes	Exhaustive bout of exercise followed by 3 days of no exercise.	3 days of high CHO intake (~70% total calories)	Ahlborg et al.[c]
Modified 3-day	No	No exercise for 3 days.	3 days of high CHO (10 g of CHO/kg of body weight per day)	Burke et al.[d]
1-day	No	No exercise for 1 day.	1 day of high CHO (10 g of CHO/kg of body weight per day)	Burke et al.[e], Bussau et al.[f]

[a]Bergstrom J, Hermansen L, Hultman E, Saltin B. Diet, muscle glycogen, and physical performance. *Acta Physiol Scand.* 1967;71:140–150.
[b]Sherman WM, Costill DL, Fink WJ, Miller JM. Effect of exercise–diet manipulation on muscle glycogen and its subsequent utilization during performance. *Int J Sports Med.* 1981;2(2):114–118.
[c]Ahlborg B, Bergstrom J, Brohult J, Ekelund LG, Maschio G. Human muscle glycogen content and capacity for prolonged exercise after different diets. *Forsvarsmedicin.* 1967;3:85–99.
[d]Burke LM, Hawley JA, Schabort EJ, Gibson ASC, Mujika I, Noakes TD. Carbohydrate loading failed to improve 100-km cycling performance in a placebo-controlled trial. *J Appl Physiol.* 2000;88:1284–1290.
[e]Burke LM, Angus DJ, Cox GR, Cummings NK, Febbraio MA, Gawthorn K, Hawley JA, Minehan M, Martin DT, Hargreaves M. Effect of fat adaptation and carbohydrate restoration on metabolism and performance during prolonged cycling. *J Appl Physiol.* 2000;89(6):2413–2421.
[f]Bussau VA, Fairchild TJ, Rao A, Steele P, Fournier PA. Carbohydrate loading in human muscle: an improved 1 day protocol. *Eur J Appl Physiol.* 2002;87:290–295.

importance to performance and the general guidelines for intake, athletes can perfect their ideal preexercise meal/snack routine.

4 to 24 hours prior to exercise, training, or competition

Four to 24 hours prior to exercise, foods high in carbohydrates should compose a majority of each meal and snack, providing approximately 60–70% of total calories. Eating high-carbohydrate foods during this time frame will help to "top off" glycogen stores in the muscles and liver, allowing athletes to start an exercise session with a full tank of "energy fuel."

In addition to carbohydrates, proteins and fats play a role in preexercise meals 4 to 24 hours before activity. By incorporating protein- and fat-containing foods, the athlete ensures balance and moderation. Proteins and fats also contribute to the feeling of satiety, preventing the athlete from overeating.

Especially when competing, athletes should consume meals and snacks consisting of familiar foods in the 24 hours prior to the event. There should be no trial-and-error at this time; meals and snacks should be planned weeks in advance after experimentation to find the optimal blend and type of solid foods and liquids. Eating or drinking unfamiliar foods in the 24 hours before an event can lead to unwanted gastrointestinal distress, such as indigestion, upset stomach, diarrhea, and cramping. Any of these symptoms will certainly compromise an athlete's ability to perform to his or her potential.

0 to 4 hours prior to exercise

At this point, carbohydrate stores are at their peak prior to exercise, and the focus shifts to foods and beverages that will digest easily and prevent the athlete from feeling hungry at the beginning of a training session or competition (see **Training Table 3.7**). Athletes should strive to consume 1–4 grams of carbohydrate per kilogram of body weight in the 1 to 4 hours prior to exercise.[21,51–54] Specific recommendations within these ranges will be based on individual tolerance. Athletes should be encouraged to experiment with varying quantities of carbohydrate and timing of intake during training to devise a plan for game day.

In the 1 to 4 hours prior to exercise, athletes should consider including the following foods:

- *Complex carbohydrates:* Carbohydrates consumed at this time will be used to elevate blood glucose levels for the start of an exercise session. Choose foods that are easy to digest and relatively low to moderate in fiber. Low GI carbohydrates may be best before exercise to avoid a spike in blood glucose and subsequent blood insulin levels immediately prior to exercise.[30–33]
- *Carbohydrate-rich protein sources:* Protein will help to maintain blood glucose levels by delaying the digestion and absorption of carbohydrates after the meal. Foods that contain both carbohydrates and protein include dairy products, dairy alternative products, soy products, and legumes. Legumes should be consumed in small amounts because they are packed with fiber, which can cause gastrointestinal discomfort in some athletes.
- *Fluids:* Approximately 2 cups of fluid should be consumed 2 hours prior to exercise. In addition, aim for 1 cup of fluid 1 hour prior and 7 ounces of fluid 30 minutes prior to exercise. Water, milk, and juice are the best choices in the 2 to 4 hours before exercise. Water provides fluid and is absorbed quickly. Milk and juices provide fluid, carbohydrates, and a variety of vitamins and minerals. In general, sports drinks are not the best choice 2 to 4 hours before exercise, but are ideal during training. Compared to milk and juice, sports drinks have a lower concentration of carbohydrates, vitamins, and minerals. One exception to this rule may be for endurance athletes preparing for a long-duration training or exercise session. Sports drinks will provide fluid and a small amount of carbohydrates before training or competition, generally without gastrointestinal distress. Some individuals find that consuming concentrated fluids such as milk or juices within an hour of exercise causes nausea and cramping. Each athlete is different; trial and error will uncover tolerances and preferences.

In the last 2 hours prior to exercise, light meals, small snacks, and beverages containing carbohydrates are ideal. Small quantities of carbohydrates help to keep blood glucose levels elevated, while minimizing the risk for gastrointestinal upset. Some research has suggested that eating carbohydrates during the 30 minutes immediately prior to exercise can be detrimental to performance. The theory is that ingested carbohydrates will elevate insulin levels, causing a reduction

Training Table 3.7: Carbohydrate-Rich Preexercise Meals (grams of carbohydrate)

- 1.5 cups cereal, 1 cup skim milk, and 1 cup orange juice (86 g)
- 2 pancakes, 3 tbsp syrup, ½ cup fresh fruit, and 1 cup skim milk (83g)
- 1 bagel, 2 tbsp peanut butter, 1 tbsp jelly, 0.5 cup unsweetened applesauce (71 g)
- 6 oz yogurt, 1 medium banana, 0.5 cup granola (85 g)
- ¾ cup oatmeal [dry], ¼ cup raisins, 2 tbsp walnuts, 1 cup skim milk (83 g)
- Turkey sandwich [2 slices bread, 6 slices turkey], 1 apple, 6 oz yogurt (101 g)
- 1.5 cup spaghetti with marinara sauce, 4 oz chicken, 2 cups garden salad, 2 tbsp salad dressing (87 g)
- Hummus/cheese wrap [4 tbsp hummus, 2 slices cheese, 1 cup lettuce, 1 flour tortilla], 1.5 cup vegetable soup, 10 Saltine crackers, 8 oz apple juice (95 g)
- 4 oz baked ham, 1 cup mashed potato, 1 cup fruit salad (96 g)

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Remember that each athlete is different. Some people may feel most comfortable eating their preexercise meal 3 to 4 hours prior to training and find that waiting longer to eat leads to stomach and intestinal cramping. Others may find that they get too hungry if too much time passes between their last meal/snack and exercise. Individuals should experiment not only with the type of carbohydrate-rich food and beverage, but also with the timing of their meals/snacks prior to exercise.

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Athletes should strive to consume 1–4 grams of carbohydrate per kilogram of body weight in the 1 to 4 hours prior to exercise. Experimentation during training will help each athlete determine the optimal amount to include in the preexercise meal for performance enhancement.

of blood glucose within 15 minutes of the initiation of exercise.[55] However, most studies have failed to demonstrate a reduction in exercise performance during endurance activities resulting from preexercise carbohydrate consumption, especially if carbohydrate consumption is continued during exercise.[56] The bottom line is that each athlete responds differently to the ingestion of carbohydrates immediately prior to exercise, and, therefore, individual preferences and tolerances must be built into an athlete's nutrition recommendations.

Some individuals are concerned about eating prior to exercise and are hesitant about consuming any type of food or beverage. In some cases, the athlete has never consumed food or liquid prior to exercise, especially morning exercise, and is doubtful or leery about testing the procedure. These athletes should be encouraged to try a small snack or beverage such as a glass of juice or milk, a piece of fruit, or a slice of toast. The athlete may not consume a full, well-balanced meal, but something is better than nothing. If an athlete becomes nervous or anxious before an event, an upset stomach or intestinal distress will often result. Suggest that the athlete eat small amounts at a time of the foods he or she has found agreeable during training. Bites of a bagel, sips of juice, or sports beverages can be used in this situation to provide some fuel without further upsetting the gastrointestinal tract.

Besides the energy that can be provided by carbohydrates ingested prior to exercise, it has also been reported that the presence of carbohydrates in the mouth activates regions of the brain that can improve exercise performance.[57] Merely rinsing the mouth for about 10 seconds with a 6% carbohydrate solution appears to stimulate oral sensory receptors that activate brain areas associated with reward and the regulation of motor activity. Although the mechanisms are not clearly understood, the evidence is convincing that mouth rinsing with carbohydrate solutions immediately prior to or during exercise may be a worthwhile practice.

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Performing a 10-second mouth rinse with a 6% carbohydrate solution before and during exercise may improve athletic performance.

What type, how much, and when should carbohydrates be consumed during exercise?

Consuming carbohydrates during exercise has been shown to help delay fatigue in short-duration and long-duration activities.[58–63] The theory is that carbohydrates provided during exercise can either reduce the reliance on the glycogen stored in the muscles and liver for energy or provide an alternative source of carbohydrates when glycogen is depleted. Various forms of carbohydrates have different properties related to digestion, absorption, availability of glucose for oxidation, and taste. Because of their varying characteristics, the type of carbohydrate ingested during activity is of importance. Athletes need to develop a nutrition plan for during activity based on the nature of their sport, the availability of foods/beverages during training or competition, and individual tolerances.

What types of carbohydrates should be consumed during exercise or sport?

Research has shown that glucose, sucrose, glucose polymers/maltodextrins, and starches are all absorbed and oxidized at high rates and therefore are appropriate fuels during exercise.[64–71] Conversely, fructose and galactose are two simple sugars that are absorbed and oxidized at a slower rate. Fructose is absorbed half as fast as glucose and has to be converted to glucose in the liver before it can be metabolized. When consumed in large amounts, fructose can cause gastrointestinal distress, cramping, or diarrhea. As a result, fructose has been viewed as a less than desirable carbohydrate fuel during exercise.

However, this does not mean that fructose should not be consumed during exercise. Fructose increases the palatability of sports performance products. In addition, research has shown that a mixture of various sugars takes advantage of the different intestinal transporters and can actually enhance carbohydrate absorption and oxidation during exercise.[21,51,72,73] As a result, sports nutrition products that contain a mixture of sugars can be highly valuable to athletes during exercise, particularly if it lasts longer than 1 hour. Common sports nutrition products geared mainly for supplying carbohydrates during exercise include sports beverages, carbohydrate gels, and energy bars (see **Table 3.12**).

How much carbohydrate should be consumed during exercise or sport?

The quantity of carbohydrates consumed during exercise is dictated by two factors: (1) the rate of

TABLE 3.12 Carbohydrate Content of Commonly Used Sport Drinks, Gels, and Bars

Sports Drink	Calories	Carbohydrates	% Sugar Solution	Type of Carbohydrates
(all values per 8 fl oz)				
All Sport	70	20 g	8	High fructose corn syrup
Gatorade	50	14 g	6	Sucrose, glucose, fructose
Powerade	70	19 g	8	High fructose corn syrup, maltodextrin
Carbohydrate Gels				
(all values per one packet)				
Gu Energy Gel	100	25 g		Maltodextrin, fructose
Hammer Gel	90	23 g		Maltodextrin, fructose
PowerBar PowerGel	110	26 g		Maltodextrin, fructose
Energy Bars				
(all values per one bar)				
Clif Bar	240	45 g		Brown rice, oats, evap. cane sugar
Hammer Bar	220	25 g		Date paste, agave nectar
PowerBar	230	45 g		Oats, rice crisps, glucose syrup

gastric emptying and intestinal absorption and (2) the rate at which the exogenous carbohydrate is utilized (i.e., exogenous oxidation rate) by the muscle during the activity. It appears that the rate of gastric emptying and intestinal absorption is the limiting factor to exogenous carbohydrate utilization during exercise. A study conducted by Jeukendrup et al.[74] compared varying doses of exogenous carbohydrates during exercise to the appearance of glucose from the gut into the systemic circulation and the subsequent muscle oxidation rates. A low dose of ingested carbohydrates (0.43 grams of carbohydrate per minute) produced an equivalent appearance rate of glucose in the bloodstream (0.43 grams per minute), and the muscle was capable of metabolizing 90–95% of the delivered glucose during exercise. When a high dose of carbohydrates was consumed (3 grams of carbohydrate per minute) the appearance of glucose into the bloodstream was only 33% of the amount ingested (0.96–1.04 grams of carbohydrate per minute), thus indicating that this was the maximum rate of digestion/absorption of glucose. It is interesting to note that the muscle was still able to oxidize 90–95% of the delivered glucose for energy. The authors concluded that intestinal absorption of glucose was the limiting factor in regard to the ability of muscle to oxidize exogenous carbohydrates during exercise. Therefore, recommending the ingestion of carbohydrates at levels above the rates of intestinal absorption is not beneficial and can cause cramping and diarrhea, because any carbohydrate not absorbed will remain in the GI tract. Research indicates that the maximal intestinal absorption rate of glucose is 1.0–1.1 grams of glucose per minute. As a result, the current recommendation is that athletes consume approximately 30–60 grams of glucose per hour during exercise to help maintain energy output while preventing gastrointestinal upset.[21]

Because the oxidation rate is limited by intestinal absorption, it has been widely held that the oxidation rate of exogenous carbohydrates for energy by muscle is the same as the intestinal absorption rate of approximately 1.0–1.1 grams of glucose per minute.[75] However, several factors, such as exercise intensity, muscle glycogen saturation, fitness level, and the mixture of carbohydrates ingested, have the potential to alter carbohydrate availability to the muscle and thus exogenous carbohydrate oxidation rates during exercise.[22] Research by Jentjens and colleagues[76–78] has shown that mixtures of different forms of carbohydrate can increase intestinal absorption above that of glucose alone. For example, it was shown that ingesting a carbohydrate mixture of glucose, fructose, and sucrose supplying 2.4 grams of carbohydrate per minute (i.e., 1.2 gram of glucose + 0.6 grams of fructose + 0.6 grams of sucrose) during exercise resulted in exogenous carbohydrate oxidation rates of greater than 1.5 grams per minute during exercise.[76] The higher oxidation rate is believed to be the result of greater intestinal absorption. The greater intestinal absorption is thought to be due to the use of multiple intestinal transporters for the different forms of carbohydrates [i.e., a sodium-dependent glucose transporter (SGLUT1) for glucose, a sodium-independent facilitative fructose transporter (GLUT 5) for fructose, and a possible disaccharidase-related transporter for sucrose]. The end result is more carbohydrate absorbed than glucose alone, and thus more exogenous carbohydrates delivered to the active muscle. As a result, it has been suggested by some nutrition researchers that the current recommendation range of 30–60 grams of carbohydrate per hour be expanded to 30–90 grams per hour during exercise.[22]

Clearly, this is a wide recommendation range, but it must be understood that individual variances in the quantity of carbohydrates tolerated during exercise may be great. Some individuals can consume 60–70 grams of carbohydrates per hour without gastrointestinal distress, whereas others start cramping and feeling bloated after ingesting 40 grams of carbohydrates per hour. Experimentation during training will reveal the ideal quantity for each athlete. The form of carbohydrate ingested can affect the quantity an athlete feels comfortable consuming. Athletes should try different combinations of sports drinks, bars, gels, and other foods to determine the best mix of solids and fluids to consume during training and competition.

Sports beverages provide a convenient means for consuming not only carbohydrate, but also fluid and electrolytes during exercise. It is generally recommended that athletes choose a sports beverage containing 6–8% carbohydrate (i.e., 14–20 grams of carbohydrate per 8 oz serving) to optimize gastric emptying and fluid absorption during exercise.[79] Beverages containing greater than 8% carbohydrate can be included in the athlete's diet, however, preferably not during training or competition (an exception to this rule is during ultra-endurance activities). These more concentrated carbohydrate beverages can also be useful during carbohydrate loading or for athletes who are struggling to consume enough total calories or carbohydrates.

When should carbohydrates be consumed during exercise or sport?

Limited research has been conducted on a wide range of carbohydrate feeding schedules. The results from recent studies suggest that athletes should begin ingesting carbohydrates early in a training session and continue to consume carbohydrates at a steady rate throughout the exercise period.

One schedule variation that has been investigated is the difference in oxidation rates between a bolus carbohydrate feeding at the start of an exercise session versus the equivalent amount of carbohydrates consumed in repetitive feedings throughout a bout of exercise. Several studies provided subjects with a single glucose load of 100 grams at the onset of exercise lasting 90 to 120 minutes.[80–82] These studies have shown a similar oxidation pattern: oxidation rates increase during the first 75 to 90 minutes of exercise, followed by a plateau thereafter. When the equivalent amount of carbohydrates (100 grams) is consumed in repetitive feedings throughout an exercise bout lasting 90 to 120 minutes, the same oxidation pattern is observed.[83–85] In general, repetitive small feedings are easier to tolerate than one large bolus feeding while exercising. If the oxidation rate is the same, then repetitive feedings may be more desirable if food and beverages are readily available. If not, then infrequent, larger doses of carbohydrates before and during prolonged exercise may provide the same effect for endurance performance.

If an athlete chooses to consume carbohydrates at regular intervals during exercise, the feedings should begin soon after the onset of exercise. A study conducted by McConell et al.[86] investigated the performance effects of consuming carbohydrates throughout exercise versus the ingestion of an equal amount of carbohydrates late in the exercise session. The results revealed a performance benefit versus controls only when carbohydrates were consumed throughout exercise. Ingestion of carbohydrates late in the exercise session did not improve performance despite an increase in circulating glucose and insulin after ingestion. Therefore, the consumption of sports drinks, energy bars, gels, or other sports-related foods and beverages should begin soon after

gaining the performance edge

Carbohydrate ingestion during exercise has been shown to help delay fatigue and thus improve exercise performance. Carbohydrate consumption of approximately 30–60 grams of carbohydrates per hour should begin near the onset of exercise and continue throughout the session. The impact of exogenous carbohydrates increases as the duration of exercise increases. Individualized nutrition plans are required for each athlete, including fluids and foods containing carbohydrates that have been tested and evaluated during training.

the initiation of exercise to enhance performance during training and competition.

What type, how much, and when should carbohydrates be consumed after exercise?

Muscle and liver glycogen are used partially or completely during moderate-intensity/moderate-duration and high-intensity/long-duration activities, respectively. After exercising, it is critical to feed the muscles with carbohydrates to replenish stores of muscle and liver glycogen to be used in the next exercise session.

Unless sufficient carbohydrates are consumed in the diet after training or competition, muscle glycogen will not normalize on a daily basis and performance will suffer. A study conducted by Costill et al.[87] studied the performance effect of a low-carbohydrate diet fed to runners on successive training days. After 3 days on the low-carbohydrate diet, muscle glycogen was depleted progressively, and, subsequently, some runners found it difficult to complete the prescribed workouts (see Figure 3.11).

When devising a postexercise recovery nutrition plan for athletes, several important factors must be considered:

- The timing of carbohydrate ingestion.
- The type of carbohydrates and inclusion of other macronutrients.
- The quantity of carbohydrates in the postexercise meal or snack.

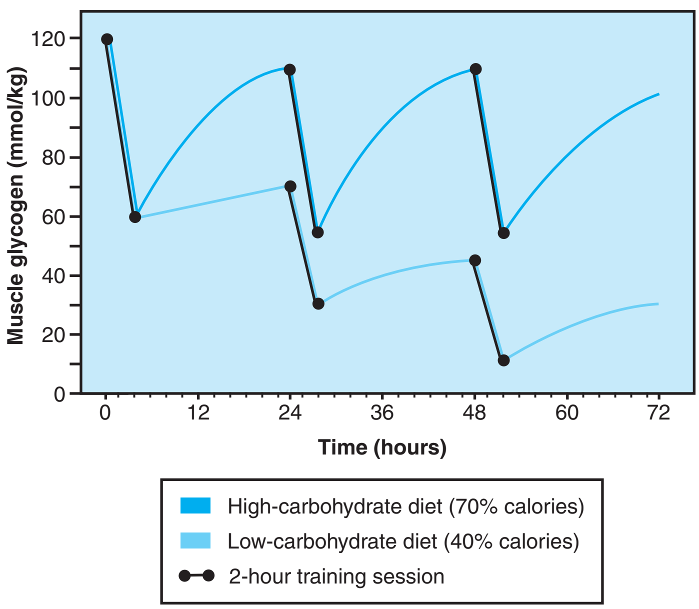

Figure 3.11 Effects of low- versus high-carbohydrate diet on glycogen stores. A high-carbohydrate diet replenishes glycogen stores better than a low-carbohydrate diet does.
Source: Modified from Costill DL, Miller JM. Nutrition for endurance sport: carbohydrate and fluid balance. *Int J Sport Nutr*. 1980;1:2–14.

When should carbohydrates be consumed after exercise or sport?

Replenishing glycogen stores used during exercise can take 20 hours or more even when consuming a diet consisting of 60% of total calories from carbohydrates.[88] This relatively slow rate of glycogen replenishment does not pose major problems for recreational athletes or others who train aerobically three to four times per week and ingest adequate carbohydrates because usually there is sufficient time between workouts to allow for glycogen recovery. However, the slow glycogen recovery rates can pose problems for endurance athletes who train daily or who perform multiple workouts per day. In these cases, the timing and type of carbohydrates ingested are important.

Research indicates that muscles absorb blood glucose and restore glycogen at higher rates when carbohydrates are ingested within 2 hours after cessation of training/sport performance.[89] Delaying carbohydrate consumption until 4 hours or more after training can cut the glycogen synthesis rate in half compared to when carbohydrates are consumed immediately after exercise.[89] To take advantage of this window of opportunity, athletes should begin consumption of high-GI carbohydrate sources as soon as possible—some suggest as soon as 15 minutes after exercise.[90] Eating immediately or as soon as possible after exercise will allow time to digest and absorb the carbohydrates into the bloodstream and shuttle it to the cells.[89] An athlete's nutrition plan should include snacks and beverages that will be available for consumption immediately postexercise. In many cases, athletes are away from home and without refrigeration during this time frame; therefore, nonperishable foods and drinks are the best options.

What type of carbohydrates should be consumed after exercise or sport?

Because the quick delivery of carbohydrates to the muscles is of utmost importance, choosing carbohydrate-rich foods that are digested and absorbed quickly is essential. Several factors have been suggested to enhance glycogen resynthesis after exercise, including high-GI foods, liquid forms of carbohydrates, and beverages combining carbohydrates and protein. High-GI foods seem to be a desirable carbohydrate source during the postexercise recovery period.[91] High-GI foods may digest more quickly, allowing for a fast delivery of carbohydrate to the muscles. Choosing high-GI foods may be more relevant when athletes are choosing a small snack after exercise versus a well-balanced meal. If the snack is large enough to supply sufficient amounts of carbohydrate, then the rapid rise in blood glucose can be beneficial for a quick delivery of carbohydrate to hungry muscle cells. However, a well-balanced meal, composed of a variety of foods, can supply a wider range of not only carbohydrates, but also protein, vitamins, and minerals to a depleted body. In this case, choosing high-GI foods may have less relevance and importance.

Liquid carbohydrate sources may not necessarily be more beneficial than solids in regard to the rate of glycogen synthesis. Several studies have found similar glycogen restoration rates after the ingestion of an equal amount of carbohydrates in liquid and solid form.[92,93] Because no differences between liquids and solids exist, individual preferences can determine the form of carbohydrates ingested after exercise. Some athletes are ready for a full meal after training; therefore, a balanced meal with sufficient carbohydrates will be appropriate. Other athletes have a small appetite after exercising, so a liquid meal has more appeal. The *Soccer Smoothie* recipe in Training Table 3.3 provides an example of a liquid source of carbohydrates as well as other nutrients. Depending on the size of the athlete and the duration of exercise, foods or beverages in addition to the smoothie might be required to supply sufficient amounts of carbohydrates to the body after a training session or a competition.

It has recently been suggested by some researchers that the combination of carbohydrates and protein in a postexercise beverage enhances glycogen storage beyond that of a carbohydrate-only product. One of the first studies to report this phenomenon was completed by Zawadzki and colleagues.[94] They reported an impressive 39% greater rate of glycogen repletion with a combined carbohydrate-protein versus carbohydrate-only supplement after exercise. However, the results are difficult to interpret because the carbohydrate-protein supplement provided 43% more energy than the carbohydrate-only supplement. Other studies have not been able to replicate the differences reported in the Zawadzki study when supplying isoenergetic beverages of varying macronutrient content.[95–97] It appears that both carbohydrate-only and carbohydrate–protein supplements can enhance glycogen resynthesis postexercise to a similar extent.[98] Therefore, at this time it can be concluded that the energy content of a postexercise beverage is more critical than macronutrient content is in determining the glycemic and insulin response as well as the extent of muscle glycogen resynthesis.

How much carbohydrate should be consumed after exercise or sport?

To maximize glycogen synthesis, athletes should consume carbohydrates at a rate of 1.0–1.5 grams per kilogram of body weight every 2 hours for 6 hours postexercise.[30] For example, Sue is a soccer player. She weighs 150 pounds (68.2 kg). After a 1- to 2-hour practice or game, her carbohydrate needs are 68–102 grams of carbohydrates (68.2 kg × 1.0–1.5 grams of carbohydrate per kilogram of body weight = 68–102 grams of carbohydrates) to be consumed within 30 minutes of the end of her training session/competition, and then again every 2 hours for 6 hours. She can obtain 68–102 grams of carbohydrates by consuming:

- A banana and 8 ounces of yogurt.
- 6–8 ounces of juice and a bagel.
- 8 ounces of milk and 1 to 1½ cups of cereal.

> ***gaining the performance edge***
>
> Consuming carbohydrates after exercise accelerates the recovery process. A carbohydrate intake of 1.0 to 1.5 grams per kilogram of body weight every 2 hours for 6 hours postexercise will ensure a complete restoration of glycogen levels.

What are some examples of good meals/snacks for after exercising?

Meals and snacks postexercise should supply adequate amounts of carbohydrates as well as other nutrients. The best way to obtain a balance of all required postexercise nutrients is to consume whole foods. **Table 3.13** presents a variety of ideas for postexercise meals/snacks that provide 50–100 grams of carbohydrates.

> **Food for Thought 3.2**
>
> **You Are the Nutrition Coach**
>
> Apply the concepts from this chapter to several case studies.

TABLE 3.13 Quality Food and Beverage Choices for Postexercise Carbohydrate Replenishment

Food/Beverage	Serving Size	Quantity of Carbohydrates
Meals and Snacks Supplying 50–75 Grams of Carbohydrates		
Juice	8 fl oz	27 g
Bagel w/peanut butter	1 medium + 2 tbsp	45 g
Tomato juice	12 fl oz	16 g
Turkey sandwich	2 slices bread + 3 oz meat	24 g
Cottage cheese w/pineapple	1 cup + 1/2 cup	25 g
Dried apricots	5 halves	11 g
Bran muffin	1 small	24 g
Yogurt (with fruit)	6 oz	33 g
Soccer Smoothie	1 smoothie	50 g
Veggie chili	8 oz	25 g
Corn bread	1 piece	29 g
Meals and Snacks Supplying 75–100 Grams of Carbohydrates		
Food/Beverage	**Serving Size**	**Quantity of Carbohydrates**
Raisin bran	1 cup	47 g
Skim milk	8 fl oz	12 g
Apple	1 medium	21 g
Whole wheat toast and jam	1 slice + 1 tbsp	27 g
Banana	1 medium	27 g
Yogurt	6 oz	33 g
Macaroni and cheese	2 cups	80 g
Green salad	1 1/2 cups	7 g
Skim milk	8 fl oz	12 g
Spaghetti	1 1/2 cups	60 g
Marinara sauce	3/4 cup	18 g
Mixed vegetables	3/4 cup	18 g

The Box Score

Key Points of Chapter

- Adequate carbohydrate intake is essential for optimal sport performance. Carbohydrate intake should be in the range of 6–10 grams per kilogram of body weight per day, which should amount to approximately 55–70% of total daily calories.
- Athletes may not consume adequate calories to meet training and competition needs. Encouraging athletes to consume adequate calories during training and competition will help ensure appropriate carbohydrate intake.
- Carbohydrates are synthesized by plants via a process known as photosynthesis. Photosynthesis is an energy-requiring process that relies on the sun's light energy to combine water and carbon dioxide to make carbohydrates.
- Carbohydrates are commonly classified as simple or complex based on their chemical composition and

structure. Both simple and complex carbohydrates provide energy, but have different nutrient profiles related to vitamins, minerals, fiber, and phytochemicals.

- Glucose is the most abundant simple carbohydrate found in nature and serves as an important energy source for cells in the human body.
- The storage form of carbohydrates in plants and animals is starch and glycogen, respectively.
- Fiber is a plant form of carbohydrate that is indigestible by the body and therefore provides minimal to no energy. However, fiber is an important part of a normal diet and helps to prevent high cholesterol, diabetes, and constipation.
- Artificial sweeteners can be derived from carbohydrates, amino acids, and other substances but are less digestible, thus limiting their caloric value to the body. Athletes may use artificial sweeteners to help control caloric intake; however, overuse can be unhealthy and detrimental to athletic performance.
- Carbohydrates are the sole energy source during very intense physical activity and thus are a key source of energy for many sport activities. Failure to ingest adequate amounts of carbohydrates not only robs the athlete of energy, but also can affect mental focus.
- The timing and type of carbohydrates consumed in the days and hours leading up to competition can be critical to performance. Experimenting with new foods or beverages on competition day can be disastrous. Always experiment weeks ahead of time for the best combination, types, and amounts of carbohydrates to consume.
- The richest sources of carbohydrates are grains, fruits, and vegetables. These nutrient-dense foods make up over half of the entire MyPlate food guidance system. Dairy/alternatives and legumes, nuts/seeds, and soy products from the protein food group also provide quality sources of carbohydrates. Carbohydrates obtained from sweets, desserts, and sodas are part of empty calories of the MyPlate food guidance system and should be moderated because they lack other nutrients important for optimal health and performance.
- The glycemic index (GI) of foods can be used to help identify the glucose response of a single food. However, the concepts of glycemic index, glycemic load, and glucose kinetics are still under investigation, and the limitations in practical daily eating need to be recognized.
- The body stores limited amounts of carbohydrates (approximately 400–600 grams), which is why athletes must pay particular attention to carbohydrate intake in their diet. Failure to replace glycogen stores used during training or competition can lead to low energy levels and decreased motivation, both of which can spell disaster for an athlete.
- Diets consisting of 60–70% of total calories from carbohydrates have been shown to increase resting muscle glycogen levels. High muscle glycogen levels have been shown to delay the time to fatigue in endurance athletes, which is one of the primary reasons endurance athletes carbohydrate-load in the week leading up to a competition.
- There is no one best precompetition meal, sports beverage, or postexercise snack that fits everyone's likes or tolerances. Athletes should follow the general guidelines of carbohydrate intake and experiment prior to competition with different meals, snacks, and/or drinks to find which best suits their unique requirements.
- Glucose polymer drinks and other carbohydrate-rich foods consumed during sport performance can increase blood glucose levels and delay onset of fatigue.
- Muscles are most receptive to uptaking blood glucose to replenish glycogen stores within 2 to 4 hours of exercise or competition. As a result, postgame snacks or meals should contain high-carbohydrate foods and should be consumed as soon as possible after the cessation of exercise.

Study Questions

1. Explain why restricting carbohydrates in the diets of athletes is detrimental.
2. Briefly discuss where carbohydrates come from and how they are formed in nature.
3. What roles do carbohydrates play in the body and how do these roles relate to athletic performance?
4. How many calories are derived from ingested carbohydrates that are classified as dietary fiber? What are the different types of fiber, and what role do they play in the body?
5. What are the basic building blocks of carbohydrates? Based on the number of building blocks, how are different carbohydrates classified?
6. What is the difference between starch and glycogen?
7. Name and briefly discuss four of the commonly used artificial sweeteners. Are artificial sweeteners carbohydrates? What are some of the positives and negatives associated with using artificial sweeteners?
8. Discuss the various sources of carbohydrates in our diet. Which sources of carbohydrates should predominate in our diet? Which sources of carbohydrates should be limited? Explain.
9. Discuss how knowledge of the glycemic index of foods can be used by athletes to optimize performance during sport. What about its application in regard to recovery?
10. Jason is an elite cross-country athlete who is currently training 5 days per week. He weighs 135 pounds.

Based on his body weight, what should his daily carbohydrate intake be? Defend your answer.

11. What is carbohydrate loading? Which athletes would benefit most from it? Defend your answer.
12. Describe the crossover concept and its relevance to sport performance.
13. Jim is excited to be competing in his first half-marathon (13.1 miles) and comes to you for dietary advice for during the race. What advice regarding intake of carbohydrates might you give him to improve his chances of having a successful race?
14. Sarah is an elite triathlete who is currently training twice a day. What nutritional advice would you give her in regard to optimizing her recovery between workouts?

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