Carbohydrate Strategies for Injury Prevention

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Abstract: *Prevention of injury involves identifying risk factors that would predispose one to injury and developing strategies to attenuate or eliminate their presence. Because muscle glycogen depletion is associated with fatigue and injury, it should be treated as a possible risk factor. Muscle glycogen stores are derived almost entirely from carbohydrate intake. Because there is a limited capacity to store muscle glycogen, and because muscle glycogen is the predominant fuel in exercise of moderate to severe intensity, the nutritional focus should be on carbohydrate consumption. Easy-to-follow nutritional strategies should be employed that will maximize muscle glycogen stores and delay the onset of fatigue. Individuals involved in activities lasting less than 60 minutes need to consume an adequate amount of carbohydrate daily and a pre-event meal before the start of the activity. However, individuals participating in activities longer than 60 minutes or participating in activities requiring repeated bouts of high intensity exercise need to: 1) consume an adequate amount of carbohydrate daily, 2) practice carbohydrate loading, 3) consume the pre-event meal, and 4) ingest carbohydrates immediately before, during, and after the activity.*

Empirically, there seems to be a relationship between fatigue and injury. Fatiguing, prolonged, continuous,[22,27,48,50] and eccentric type[21,23,42,43] of exercise has been associated with ultrastructural damage to the muscle fiber. Although it may be speculative, it has been suggested that fatigued muscles lose their strength and ability to protect anatomically weak joints.[1,38] There is also evidence that links muscle glycogen depletion with both fatigue[5,6,23,27,29,30,48] and injury.[19,50] Because muscle glycogen depletion is associated with fatigue, and fatigue, in turn, is associated with injury, an indirect link between muscle glycogen depletion and injury is established. However, there is direct evidence relating muscle glycogen depletion with muscle fiber damage,[50] as well as with sports-related injuries.[19]

Prevention involves identifying and correcting for those risk factors that predispose one to injury. Since there is evidence supporting the notion that muscle glycogen depletion is not only associated with fatigue, but also with injury, it is appropriate to consider muscle glycogen depletion as a risk factor. Nutritional counseling and the implementation of easy-to-follow behavioral strategies are important tools in maximizing muscle glycogen stores, delaying the onset of fatigue, and, perhaps, preventing injury. The purpose of this paper is to: 1) examine the relationship between fatigue and injury, and between muscle glycogen depletion and injury; and 2) present carbohydrate strategies to maximize and replenish muscle glycogen stores.

The Relationship Between Fatigue and Injury

The term fatigue is very complex. Fatigue may be defined as "the failure to maintain the required energy output."[32] Such a definition relates to voluntary exercise. It also may be defined as "the decline in force generation."[54] This definition is more appropriate for experimental studies of electrically stimulated muscle in situ.

It is helpful to conceptualize fatigue in terms of the anatomical regions where it occurs. Fatigue develops in the central nervous system, motor nerve, neuromuscular junction, and/or the muscle. Within each anatomical region, there are many mechanisms that may contribute to the onset of fatigue,[20] and they are likely to be interdependent, synergistic, and integrated.[25] An understanding of muscle fatigue is important to the athletic trainer because nutritional strategies can be employed to attenuate or delay the onset.

There are two basic metabolic components of fatigue that develop in the muscle region: 1) an accumulation component and 2) a depletion component. The accumulation component includes the intramuscular increase in hydrogen ions and/or diprotonated phosphate, whereas the depletion component includes the decrease in calcium released from the sarcoplasmic reticulum and/or intramuscular substrates, ie, adenosine triphosphate/phosphocreatine (ATP/PC) and glycogen.[39]

The relationship between fatigue and injury is nebulous. It is difficult to confirm the assumption that there is a cause-and-effect relationship between fatigue and injury. However, there is evidence that suggests that fatigue is associated with injury. Empirically, fatigued individuals are vulnerable to injury. Arnheim and Prentice[1] are of the opinion that the chronically fatigued individual may be "an injury waiting to happen." Kvitne and Jobe[38] support the notion that fatigue may result in the substitution of movement patterns, exposing untrained musculature and joints to injury. The investigators reported that repetitive overhand throwing fatigues the stabilizing muscles surrounding the shoulder allowing for anterior glenohumeral subluxation. The body is a complex machine, and training is a process which improves performance and reduces the risk of

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injury caused by unskilled or uncoordinated muscle movement.[23] Fatigue may not be the sole cause of injury, but rather a contributing factor. After reviewing the literature regarding the etiology of hamstring strains, Worrell and Perrin[53] reported that fatigue was one of several factors that may contribute to this type of injury. It appears that injury is associated with fatigue.

Under the electron microscope, it is quite clear that there is muscle injury as a result of fatiguing prolonged exercise and eccentric exercise. Hagerman et al[27] obtained gastrocnemius biopsy samples of 10 marathon runners immediately before and after a marathon. There was an exercise-induced deterioration and degeneration of the organelles and significant inflammation following the marathon. Sjöström et al[48] also found changes in the skeletal muscle of a marathon runner. The investigators secured muscle biopsies before and after an extremely long distance run (3529 km in 7 weeks) in a 46-year-old well-trained man. The tissue preparations revealed structural abnormalities characterized by diffuse increase in connective tissue, fiber size variation, and degenerated and regenerated muscle fibers. Warhol et al[50] examined the biopsies of 40 male marathon runners which were secured immediately after the completion of the race. Electron microscopy revealed myofibrillar alterations which included intra- and extracellular edema, myofibrillar lysis, disruption of the T-tubule system, and focal mitochondrial degeneration.

There is also evidence that fatiguing eccentric exercise contributes to muscle damage. Newham et al[42] reported very high levels of creatine kinase in elbow flexors following maximal eccentric contractions for 20 minutes. Creatine kinase is found almost exclusively in muscle tissue and serum or plasma, and is considered an indicator of muscle damage.[2,45] Fridén et al[21] reported Z-line disruption and streaming in human muscle fibers following an exercise protocol that involved running downstairs, which is an eccentric type of exercise.

Clinical manifestations that are associated with microscopic ultrastructural muscle damage after fatiguing eccentric exercise are soreness and tenderness. Costill et al[15] reported that after 10 sets of 10 eccentric contractions of the knee extensor muscles, the subjects experienced severe muscle soreness and edema. Newham et al[43] found similar results using an exercise protocol involving eccentric contraction of the quadriceps. Pain was noted approximately 8 hours after exercise and was maximal at approximately 48 hours after exercise. After a later experiment, they reported that subjects experienced muscle pain in the elbow flexors after repeated high intensity eccentric exercise.[42]

The obvious clinical signs of muscle pain and tenderness as a result of ultrastructural damage to the muscle may not be quite so apparent after prolonged exercise. Hagerman et al[27] reported that exercise-induced muscle soreness is apparent 12 to 24 hours in experienced and nonexperienced long distance runners. However, other studies did not support this observation.[48,50] This inconsistency in the presence of muscle soreness after a long distance event could be attributed to differences in the subject's training level, perception of soreness, and/or the level of circulating endorphins.

In summary, there appears to be an association between fatigue and injury. Fatiguing prolonged exercise and eccentric exercise represent two distinct mechanisms of ultrastructural muscle damage, resulting in a common cellular pathology. The etiology of muscle damage as a result of eccentric exercise seems to be mechanical in origin. High tension developed in single muscle fibers during muscle lengthening may attribute to the ultrastructural changes.[3,21,23,42,43] In comparison, prolonged exercise is associated with a depletion in muscle glycogen stores resulting in a decrease in energy production. Substrate lack may serve to be the etiology of injury to the muscle cell during prolonged exercise.[15,22,46,48,50]

The Relationship Between Muscle Glycogen Depletion and Injury

Muscle glycogen is the storage form of glucose, which is a monosaccarhide derived from carbohydrate digestion.[40] Glucose provides energy in the form of ATP to fuel muscles.[11,26,44] ATP is continually being broken down to adenosine diphosphate by various tissues of the body for biological work, eg, nerve transmission, circulation, tissue synthesis, glandular secretion, digestion, and muscle contraction.[35] The availability of ATP is an important determinant in delaying the onset of skeletal muscle fatigue.[28] Because there is only a very minute store of ATP in the muscle cell, ATP is constantly being resynthesized to provide the cell with energy.[44] Foods consumed and stored are potential warehouses of ATP.[35,44]

Intensity and duration of exercise, as well as the individual's fitness status and diet, are important determinants of fuel use.[10–12,28,29,41] Fatigue resulting from low intensities (less than 50% VO_2 max), is a consequence of a central neurological component.[29]

In highly trained individuals, fatigue resulting from exercise of moderate to heavy intensities (50% to 75% VO_2 max), coincides with liver glycogen and muscle glycogen depletion and eventually a decline in blood glucose. When liver glycogen levels become depleted, critical blood glucose is maintained for a short time by gluconeogenesis, which is the formation of glucose from a noncarbohydrate source, ie, proteins and lactate.[28,44] However, this process eventually fails to keep up with the pace of skeletal muscle blood glucose use. Hypoglycemia ensues and can produce symptoms of nausea and extreme discomfort.[12,39] In contrast, an unfit individual does not usually experience the depletion component of muscle fatigue at moderate to high intensities, but rather the accumulation component. Lactic acid accumulates in the body resulting in a decrease of work output. Thus, the

specific mechanism for the onset of skeletal muscle fatigue in moderate to heavy intensity exercise is dependent on one's level of fitness.[11,29,52]

As exercise intensities increase to 75% to 90% VO_2 max, fit individuals may experience fatigue because of muscle glycogen depletion and possible lactic acid accumulation. In contrast, unfit individuals cannot tolerate this intensity for very long because of lactic acid accumulation. Thus, the mechanism of fatigue for unfit individuals is usually lactic acid accumulation and not glycogen depletion. Again, one's level of fitness is an important issue when examining skeletal muscle fatigue at heavy intensities.[11,29,52]

Very short and supramaximal bursts of activity (greater than 100% VO_2 max), cannot be sustained for very long. PC is stored in the muscle cell in limited amounts and is the only available substance that can be used to resynthesize ATP. Once the PC stores are depleted, extremely intense exercise can no longer be sustained.[29,39]

Similar to continuous exercise, intermittent exercise results in glycogen depletion. Bergstrom and Hultman[6] examined glycogen depletion in subjects after engaging in an activity performed intermittently. The investigators reported that glycogen was nearly depleted after 60 minutes of exercise. Another study reported glycogen depletion after six 1-minute sprints were performed with a 10-minute rest on a bicycle ergometer.[24]

Several studies support the finding that prolonged moderate and intermittent exercise coincide with muscle glycogen depletion and relate it to injury. Using the needle biopsy technique, Eriksson et al[19] examined the glycogen content of a muscle homogenate. There was a large decline in muscle glycogen content after an entire day of downhill skiing. The investigators related the finding to downhill skiing injuries and were of the opinion that depleted glycogen stores were the reason that more injuries occur toward the end of the day.

Warhol et al[50] examined the association of exercise-induced muscle glycogen depletion and repletion on the myofibrillar changes in the muscle cell. Forty runners completed a marathon and needle biopsies of the lateral gastrocnemius were performed immediately, 1 week, and 1 month after the race. Muscle biopsies revealed glycogen depletion and cellular damage, ie, intra- and extra-cellular edema, myofibrillar lysis, dilation and disruption of the T-tubule system, and focal mitochondrial degeneration. Biopsies taken 1 week after competition showed signs of resolution coinciding with the reconstitution of muscle glycogen. One month after competition, most of the myofibrillar damage was resolved, and muscle fibers contained an abundance of glycogen. The investigators surmised that the focal damage may result specifically from metabolic stress. In other words, there was a continued demand on the muscle to produce work in spite of depleted glycogen stores. The glycogen depletion and repletion pattern immediately after the race and during recovery correlated with restoration from myofibrillar damage.

Thus, glucose is an important substrate during prolonged moderate and intermittent exercise. There is evidence indicating that muscle glycogen stores are depleted when the exercise is continued to fatigue[5,6,30] and at the end of competition in sports that are intermittent in nature, eg, soccer.[4,34,36]

Both indirect and direct evidence support the notion that depleted muscle glycogen stores contribute to injury. Indirectly, it is quite clear that depleted muscle glycogen stores coincide with fatigue, and fatigue in turn is associated with injury. Although most of the evidence involves relationships rather than showing cause, many of the investigations strongly suggest a cause-and-effect relationship.

Prevention of Injury Through Carbohydrate Strategies

Injury prevention involves screening individuals and identifying extrinsic risk factors that may predispose one to injury. After the risk factor has been identified, appropriate modifications can be implemented to eliminate or attenuate its presence. Extrinsic injury risk factors are those that occur outside the body (eg, equipment, playing field, weather conditions, etc) and are easily corrected.[49] Feeding behavior involves extrinsic choices and, therefore, can be modified through appropriate nutritional strategies.

An understanding of proper nutrition, particularly carbohydrate, is exceedingly important for the physically active individual. Depleted muscle glycogen stores are associated with fatigue and injury. Since muscle glycogen is derived mostly from carbohydrate consumption, active individuals must make a conscious effort to consume an adequate amount of carbohydrate. Nutritional strategies should focus on carbohydrate intake to maximize and replenish glycogen stores[12,14] and to prevent possible injury.

Daily Carbohydrate Intake

Regardless of activity, adults should consume approximately 60 to 70% of their total caloric intake in carbohydrates, 22 to 30% in fat, and 12 to 20% in protein.[12,16,52] To achieve the appropriate carbohydrate intake, the individual can choose one of three methods: 1) percentage of the total caloric intake, 2) g/kg of body weight, or 3) the food pyramid system (Table 1).

The percent of the total caloric intake method requires the determination of total caloric intake. Total caloric intake for the inactive is 26 to 27 kcal/kg of body weight, for the moderately active is 33 to 34 kcal/kg of body weight, for the very active is 35 to 44 kcal/kg of body weight, and for the intensely active is 55 to 66 kcal/kg of body weight.[9] Multiply total caloric intake by 60% to 70% to determine the number of carbohydrate calories that should be consumed. To determine total number of carbohydrate grams, divide carbohydrate calories by 4, since 4 calories equals 1 g of carbohydrate.

Table 1.—Three Dietary Methods for Daily Carbohydrate Intake

Method	Body Weight (kcal/kg)
Method I: Percentage of Total Caloric Intake	
1. Determine caloric intake activity level	
a. inactive	5–6
b. moderately active	7
c. very active	8–9
d. intensely active	11–14
2. Percentages of total caloric intake	
a. carbohydrate	60–70%
b. protein	12–20%
c. fat	22–30%
3. Multiply total caloric intake (from step 1) by each of the percentages in step 2 to determine the kcal of carbohydrate, protein, and fat.	
Method II: Gram/kg of Body Weight	
1. Heavy training	10 g/kg
2. Moderate training	8 g/kg
3. Light training (no less than)	6 g/kg
Method III: Food Pyramid/Exchange System	

Another method of determining daily total carbohydrate intake is by gram of carbohydrate/kg of body weight. There is evidence that 8 to 10 g of carbohydrate/kg of body weight will maintain appropriate glycogen levels during heavy training.[11,12,28] It is advisable that all active individuals should consume no less than 6 g of carbohydrate/kg/day.[12]

The last method for determining daily carbohydrate intake uses a combination of the Food Pyramid, which was developed by the USDA in 1992, and the Exchange System, which was developed by the American Diabetic Association and the American Dietetic Association. Using the six food lists from the pyramid: 1) meats, 2) vegetables, 3) fruit, 4) bread/grain, 5) milk, and 6) fat, Coleman[11] developed a meal plan (Table 2). The foods within each list are similar in terms of carbohydrate, fat, and protein. Table 3 reports the meal plan and exchanges for selected caloric intakes and is based on a diet containing approximately 60% carbohydrate, 15 to 20% protein, and less than 25% fat. Because the individual learns caloric, carbohydrate, protein, and fat content of a wide variety of foods, the Food Pyramid/Exchange System is an excellent educational tool.[12] Houtkooper[31] developed a similar system using the Food Pyramid, but instead of using the exchanges, this author uses serving sizes and refers to the meal plan as the Sport Food Swap. The biggest drawback with Coleman's[11] and Houtkooper's[31] meal plans is that it is difficult to estimate combination foods.

Carbohydrate Loading

Carbohydrate loading is designed to increase intramuscular glycogen stores.[52] This protocol is only beneficial for those individuals whose event is longer than 60 minutes (eg, endurance events) and whose event requires repeated bouts of high intensity exercise (eg, day-long soccer and tennis tournaments). Maximizing glycogen stores can increase time to exhaustion. Larger glycogen stores will not prevent fatigue, but will delay its onset.[16,44]

The "classical" carbohydrate-loading program begins 1 week before competition. The program involves two exhaustive bouts of exercise 7 and 4 days prior to the event, and the consumption of a diet low in carbohydrate 7,6,5, and 4 days prior to the event. Three days before the event, carbohydrate intake increases to 90% of the total caloric intake.[44] Although the "classical" regimen doubles muscle glycogen levels, it has its disadvantages. Diets low in carbohydrate result in hypoglycemia, hypokalemia, and ketosis, which can produce associated symptoms, eg, fatigue, nausea, and dizziness.[12] Although diets low in carbohydrates have undesirable physiological consequences, it is important to keep in mind that diets too high in carbohydrates may produce bloating and gastrointestinal distress.[51]

A modified version of the "classical" method results in a similar increase of muscle glycogen. Like the "classical" method, it begins 7 days before the event and involves a gradual tapering of activity, and a normal consumption of carbohydrate (350 g/day) on days 7,6,5, and 4 prior to the event. Three days before the event, carbohydrate intake dramatically increases to 500 to 600 g/day and is maintained until the day of the event.[47] The "modified" method does not produce hypoglycemia and associated symptoms.[12]

Pre-event

Pre-event meals should be eaten by active individuals 4 hours before the activity to prevent the possible onset of hypoglycemia by normalizing blood glucose and insulin levels.[14] The pancreas releases insulin in response to carbohydrate intake. If more insulin is secreted than is needed to clear the blood of excess glucose, hypoglycemia can ensue.[26] It is important to stress that not all individuals experience the hypoglycemic response as a result of carbohydrate consumption.[11,16,28]

Individuals consuming a pre-event meal 4 hours before the event should eat 4 g of carbohydrate/kg of body weight. The general rule of thumb, when consuming a pre-event meal less than 4 hours prior to the activity, is to eat fewer and fewer grams of carbohydrate as the event draws near.[44] For example, if one consumes a meal 3 hours before the activity, then the participant should consume 3 g of carbohydrate/kg of body weight. Likewise, the participant who consumes a meal 2 hours before

Table 2.—Sample of the American Diabetic Association's Food Exchange List (by Food Group)

1. **Starch/Bread List (80 kcal)**
   - Carbohydrate—15 g
   - Protein—3 g
   - Fat—0 g
     - whole wheat bread (1 slice)
     - peas (1/2 cup)
     - baked beans (1/4 cup)
     - pasta (cooked, 1/2 cup)
2. **Meat List**
   - *Lean Meats* (55 kcal)
   - Carbohydrate—0 g
   - Protein—7 g
   - Fat—3 g
     - cottage cheese (1/4 cup)
     - luncheon meat (<95% fat free)
     - sirloin (1 oz)
     - chicken (1 oz)
   - *Medium Fat Meats* (75 kcal)
   - Carbohydrate—0 g
   - Protein—7 g
   - Fat—5 g
     - ground beef (1 oz)
     - veal cutlet (1 oz)
     - mozzarella (1 oz)
     - tuna (in oil, 1/4 cup)
   - *High Fat Meats* (100 kcal)
   - Carbohydrate—0 g
   - Protein—7 g
   - Fat—8 g
     - corn beef (1 oz)
     - fried fish (1 oz)
     - bratwurst (1 oz)
     - American cheese (1 oz)
3. **Vegetable List (25 kcal)**
   - Carbohydrate 5 g
   - Protein—2 g
   - Fat—0 g
     - asparagus (1/2 cup)
     - carrots (1/2 cup)
     - tomato (1 large)
     - peppers (1/2 cup)
4. **Fruit List (60 kcal)**
   - Carbohydrate—15 g
   - Protein—0 g
   - Fat—0 g
     - banana (1/2)
     - orange (1)
     - cherries (1/2 cup)
     - apple (1)
5. **Milk List**
   - *Very Lowfat Milk* (90 kcal)
   - Carbohydrate—12 g
   - Protein—8 g
   - Fat—0 g
     - skim milk (1 cup)
   - *Lowfat Milk* (120 kcal)
   - Carbohydrate—12 g
   - Protein—8 g
   - Fat—5 g
     - 2% milk (1 cup)
   - *Whole Milk* (150 kcal)
   - Carbohydrate—12 g
   - Protein—8 g
   - Fat—8 g
     - whole milk (1 cup)
6. **Fat List (45 kcal)**
   - Carbohydrate—0 g
   - Protein—0 g
   - Fat—5 g
     - avocado (1/8)
     - salad dressing (oil, 1 Tbsp)
     - olives (10 small)
     - peanuts (20 small)

Table 3.—Meal Plans Using the Exchange Lists (Table 2) and Providing Approximately 60 to 70% Carbohydrate, 12 to 20% Protein, and 25% Fat[4]

	Number of Exchanges					
Calorie Level	1500	2000	2500	3000	3500	4000
Food group						
Milk	3	3	4	4	4	4
Meat	5	5	5	5	6	6
Fruit	5	6	7	9	10	12
Vegetable	3	3	3	5	6	7
Grain	7	11	16	18	20	24
Fat	2	3	5	6	8	10

the event, should eat 2 g of carbohydrate/kg of body weight, and so forth.

Immediately Before the Exercise

It may be advantageous for individuals who participate in endurance events (longer than 60 minutes in duration), and in repeated bouts of high intensity exercise (eg, day-long soccer and tennis tournaments), to consume a liquid carbohydrate meal 1 hour before the event. A liquid carbohydrate meal promotes fluid uptake and requires a shorter gastric emptying time.[12] It has been reported that consuming a carbohydrate drink 30 to 60 minutes before the event can increase the rate of muscle glycogen use and decrease time to exhaustion[13,14]; however, several reports fail to support that finding.[29,52] It is acceptable to consume carbohydrates 5 to 10 minutes before the event of moderate intensity because peak blood glucose levels occur 15 to 30 minutes after the carbohydrate ingestion.[29] The insulin response to carbohydrate intake is blunted during exercise, and the concern for hypoglycemia is thwarted.[12,52]

During Exercise

Carbohydrate intake during exercise lasting longer than 60 minutes and for events requiring repeated bouts of high intensity exercise is important because it delays the onset of fatigue.[14] Muscle glycogen supplies the muscle with the majority of carbohydrate energy during the early portions of exercise. However, as exercise continues, muscle glycogen contributes a smaller portion while blood glucose contributes a greater percentage resulting in hypoglycemia and fatigue.[11,16,52]

It is essential that nutritional strategies focus on maintaining adequate levels of blood glucose. Dry glucose polymers, which are mixed in water and are available commercially, work quite well to normalize blood glucose and insulin levels. To avoid a delay in gastric emptying and gastrointestinal distress, it is recommended that such drinks consist of 6% to 8% percent solution containing 15 to 20 g

of carbohydrate/7 oz of water and be consumed every 15 minutes.[12,51]

After Exercise

To minimize postexercise fatigue, it is very important to restore muscle glycogen stores associated with repeated bouts of heavy training or physical workouts lasting 60 minutes or longer. Factors that influence muscle glycogen resynthesis are: 1) the timing of the carbohydrate ingestion after exercise, 2) the carbohydrate type, and 3) the rate of carbohydrate ingestion.

Because there is a slightly faster rate of muscle glycogen resynthesis immediately following a workout, carbohydrate should be consumed very soon after the exercise session. Fifty grams of carbohydrate for a 70-kg individual is the necessary amount to promote optimal muscle glycogen resynthesis. However, more than 50 g of carbohydrate does not enhance muscle glycogen resynthesis.[7,17,18]

Glycemic index represents the effect that a particular food has upon the rate and amount of increase in blood glucose levels.[51] Foods and beverages having a high-to-moderate glycemic index augment muscle glycogen resynthesis. Fifty grams of carbohydrate having a high to moderate glycemic index include: glucose (4.2 Tbsp), sucrose (4.2 Tbsp), bagels (1.6), bread (3.5 slices), baked potatoes,[1] rice (1 cup), macaroni (1.5 cups), oranges,[3] corn (1.2 cups), 6% sucrose solution (3.5 cups), 10% corn syrup (carbonated drink; 2.1 cups), and 20% maltodextrin solution (1.1 cups). Fructose, a carbohydrate found in fruits and honey, has a low glycemic index and produces a slow rate of muscle glycogen resynthesis.[7,17,18,37]

It is recommended that following a workout, 600 g of carbohydrate should be consumed by a 70-kg person within a 24-waking-hour period to completely replenish muscle glycogen stores. The maximal rate of muscle glycogen resynthesis immediately following exercise is 7% to 8% per hour. Approximately 2 to 4 hours after exercise the maximal rate of muscle glycogen resynthesis slightly decreases to 5% to 6% per hour. Approximately 50 g of carbohydrate should be ingested every 2 hours for a period of 24 waking hours to maximize muscle glycogen resynthesis.[17,18,33]

Thus, to hasten the postexercise recovery between workout sessions, the active individual should consume approximately 50 g of a high-to-moderate glycemic carbohydrate immediately following the exercise bout. Thereafter, 50 g of a high to moderate glycemic carbohydrate should be consumed every 2 hours/24 waking hours. Practicality, palatability, and preference of foods should dictate what is consumed. In terms of muscle glycogen resynthesis, beverages have no advantage over foods. The amount and timing, as well as the glycemic index, are very important factors in postexercise muscle glycogen repletion.

Injury prevention is one of the six domains reported in the 1990 role delineation study conducted by the NATA[8] and involves identifying risk factors that make one vulnerable. Muscle glycogen depletion is not only associated with fatigue, but also with injury. Athletic trainers should employ easy-to-follow nutritional strategies that would maximize muscle glycogen stores and delay the onset of fatigue.

If an active individual has normal glycogen stores and participates in an activity lasting less than 60 minutes or in an event requiring repeated bouts of high intensity exercise, then it is unlikely that glycogen stores will be depleted. However, if that same individual participates in an event lasting longer than 60 minutes, then glycogen stores may be depleted and nutritional strategies should focus on daily carbohydrate intake, carbohydrate loading, the pre-event meal, and carbohydrate intake immediately before, during, and after the event.

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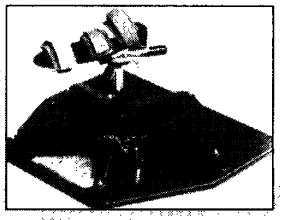

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