

Carbohydrates That Speed Recovery From Training

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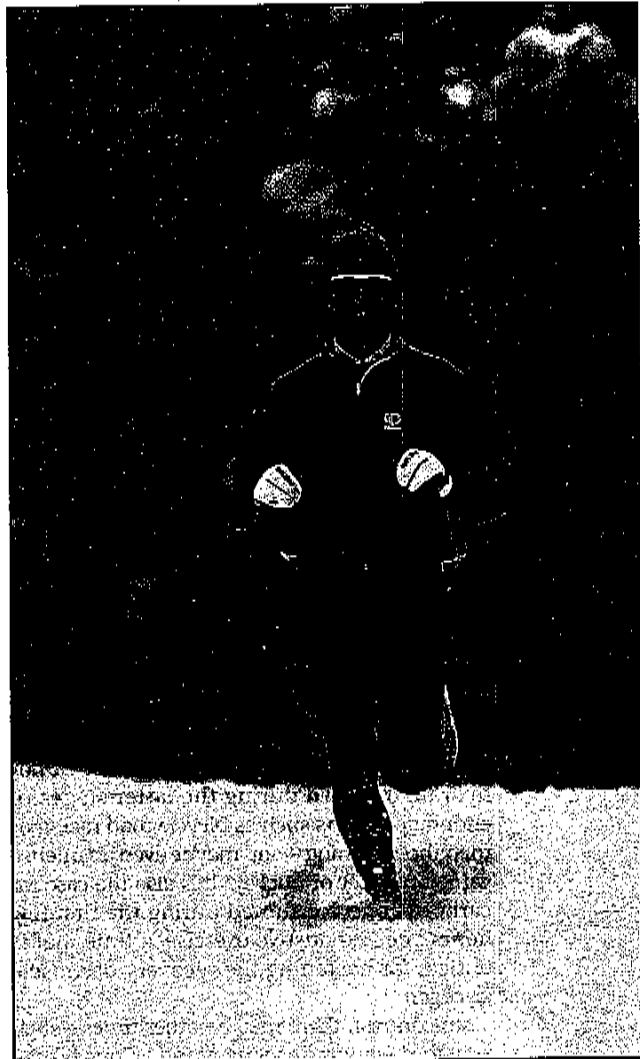
The most useful way to classify carbohydrate food for active people is by its ability to raise blood glucose concentration. To hasten recovery after intense training, athletes should consume at least 50 g of high- or moderate-glycemic carbohydrates as soon after exercise as is practical. They should eat at least an additional 50 g every 2 hours until they eat a large meal. To obtain the recommended 70% of calories from carbohydrate, athletes may find it helpful to determine how many 50-g carbohydrate food portions they need to eat daily.

Almost all those in the athletic community, including athletes, coaches, trainers, and team physicians, realize that optimal nutrition is vital to most training programs. For the most part, athletic patients also realize that carbohydrate is the single most important nutrient in their diet because it is the predominant source of energy for exercising muscles.

Despite this understanding, however, some athletes remain deficient in carbohydrate because they are not taught how to select foods that have the "best types and optimal amounts"

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carbohydrates continued

Hockey players often become glycogen depleted after a couple periods of intense play. It may help to consume carbohydrate that the body can quickly convert to blood glucose.

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of carbohydrate to meet their immediate or long-term energy needs. As a result, their training and performance often suffer.

The Glycemic Index

Athletes and other active people sometimes need to consume carbohydrate that can be very quickly converted to blood glucose and transported via the bloodstream to the muscles during exercise. This is certainly the case for carbohydrate ingested during the latter stages of endurance sports such as bicycle road racing or marathon running—and maybe even an intense game of soccer or hockey.¹ It is also the case for carbohydrate consumed during the first few hours after exhaustive exercise, a time that is critical for hastening the recovery of muscle glycogen.^{2,3}

In contrast, there may be other times—such as at the beginning of a marathon or long hike—

when athletes and active people would benefit most from carbohydrates that are converted to blood glucose at a slower rate and for more prolonged periods.⁴ To help meet the athlete's need to regulate glucose entry into blood at various rates, food should be classified according to its *glycemic index*.⁵

The glycemic index measures the extent to which blood glucose is elevated above basal levels for a period of time after eating a food containing 50 g of carbohydrate. The increase in blood glucose is expressed as a percentage relative to the increase observed after eating a standard type of carbohydrate, such as bread or simple glucose, which rate 100. Foods can be classified as having a high, moderate, or low glycemic index.⁷ Additionally, active people should consider the optimal amount of carbohydrate to be ingested as well as the best timing of meals.

An Active Person's Carbohydrate Need

When exercise is prolonged and intense enough to deplete muscle glycogen and produce hypoglycemia, the exerciser will be forced to lower the intensity of the workout to a pace comparable to a slow run or jog.¹ Marathon runners call this phenomenon "hitting the wall," and cyclists call it "the bonk."

It takes 90 to 180 minutes of continuous exercise performed at 60% to 80% $\dot{V}O_2$ max to deplete muscle glycogen.¹ However, muscle glycogen can also be depleted after only a 15- to 30-minute exercise session performed at very high intensities (90% to 130% $\dot{V}O_2$ max) in intervals of 1 to 5 minutes alternated with rest periods.⁶

It is not uncommon for soccer or hockey players to become glycogen depleted well before completing a game or after a hard practice.^{7,8} Therefore, athletes who attempt to train daily at intensities that deplete muscle glycogen must take extraordinary measures to eat high-glycemic carbohydrates at optimal times.^{9,10}

Classification of Carbohydrates

Simple sugars include the monosaccharides glucose and fructose as well as the disaccharides sucrose (glucose plus fructose), lactose (glucose plus galactose), and maltose (glucose plus glucose).

Complex carbohydrates have many glucose units chained together. The number of glucose units can range from a few to several thousand, and these molecules are generally classified as starch. A straight chain of glucose units is called amylose, and many-branched glucose chains are called amylopectin.

Dietary carbohydrate is primarily converted to blood glucose, the only type of carbohydrate (excluding lactate) that skeletal muscle can readily metabolize for energy or store as glycogen. A secondary purpose of dietary carbohydrate is to supply glucose and fructose to the liver for glycogen synthesis.

Carbohydrates can be functionally classified according to their glycemic index.⁵ The glycemic index is largely determined by the rate at which

ingested carbohydrate is made available to intestinal enzymes for hydrolysis and intestinal absorption.¹¹ This is regulated by gastric emptying time¹² and the physical availability of the sugar or starch to hydrolytic enzymes. The latter is influenced by cooking, which alters both the integrity of the starch granule¹³ and the degree of gelatinization.¹¹ Amylopectin is hydrolyzed more rapidly in the intestines than amylose and thus has a somewhat higher glycemic index.¹⁴

Glycemic index is not determined by whether a carbohydrate is simple or complex. Some starchy complex carbohydrates such as mashed or baked potatoes and bread produce glycemic responses similar to that of glucose.^{5,15} Sucrose also has a glycemic index comparable to or somewhat less than that of starchy complex carbohydrates.⁵ Additionally, amylose and maltodextrin elicit glycemic responses identical to glucose.¹⁵ Maltodextrin is used in some sport drinks in place of glu-

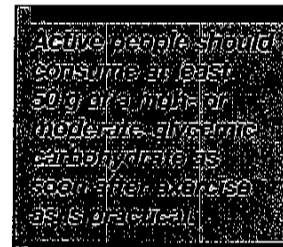
ucose or sucrose because it does not taste as sweet; maltodextrin makes the drink more palatable, especially when the concentration of carbohydrate is high (greater than 20 g/100 mL of water). Fructose, on the other hand, has a low glycemic index because it is only slowly converted to glucose in the liver.

Postexercise Glycogen Resynthesis

The time needed for an athlete to recover between intense training sessions is often dictated by how quickly muscle glycogen is restored. Muscle glycogen is resynthesized to normally high levels at a rate of only about 5% per hour (eg, 5 mmol·kg of muscle⁻¹·hr⁻¹ when attempting to increase muscle glycogen by 100 mmol/kg). Therefore, even when diet is optimal, approximately 20 hours are required to recover muscle glycogen stores.

Thus, athletes who work out twice a day will have chronically low muscle glycogen stores unless they perform one of the training sessions at

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carbohydrates continued

Table 1. Quantity Needed to Obtain 50 g of Carbohydrate From High-, Moderate-, and Low-Glycemic Foods

Food*	Amount for 50 g Carbohydrate	Food*	Amount for 50 g Carbohydrate
High-Glycemic			
Sugars			
Glucose	4.2 tbsp		
Sucrose (white granular)	4.2 tbsp		
Sucrose (white powdered)	6.6 tbsp		
Syrups/Jellies			
Cane and maple syrup	3.9 tbsp		
Corn syrup (light)	3.4 tbsp		
Honey	2.8 tbsp		
Molasses (medium)	4.2 tbsp		
Beverages			
8% sucrose solution	3.5 c		
7.5% maltodextrin and sugar	2.8 c		
10% corn syrup (carbonated drink)	2.1 c		
20% maltodextrin solution	1.1 c		
Cereal products			
Bagel (2 oz each)	1.6 bagels		
Bread (white or whole meal, 1 oz each)	3.5 slices		
Bread sticks	6.7 sticks		
Corn flakes	2 c		
Fruits			
Raisins	0.41 c		
Vegetables			
Potato (baked, 7 oz)	1 potato		
Potato (boiled and mashed)	1.5 c		
Sweet corn (yellow)	1.2 c		
Moderate-Glycemic			
Cereal products			
Oatmeal	2.1 c, cooked		
Rice	1 c, cooked		
Spaghetti; macaroni	1.5 c, cooked		
Whole grain rye bread (1 oz each)	3.5 slices		
Fruits			
Grapes (American slip skin)	3.1 c		
Grapes (European)	1.8 c		
Orange (navel, 5 oz each)	3 oranges		
Vegetables			
Corn (yellow, boiled)	1.2 c		
Yams (boiled or baked)	1.3 c of cubes		
Legumes			
Baked beans	0.9 c		
Low-Glycemic			
Fruits			
Apple (raw, 5 oz)	2.4 medium apples		
Applesauce (sweetened)	1 c		
Cherries (sweet, raw)	44 cherries		
Dates (dried)	38 dates		
Figs (raw, 2 oz)	16 figs w/ly		
Grapefruit (raw, 4 oz)	2.5 grapefruits		
Peach (raw, 3 oz)	5 peaches		
Pear (raw, 6 oz)	2 pears		
Plum (raw, 2 oz)	5.6 plums		
Legumes			
Butter beans	1.4 c		
Chick-peas	1.1 c		
Green beans	1.7 c		
Green peas	2.1 c		
Kidney beans	1.2 c		
Navy beans	1.1 c		
Red lentils	1.2 c		
Dairy Products			
Skim milk	4.2 c		
Whole milk	4.4 c		
Yogurt (plain custard)	2.8 c		

*High-glycemic foods have a glycemic value above 85, moderate-glycemic foods have a rating from 60 to 85, and low-glycemic foods have a rating less than 60. Bread has a glycemic index of 100.

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an intensity low enough not to rely heavily on muscle glycogen. The important dietary factors that dictate the rate of muscle glycogen resynthesis are (1) the rate of carbohydrate ingestion, (2) the carbohydrate type, and (3) the timing of carbohydrate ingestion after exercise.

Rate of Carbohydrate Consumption

To determine the optimal rate of carbohydrate ingestion, athletes have been given various amounts of high-glycemic food to eat after exercise.^{23,16,17} Excluding the 2 hours immediately after exercise, glycogen was resynthesized at only 2% per hour when athletes consumed 25 g of carbohydrate every 2 hours. The resynthesis rate increased to 5% per hour when athletes ate 50 g every 2 hours. However, muscle glycogen resynthesis did not increase by more than 5% to 6% per hour when 100 g, 112 g, or 225 g were ingested every 2 hours.

This plateau in glycogen resynthesis is not simply due to an accumulation of carbohydrate in the gastrointestinal tract. Intravenous glucose infusion at about 100 g every 2 hours does not increase muscle glycogen synthesis above 7% to 8% per hour.¹⁷

Higher rates of intravenous glucose infusion may, however, accelerate glycogen synthesis,¹⁸ and it has recently been suggested that eating a large amount of carbohydrate (28 g every 15 minutes, which totals 448 g in 4 hours) may increase glycogen synthesis to 9% per hour for a short period.¹⁹ However, excluding the first 2 hours postexercise, muscle glycogen synthesis appears near optimal (5% to 7% per hour) when an athlete consumes at least 50 g of glucose every 2 hours. Tables 1 and 2 present the portions of various types of food that contain 50 g of carbohydrate.

Recommendations in the text of this paper for the grams and portions of carbohydrate food are for a person weighing 70 kg (154 lb). A person's actual carbohydrate intake, however, should be adjusted to his or her body weight. Patients need to factor in the extent to which their body weight differs from 70 kg. For example, a person weighing 100 kg should multiply the recommended grams and portions by 1.4

Table 2. Quantity Needed to Obtain 50 g of Carbohydrate From Common Foods That Have an Undetermined Glycemic Index

Food	Amount for 50g Carbohydrate
Syrups	
Sorghum	3.6 tsp
Beverages	
Apple juice	1.5 c
Fruit punch	1.5 c
Grape juice	1.3 c
Orange juice	1.9 c
Papaya nectar	1.4 c
Pineapple juice	1.6 c
Prune juice	1.4 c
Cereal/grain products	
Corn grits (cooked)	1.6 c
English muffin	2 muffins
Farina (cooked)	2.6 c
Graham crackers	46 2-in. graham crackers
Pancakes (thin)	3 pancakes
Rita cookie	24 cookies
Rice cakes	62 cakes
Soda crackers	25 crackers
Tortillas (corn)	12 tortillas
Tortillas (flour)	17 tortillas
Whole wheat hot cereal (cooked)	1.5 c
Vegetables	
Sweet potato (mashed)	0.7 c
Water chestnuts (raw)	2.7 c
Legumes	
Azuki beans (cooked)	0.9 c
Black beans (boiled)	1.2 c
Cowpeas (black-eyed peas) (boiled)	1.2 c
Great northern beans (boiled)	1.2 c
Lima beans (boiled)	1.2 c

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(100kg/70 kg), whereas a person weighing 50 kg should multiply the grams and portions by 0.7 (50kg/70 kg).

Athletes can also be advised to optimize carbohydrate intake by obtaining about 70% of

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carbohydrates continued

Table 3. Daily Recommended Caloric Intake and Carbohydrate Consumption

Total Recommended Caloric Intake (kcal)†	Recommended Kilocalories From Carbohydrate (70% of total)	Recommended Grams of Carbohydrate‡	Daily Recommended Number of Portions of Carbohydrate-Rich Foods Containing 50 g per Portion
1,500	1,050	262	5-6
2,000	1,400	350	7
2,500	1,750	438	8-9
3,000	2,100	525	10-11
3,500	2,450	612	12-13
4,000	2,800	700	14
4,500	3,150	787	15-16

* Estimates of the number of food portions (50 g carbohydrate per portion) and total grams of carbohydrate needed to obtain the recommended 70% of total caloric intake from carbohydrate-rich foods listed in tables 1 and 2.

† Total caloric intake should be adjusted for body weight and activity level.

‡ Because carbohydrate contains 4 kcal/g, recommended grams of carbohydrate are found by dividing recommended kilocalories from carbohydrate by 4.

their total caloric intake from carbohydrate.²⁰ This advice, though sound, is difficult to implement because it does not directly inform athletes as to what foods to eat and how much. As shown in table 3, this can be simplified by telling athletes how many grams of carbohydrate they should eat per day.

For caloric needs not specified in table 3, patients can estimate the amount of carbohydrate they need by multiplying their estimated total caloric intake by 0.7 (70% of calories). They can then divide this number by four (because carbohydrates contain 4 kcal/g) to estimate the number of grams of carbohydrate they should consume. Food labels list the grams of carbohydrate per serving, and athletes can total their daily intake.

The easiest method, however, is to simply tell athletes how many 50-g portions of carbohydrate-rich foods they need to eat per day. Endurance athletes who are expending 3,000 to 4,000 kcal per day are advised to eat about 525 to 700 g/day of carbohydrate, which amounts to 8 to 10 g·day⁻¹·kg of body weight⁻¹.^{10,20} More sim-

ply, this equals 10 to 14 50-g portions of carbohydrate each day.

Glycogen Resynthesis

If high-glycemic foods resynthesize glycogen at 5% to 6% per hour, how do foods with a moderate or low glycemic index compare? Although the glycemic index of sucrose is slightly less than that of glucose,⁵ it also promotes glycogen synthesis at 5% to 6% per hour.³ Moderate-glycemic foods such as rice and pasta also appear to promote resynthesis at about 5% per hour.^{20,21}

Therefore, based on the limited data available at this time, there is no indication that moderate-glycemic foods are less effective than high-glycemic foods at synthesizing muscle glycogen. Also, it makes little difference if the carbohydrate is in liquid or solid for high- and moderate-glycemic foods.^{4,17}

Muscle glycogen resynthesis from low-glycemic foods is, however, clearly suboptimal. This is most apparent with fructose, which stimulates glycogen resynthesis at only 3% per hour because of the slow rate at which the liver con-

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carbohydrates continued

verts fructose to glucose.³

Legumes have a low glycemic index largely because the carbohydrate granule is not as accessible to digestive enzymes,¹² a factor that can be influenced by food processing and cooking. Legumes also do not appear to promote a high rate of glycogen synthesis during the first 6 hours after exercise, although they may be comparable to high- and moderate-glycemic carbohydrates at 20 to 44 hours postexercise.²²

Timing of Carbohydrate Consumption

During the first 2 hours after a workout, an exerciser's rate of muscle glycogen resynthesis is 7% to 8% per hour. Although this is somewhat faster than the normal rate of 5% to 6% per hour,

it isn't rapid.² However, the rate of early resynthesis is important for an active person because it allows quicker recovery before the next practice, competition, or workout.

Because eating more than 50 g of carbohydrate with a high or moderate glycemic index every 2

hours does not seem beneficial for increasing muscle glycogen resynthesis, it may seem best for an athlete to eat small, frequent meals until enough carbohydrate has been consumed (more than 600 g for a 70-kg person). However, Costill et al²⁰ fed runners 525 g of carbohydrate (70% of their caloric intake) over 24 hours and found that muscle glycogen synthesis was similar whether the runners ate two large meals or seven smaller meals. This may indicate that the gastric emptying rates of the two larger meals were slow enough to result in a prolonged rate of glucose entry into the blood, with a pattern of carbohydrate absorption similar to when small, frequent meals are eaten.

Specific, Practical Recommendations

To derive 70% of their total calories from carbohydrate, active patients should know how many grams of carbohydrate they need to con-

sume. As stated earlier, a simple method is to inform them how many 50-g carbohydrate food portions they should eat per day.

Within 4 hours after exercise. To hasten recovery of muscle glycogen, athletes should consume at least 50 g of a high- or moderate-glycemic carbohydrate as soon after exercise as is practical. Also, they should eat at least an additional 50 g every 2 hours until they eat a large meal.

The food can be either liquid or solid. Most important, it should be palatable to the athlete. Because appetite is usually suppressed for a period after intense exercise, foods should contain more concentrated carbohydrate and less bulk.

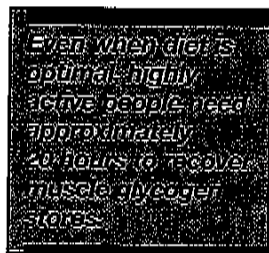
Foods and drinks that contain primarily glucose, sucrose, maltodextrins, and other starches serve an important function. Cyclists riding in the Tour de France derive most of their total calories from these high-glycemic sources.²³ These sugars and syrups are sometimes considered empty calories for sedentary adults whose carbohydrate intake is restricted to only 200 to 400 g/day and who are therefore advised to select carbohydrate foods that provide recommended daily fiber, vitamins, and minerals.

However, athletes often are not able to eat enough cereals, grains, and vegetables to meet their extreme carbohydrate needs. They have difficulty eating large amounts of bulky, high-fiber food in the limited time available, and they can become satiated prematurely and may experience gastrointestinal discomfort.²³

Four to 24 hours after exercise. The most important factor for glycogen resynthesis during the 4- to 24-hour period after exercise is the total amount of carbohydrate consumed. Based on the limited data currently available, it does not appear that the glycemic index plays a major role in determining the rate of muscle glycogen synthesis during the 4- to 24-hour period after exercise, as long as the athlete has ingested at least 100 g of carbohydrate within 4 hours after exercise.

Any fat consumed during the 4- to 24-hour period will blunt the glycemic response, and protein may have a variable influence.²⁴ There-

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carbohydrates continued

fore, the glycemic responses to high-carbohydrate meals containing fat and protein may be influenced less by the glycemic index of the individual carbohydrate in the meal.

The Dietary Difference

When training extensively, active patients must not lose sight of the importance of con-

suming carbohydrate-rich foods and beverages. When consumed after exercise, foods with a high or moderate glycemic index can help patients recover more quickly from intense training. **FSM**

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