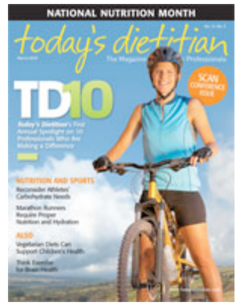

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**Reconsider Athletes’ Carbohydrate Needs**
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Watching the recent Winter Olympics, we stood in awe of the dedication and hard work these athletes manifest in their quest to achieve the pinnacle of performance. Most, if not all, pay strict attention to diet and nutrition as well.

Adequate carbohydrate stores (muscle and liver glycogen and blood glucose) are critical for optimum performance during both intermittent high-intensity work such as ski racing and prolonged endurance exercise such as the biathlon or long-distance skating. Thus, current sports nutrition guidelines recommend strategies to enhance carbohydrate availability before, during, and after exercise to promote optimum athletic performance and glycogen restoration.1

Experts have long assumed that consuming a carbohydrate-rich diet during training allows athletes to train harder and longer and thus achieve a superior training response. However, some practitioners are now suggesting that athletes train with low carbohydrate stores but restore carbohydrate availability for competition—in other words, train low, compete high. In theory, exercising in a low-fuel state enhances the body’s adaptation to training and results in superior endurance performance.

This article will review current research on athletes’ carbohydrate requirements and evaluate the limited research on the train low concept.

**Fuel for Exercise**
During moderate-intensity exercise (65% of VO2max), muscle glycogen and plasma glucose supply about one half of energy, with the remainder coming from fat oxidation. Plasma free fatty acids and intramuscular triglycerides initially contribute equally to total fat oxidation during moderate-intensity exercise in endurance-trained individuals. The absolute rate of fat oxidation is highest during moderate-intensity exercise.2

High-intensity exercise (85% of VO2max) promotes relatively high rates of glycogenolysis (glycogen breakdown), glycolysis, and accumulation of lactic acid in the muscles and blood. Muscle glycogen and blood glucose provide more than two thirds of the needed energy during exercise at 85% of VO2max, with the remainder coming from plasma fatty acids and intramuscular triglycerides.2

There are several explanations for the shift toward greater carbohydrate oxidation as the exercise intensity increases. Lipolysis (the breakdown of triglycerides to fatty acids) is markedly suppressed during high-intensity exercise, thus reducing the availability of fatty acids to the muscles. Also, the increased rate of glycogenolysis, glycolysis, and lactic acid production during intense exercise appears to limit the entry of long-chain fatty acids into the muscle cell mitochondria, thereby hindering fat oxidation. The rate of fat oxidation appears to be limited more by the muscles’ ability to oxidize fat rather than by the availability of fat.2

Since fat can provide only about one half of the energy required for moderate-intensity exercise and no more than one third of the energy for high-intensity exercise, it is understandable that nutrition guidelines for athletes routinely recommend a carbohydrate-rich diet.

carbohydrate-rich diet.

**Effect on Performance**
In evaluating recovery from training, it is important to differentiate between acute and chronic restoration of endurance capacity.

It is apparent that a high carbohydrate intake acutely enhances recovery and improves endurance performance over 24 to 72 hours.3,4 Fallowfield and Williams report that a high-carbohydrate diet (8.8 g/kg/day) restored endurance capacity within 22.5 hours of recovery between training sessions. An isocaloric diet containing less carbohydrate (5.8 g/kg/day) was associated with decreased endurance.5

Although a high carbohydrate intake promotes greater recovery of muscle glycogen, only a handful of studies show chronic improvements in training outcomes over seven to 28 days.3 Achten and colleagues found that a high-carbohydrate diet (8.5 g/kg/day) allowed for better maintenance of physical performance and mood state during 11 days of intensified running training compared with a moderate-carbohydrate diet (5.4 g/kg/day).6 Simonsen and colleagues found that a diet containing 10 g of carbohydrate per kilogram per day promoted greater muscle glycogen content and power output during training than a diet containing 5 g/kg/day over four weeks of intense twice-daily rowing training.7

Considering the widespread practice of carbohydrate loading, it is odd to note that only a few training studies have found a performance benefit from a high-carbohydrate diet.4 In addition to methodological issues, it is possible that athletes adapt to lower muscle glycogen stores resulting from a moderate-carbohydrate intake so that their training and competitions are not adversely affected.4 However, the internationally renowned Australian researcher Louise Burke, PhD, BSc, emphasizes that no study has shown a moderate carbohydrate intake of 5 to 7 g/kg/day produces greater training adaptations and performance compared with a higher carbohydrate intake of 8 to 10 g/kg/day.4 The absence of positive results from lower carbohydrate intake, by default, leads athletes to a higher intake during training, though there is no corresponding research to support that position. Thus, current sports nutrition guidelines recommend strategies to promote carbohydrate availability during daily training.1,3,4

These guidelines are founded on abundant evidence that enhancing carbohydrate availability (eg, consuming carbohydrate before and during exercise) during a single session of exercise improves endurance and performance.1,3,4 Since the literature fails to provide clear evidence that long-term carbohydrate-rich diets enhance training adaptations and performance, further well-controlled studies are necessary to test this assumption.4 For now, evidence from studies of acute carbohydrate intake and performance remain the best estimate of athletes' chronic carbohydrate needs.4

**Daily Recommendations**
Dietary guidelines for the general population usually express goals for macronutrient intake as a percentage of total energy. For example, the Food and Nutrition Board of the Institute of Medicine has established an Acceptable Macronutrient Distribution Range for carbohydrate at 45% to 65% of energy.

However, the absolute quantity of carbohydrate rather than the percentage of energy from carbohydrate is important for exercise performance. Increased work creates increased demand. An athlete's estimated carbohydrate requirements should consider the amount of carbohydrate required for optimal glycogen restoration or the amount expended during training. These estimates should also be provided according to athletes' body weight to account for the size of their muscle mass.3,4

Current sports nutrition guidelines recommend 5 to 12 g of carbohydrate per kilogram of body weight per day.3,4 This recommendation is clear, user friendly, and practical; it is relatively easy for athletes to determine the carbohydrate content of their meals and snacks to achieve recommended daily carbohydrate goals. Athletes engaged in moderate-intensity exercise for 60 to 90 minutes per day should consume 5 to 7 g/kg/day. During moderate- to high-intensity endurance exercise for one to three hours, athletes should consume 7 to 12 g/kg/day. Athletes participating in extreme endurance exercise for 4 to 6 hours per day (eg, Tour de France) should consume 10 to 12 g/kg/day.3,4

These are general recommendations and should be adjusted according to athletes' total energy needs, specific training needs, and feedback from their training performance.3,4 These guidelines seem to work well for events, but what about training? Recently, another school of thought has emerged.

**Training Low**

Some practitioners have proposed that athletes train with low carbohydrate stores but compete with high fuel availability to promote performance—train low, compete high. In theory, training with low muscle glycogen stores maximizes the physiological adaptations to endurance training and improves performance when higher levels are available during events.

Although there are numerous ways to reduce carbohydrate availability for training, the current research is confined to studies of twice-a-day training (starting the second session with low muscle glycogen stores) and holding back on carbohydrate during training sessions.

A 2005 study by Hansen and colleagues at the Copenhagen Muscle Research Centre sparked intense interest in the train low concept.8 Seven untrained men participated in a 10-week program of leg (knee extensor) exercise and consumed a carbohydrate-rich diet (8 g/kg/day). Each subject's legs completed the same weekly five-hour training program but received a different daily schedule: One leg was trained twice per day on every second day and the other leg was trained once daily. Thus, one leg exercised with full restoration of glycogen each day (train high), while the twice-a-day leg underwent the second session with depleted muscle glycogen stores (train low).

Compared with the leg that trained daily with normal glycogen reserves, the leg that started the second training session with low muscle glycogen levels had higher resting glycogen content and citrate synthase activity. The increase in maximal power was identical for the two legs. However, there was about a twofold greater training-induced increase in one-leg time to fatigue in the train low leg compared with the leg trained with normal glycogen stores. These results suggest that training adaptations may be enhanced by low glycogen availability, thereby improving endurance.8

This study had several limitations. The subjects were untrained, so these results may not apply to endurance-trained athletes. The training sessions were also held at a fixed submaximal intensity during the training program and do not reflect how athletes actually train. Lastly, the type of training (one-legged knee extensor exercise) and performance trial do not remotely resemble how most competitive athletes train and compete.9

Yeo and associates evaluated the effects of undertaking training with low muscle glycogen content on training capacity, endurance performance, and substrate metabolism in endurance-trained cyclists/triathletes. The authors also measured the activity of several muscle enzymes associated with training adaptation: beta-hydroxyacyl-CoA-dehydrogenase (an indicator of beta-oxidation) and citrate synthase (an indicator of Krebs cycle activity). The subjects consumed 8 g of carbohydrate per kilogram per day and completed six training sessions (about eight hours total) per week for three weeks. Seven subjects trained daily (train high), alternating between a steady-state aerobic ride one day (100 minutes at 70% of VO2 peak) and a high-intensity interval training session the next day (five-minute intervals at maximum self-selected power output, repeated eight times with a one-minute recovery between intervals).

Another seven subjects trained twice every other day (train low) with the steady-state aerobic ride followed by the interval session one hour later. The subjects' training intensity was measured as the self-selected power outputs achieved in the interval session. Performance was measured 48 hours before and after the first and last training session by a one-hour time trial completed after one hour of steady-state cycling.9

The authors found that only the train low group experienced significant increases in resting muscle glycogen concentrations, fat oxidation during steady-state cycling, and activity of the muscle enzymes beta-hydroxyacyl-CoA-dehydrogenase and citrate synthase. Although training intensity was significantly lower in the train low group for the first two weeks, during the last week there were no differences whether the subjects started the workouts with low or high glycogen stores. Performance during the one-hour time trial was significantly higher for both groups (12% for train low and 10% for train high), but there were no significant differences in performance between the two groups.9

The researchers concluded that despite metabolic and muscle enzyme changes indicating an enhanced training adaptation in the train low group, there was no obvious benefit to endurance performance compared with when the subjects undertook training with high muscle glycogen stores.9

Morton and colleagues evaluated recreationally active men who performed six weeks of high-intensity intermittent running with varying carbohydrate availability.10 Eight subjects trained once per day, four times per week (train norm), seven subjects trained twice per day, two times per week (train low), and eight subjects trained low but consumed a 6.4% glucose solution before and during the second training session (train low with carbohydrate).

Although the train low group had significantly greater increases in the activity of the oxidative enzyme succinate dehydrogenase, all three groups had similar improvements in maximal oxygen uptake and distance covered on a performance trial. The researchers concluded that while training with low availability of endogenous and exogenous carbohydrate sources generated greater training adaptations in muscle oxidative enzymes, this did not translate into improved performance during high-intensity exercise.10

Akerstrom and researchers from the Copenhagen Muscle Research Centre who undertook the first train low study examined whether consuming carbohydrate during exercise would diminish training adaptations.11 Nine untrained subjects completed 10 weeks of one-legged knee extensor training. One leg was trained while the subject consumed a 6% glucose drink, and the other leg was trained while the individual consumed a placebo. Following training, both legs had similar increases in muscle glycogen content, the enzymes beta-hydroxyacyl-CoA-dehydrogenase and citrate synthase, and performance. The researchers concluded that consuming carbohydrate during training does not alter the training response.11

De Bock and associates evaluated the effect of six weeks of endurance training (three times per week for one to two hours at 75% of VO2 peak) in the fasted state compared with training with carbohydrate on substrate selection during exercise when fed carbohydrate.12 Ten subjects trained in the fasted state while 10 subjects received a carbohydrate-rich breakfast 90 minutes before training and consumed carbohydrate during training (1 g/kg/hour). The fasted group received additional carbohydrate later in the day to match the daily carbohydrate and energy intake of the group that trained with carbohydrate. Substrate use during a two-hour exercise session was determined before and after the six-week training period. All subjects received a carbohydrate-rich breakfast and consumed 1 g of carbohydrate per kilogram per hour during these exercise sessions.

The authors found that adaptations to endurance training in the fasted state were similar to training in the carbohydrate-fed state. Although there was a decrease in muscle glycogen utilization and an increase in proteins involved in fat utilization, training in the fasted state did not result in an increased rate of fat oxidation during exercise when the subjects were fed carbohydrate.12

***Benefits and Risks***

In theory, training low enhances the training stimulus, increases the ability to utilize fat as an exercise fuel, and reduces the reliance on carbohydrate. Despite creating metabolic and muscle enzyme adaptations that should enhance endurance, there is no clear proof that training low improves endurance performance.9,10

Proponents claim that training low improves athletes' body fat loss and decreases their need for carbohydrate during competition. Thus, training low may reduce risk of developing gastrointestinal distress by decreasing the amount of carbohydrate-rich foods and fluids they consume during competition. This area requires further study, although the premise seems logical.

Training low may offer an athlete who is unable to train daily a time-efficient method of maintaining training adaptations and performance. The athlete can perform two workouts close together so that he or she undertakes the second session with low muscle glycogen stores. As Yeo and associates demonstrated, despite a diminished high-intensity training capacity, training twice every second day produced an increase in endurance performance comparable to that achieved by training every day.9

An athlete's diet and ability to complete strenuous training sessions day after day are highly connected. Experts generally assume that training with high carbohydrate availability allows an athlete to train harder and improve performance. Training low may interfere with the intensity and/or volume of endurance training. Thus, experimenting with training low is most suitable in the beginning of a training cycle when it is least likely to harm performance. High carbohydrate availability is recommended for high-intensity training sessions and when the athlete is preparing to peak for competition.

The results of the training low studies bring to mind another dietary periodization strategy for athletes who failed to meet expectations: adaptation to high-fat diets, or fat loading. This strategy also looked good on paper, but Burke and Kiens found that what was initially considered glycogen sparing following fat adaptation actually represented a down-regulation of carbohydrate metabolism, or glycogen impairment.13 Fat adaptation increased fat utilization but reduced the activity of pyruvate dehydrogenase, a rate-limiting enzyme in carbohydrate utilization. In fact, not only did fat adaptation fail to improve athletes' endurance performance, but it also reduced their ability to perform high-intensity exercise.13 This is significant because the strategic moves that occur during competition (eg, breaking away, surging up a hill, sprinting to the finish line) all depend on the athlete's ability to work at high intensities, which are in turn fueled by carbohydrate.13

There is also the concern that training with low carbohydrate availability may increase risk of illness. Consuming carbohydrate during high-intensity endurance exercise attenuates rises in stress hormones such as cortisol and appears to limit the degree of exercise-induced immune depression.14

More research is certainly warranted on the train low model. While training with low carbohydrate availability may augment the training response, there is no obvious benefit to endurance performance. It is possible that the current research has been unable to detect small improvements in performance that may be worthwhile in real-life competitive events.4

A large body of evidence indicates that carbohydrate supplementation before and during exercise improves performance. The use of short-term dietary and training strategies to increase muscle glycogen stores (eg, carbohydrate loading) also improves performance. Thus, it is reasonable to continue to recommend dietary strategies that promote carbohydrate availability to support optimum athletic performance.3,4

**Recommend Strategies to Promote Carb Availability**
Adequate carbohydrate stores are critical for optimum performance during both intermittent high-intensity work and prolonged endurance exercise. It is assumed that consuming a carbohydrate-rich diet during training will allow the athlete to train harder and longer and thus achieve a superior training response. Current sports nutrition guidelines recommend 5 to 12 g of carbohydrate per kilogram per day.

Some practitioners have proposed that athletes train with low carbohydrate stores but compete with high fuel availability to promote performance—train low, compete high. In theory, training with low muscle glycogen stores maximizes the physiological adaptations to endurance training and improves performance. Despite creating metabolic and muscle enzyme adaptations that should enhance endurance, there is no clear proof that "training low" improves endurance performance.

While more research is certainly warranted on the train low model, it is reasonable to continue to recommend dietary strategies that promote carbohydrate availability to support optimum athletic performance.

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**Carbohydrate Recommendations**
• 5 to 7 g of carbohydrate per kilogram per day for athletes engaged in moderate-intensity exercise for 60 to 90 minutes per day
• 7 to 12 g of carbohydrate per kilogram per day for athletes engaged in moderate- to high-intensity endurance exercise for one to three hours
• 10 to 12 g of carbohydrate per kilogram per day for athletes participating in extreme endurance exercise for four to six hours per day (eg, Tour de France)

**Learning Objectives**
After completing this continuing education exercise, the student should be able to:
1. Explain the importance of dietary carbohydrate based on fuel usage during exercise.
2. Provide general recommendations for daily carbohydrate intake based on exercise intensity and duration.
3. Describe the potential risks and benefits of the training low concept.
4. Review the results of the present research on the training low concept.

**Examination**
1. Muscle glycogen and blood glucose provide more than _____ of the needed energy during exercise at 85% of VO2max.
a. three quarters
b. one half
c. one quarter

d. two thirds
e. one third

2. Athletes engaged in moderate-intensity exercise for 60 to 90 minutes per day should consume:
a. 45% to 65% of energy from carbohydrate.
b. 5 to 7 g of carbohydrate per pound of body weight per day.
c. 7 to 12 g of carbohydrate per kilogram of body weight per day.
d. 10 to 12 g of carbohydrate per kilogram of body weight per day.
e. None of the above

3. All of the following statements about carbohydrate and performance are true except the following:
a. A high carbohydrate intake acutely enhances recovery and improves endurance performance over 24 to 72 hours.
b. Numerous studies show that a high carbohydrate intake promotes chronic improvements in training outcomes over seven to 28 days.
c. The use of short-term dietary and training strategies to increase muscle glycogen stores (eg, carbohydrate loading) improve performance.
d. Studies of acute carbohydrate intake and performance remain the best estimate of athletes' chronic carbohydrate needs.
e. Adequate carbohydrate stores are critical for optimum performance during both intermittent high-intensity work and prolonged endurance exercise.

4. Despite creating metabolic and muscle enzyme adaptations that should enhance endurance, there is no clear proof that training low improves endurance performance.
a. True
b. False

5. The Hansen study on training low has the following limitations:
a. The subjects were untrained.
b. The subjects were endurance athletes.
c. The type of training did not resemble how competitive athletes train and compete.
d. b and c
e. a and c

6. In the Yeo study, the train low subjects experienced significant increases in:
a. resting muscle glycogen.
b. fat oxidation during steady-state cycling.
c. performance.
d. a and b
e. b and c

7. In the De Bock study, the fasted subjects had a significant:
a. decrease in muscle glycogen utilization.
b. increase in proteins involved in fat utilization.
c. increase in fat oxidation when fed carbohydrate.
d. a and c
e. a and b

8. All of the following phrases about the group in the Akerstrom study that consumed carbohydrate during exercise are true except the following:
a. Decrease in training adaptations
b. Similar increase in beta-hydroxyacyl-CoA-dehydrogenase
c. Similar increase in citrate synthase
d. Similar increase in muscle glycogen content
e. Similar increase in performance

9. Potential benefits of training low include the following:
a. enhanced training stimulus.
b. reduced reliance on carbohydrate.
c. improved endurance performance.
d. a and b
e. a and c

10. Potential risks of training low include the following:
a. interference with the intensity of training.
b. interference with the volume of training.
c. increased risk of illness.
d. a and c
e. a, b, and c

**References**

1. Rodriguez NR, Di Marco NM, Langley S. Position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. ***J Am Diet Assoc***. 2009;109(3):509-527.

2. Coyle EF. Substrate utilization during exercise in active people. ***Am J Clin Nutr***. 1995;61:968S-979S.

3. Burke LM, Kiens B, Ivy JL. Carbohydrates and fat for training and recovery. ***J Sports Sci***. 2004;22(1):15-30.

4. Burke L. Nutrition for recovery after competition and training. In: Burke L, Deakin V (eds). ***Clinical Sports Nutrition***, 3rd ed. McGraw-Hill: Australia; 2006.

5. Fallowfield JL, Williams C. Carbohydrate intake and recovery from prolonged exercise. ***Int J Sports Nutr***. 1993;3(2):150-164.

6. Achten J, Halson SH, Moseley L, et al. Higher dietary carbohydrate content during intensified running training results in better maintenance of performance and mood state. ***J Appl Physiol***. 2004;96(4):1331-1340.

7. Simonsen JC, Sherman WM, Lamb DR, et al. Dietary carbohydrate, muscle glycogen, and power output during rowing training. ***J Appl Physiol***. 1991;70(4):1500-1505.

8. Hansen AK, Fischer CP, Plomgaard P, et al. Skeletal muscle adaptation: Training twice every second day vs. training once daily. ***J Appl Physiol***. 2005;98(1):93-99.

9. Yeo WK, Paton CD, Garnham AP, et al. Skeletal muscle adaptation and performance responses to once a day versus twice every second day endurance training regimens. ***J Appl Physiol***. 2008;105(5):1462-1470.

10. Morton JP, Croft L, Bartlett JD, et al. Reduced carbohydrate availability does not modulate training-induced heat shock protein adaptations but does upregulate oxidative enzyme activity in human skeletal muscle. ***J Appl Physiol***. 2009;106(5):1513-1521.

11. Akerstrom TC, Fischer CP, Plomgaard P, et al. Glucose ingestion during endurance training does not alter adaptation. ***J Appl Physiol***. 2009;106(6):1771-1779.

12. De Bock K, Derave W, Eijnde BO, et al. Effect of training in the fasted state on metabolic responses during exercise with carbohydrate intake. ***J Appl Physiol***. 2008;104(4):1045-1055.

13. Burke LM, Kiens B. "Fat adaptation" for athletic performance: The nail in the coffin? ***J Appl Physiol***. 2006;100(1):7-8.

14. Nieman DC. Marathon training and immune function. ***Sports Med***. 2007;37(4-5):412-415.

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