KEY POINTS

- Recovery from strenuous daily training or competition is improved when athletes consume a high-carbohydrate diet. The most important effect of such a diet is to maximize the stores of glycogen in the muscles. Roughly 10 g carbohydrate per kg body weight should be sufficient to replenish glycogen stores after a tough training session.
- Recovery of muscle glycogen can be achieved in 24 h when sufficient dietary carbohydrate is ingested.
- Carbohydrate should be consumed immediately after exercise and thereafter at 30-min intervals for about 5 hours. This “early recovery” diet should provide the equivalent of 1-1.2 g of carbohydrate per kg body weight each hour.
- Restoration of muscle glycogen stores may take longer when exercise causes muscle damage and soreness.
- Rehydration after exercise is optimized when athletes ingest a volume of fluid (a sports drink with sufficient electrolytes is better than water) equivalent to 150% of the body weight deficit.

INTRODUCTION

To train optimally, athletes must often recover quickly from training bouts in order to cope with the next training session, especially if it occurs later the same day. Moreover, in some situations, e.g., wrestling tournaments, soccer tournaments, and track-and-field championships, athletes may be required to compete every day (and often more than once each day) for several days, making optimal recovery essential for sustained performance. Optimal recovery is also important for weekend warriors and for those who participate in noncompetitive sports and exercise because it encourages continued participation. This is especially important in general fitness programs in which the participants need a great deal of encouragement to adopt regular exercise as a way of life.

Strategies for optimizing recovery from exercise depend on the specific sport or type of exercise, its intensity and duration, and the time between training sessions or competitions. Successful recovery involves many physiological and metabolic processes that act in concert to prepare the athlete for the next bout of exercise. However, the essential requirements for successful short-term
recovery are (1) resynthesis of the body’s carbohydrate stores (2) rehydration, and (3) rest. For long-term recovery, i.e., over days and weeks, it is also important to optimize net protein synthesis in the muscles, an important consideration, but one not fully covered in this article.

To most athletes, successful recovery means the restoration of performance capacity and the desire to continue training in preparation for competition. Therefore, this brief review will emphasize only those studies that have assessed the influences of recovery nutrition during medium (24 hours) and short (4-5 hours) recovery periods following constant-pace exercise such as prolonged running and protocols that that mimic the physical demands of sports such as soccer and basketball.

**RESEARCH REVIEW**

**The Critical Role of Muscle Glycogen in Metabolism During Intense Exercise**

During prolonged constant-paced cycling or running at a moderate intensity, e.g., ~ 70% VO2max, carbohydrate and fat are the main fuels for energy production. The carbohydrate contribution is mainly from glycogen stores in skeletal muscle, and the contribution of fat is from the oxidation of fatty acids from adipose tissue cells as well as from intramuscular triglycerides. Muscle glycogen provides the main contribution to metabolism during high-intensity exercise that lasts more than about 30 seconds, with smaller roles played by blood glucose and fatty acids. As the exercise duration increases, the muscle glycogen stores are progressively diminished, and the contribution of fatty acid oxidation increases in an attempt to ensure the continued rapid production ATP. However this up-regulation of fat metabolism is normally inadequate to cover the required high rate of ATP production for intense exercise. The contribution of blood glucose to muscle metabolism increases, but is also inadequate to sustain high-intensity exercise, even when high concentrations of blood glucose are maintained throughout exercise by glucose infusion (Claassen et al., 2005). As a consequence of a decreased rate of ATP production, the athlete can no longer sustain the required intensity of exercise and becomes fatigued (Hargreaves, 2005).

**Optimizing Restoration of Muscle Glycogen: Carbohydrate Feedings in the Early Phase of Recovery**

The process of glycogen resynthesis begins immediately after exercise and is most rapid during the first 5-6 h of recovery (Goforth et al., 2003; Piehl, 1974), so it is not surprising that eating carbohydrate immediately after exercise accelerates this process. As reviewed by Ivy (1991), early studies on postexercise glycogen resynthesis suggested that the optimal amount of carbohydrate is about 1 to 1.5 g of carbohydrate/kg body weight, consumed immediately after exercise and at 2-h intervals until the next meal. Higher rates
of muscle glycogen resynthesis may be achieved when carbohydrate is consumed more frequently, for example, 1.2 g/kg/h every 30 min during a 5-h recovery period (van Loon et al., 2000b).

Optimizing Restoration of Muscle Glycogen: Carbohydrate Loading in the Days Following Exhaustive Exercise

It is well established that a carbohydrate-rich diet after prolonged heavy exercise, i.e., “carbohydrate loading,” will increase muscle glycogen concentrations to supranormal concentrations (Bergstrom et al., 1967). Sherman and colleagues (1981) introduced a method of achieving “supercompensation” of normal muscle glycogen concentrations that was more acceptable to athletes than that recommended by Bergstrom et al. (1967) (Sherman et al., 1981). The subjects in the study reported by the Sherman group tapered their training intensity and volume during the week leading up to competition and then increased the carbohydrate content of their diet to 9-10 g•kg-1•d-1 during the 3-4 days before the event. This was an important study, not only because it demonstrated the efficacy of a more acceptable approach to carbohydrate loading, but also because it was one of the first to show that carbohydrate loading could produce high concentrations of muscle glycogen after running.

Athletes are eager to continue training even while carbohydrate-loading but are concerned that training might delay the restoration of muscle glycogen stores. There does appear to be some slowing of glycogen resynthesis during the first hour of recovery while performing even low-intensity exercise (40-50% VO2max) compared with passive recovery (Choi et al., 1994), but more recent research suggests that daily 20-min sessions of light exercise (~ 65% VO2max) do not to limit the supercompensation process (Goforth et al., 2003). Furthermore, the high concentrations of muscle glycogen achieved by carbohydrate loading remain high for 3 to 4 days, even when the amount of carbohydrate consumed is reduced from 80% to 60% of daily energy intake.

Most studies on restoring glycogen concentrations after exercise have used men as subjects. Earlier studies on carbohydrate loading in women suggested that they were unable to increase the concentration of glycogen in their muscles (Tarnopolsky et al., 1990), or at least not to the same extent as occurs in men (Walker et al., 2000). However, subsequent research demonstrated that when the carbohydrate intakes of men and women are carefully matched, both genders increase their glycogen stores to similar supranormal values (James et al., 2001)

Optimizing Recovery to Enhance Subsequent Exercise Performance

In studies of exercise performance, investigators have typically required their subjects to complete a fixed amount of work as quickly as possible (i.e., time trials) or exercise as long as possible at a fixed power output or pace (i.e.,
endurance trials or constant-pace trials). Time trials presumably more accurately represent the types of performance engaged in by individual athletes in running and cycling events, but endurance trials may be more appropriate models for studying the ability of athletes to persist at high exercise intensities in sports such as soccer and field hockey.

**Carbohydrate supplementation during 24 hours of recovery: constant-pace exercise.**

Consuming a high-carbohydrate diet during the first 24 h after prolonged strenuous exercise restores muscle glycogen concentrations to normal values (Goforth et al., 2003; Keizer et al., 1987). Interestingly, Keizer and colleagues noted that when some of their subjects were allowed to eat whatever they wished, they failed to restore their muscle glycogen concentrations after 22 h (Keizer et al., 1987). Therefore, to maximize glycogen recovery, it is essential to prescribe and carefully monitor the amount of carbohydrate that athletes consume during the recovery period.

The question athletes ask is whether or not adopting the carbohydrate loading practice will result in recovery of performance. Unfortunately, there are only a few studies that have considered the impact of carbohydrate-loading on performance 24 h later. In one such study, successful recovery of endurance running capacity 22 hours after prolonged exercise was reported by Fallowfield and Williams (1993). When their subjects ran on a treadmill at 70% VO2max for 90 min or to fatigue (whichever occurred first) and were then fed either a high-carbohydrate diet (9 g/kg) or an isoenergetic mixed diet that included 6 g of carbohydrate/kg during a 22-h recovery period, only those runners on the high-carbohydrate diet were able to match their previous day’s run time of 90 min. Runners who consumed the mixed diet could only manage to complete 78% of their previous day’s exercise, even though their recovery diet contained their normal carbohydrate intake (Fallowfield & Williams, 1993) (Figure 1).
FIGURE 1. Recovery of endurance running capacity 22 hours after the first run, which was treadmill running at 70% VO2max for 90 min or to fatigue, whichever occurred first. The high-carbohydrate (9 g/kg/d) and mixed recovery diets were isoenergetic (Fallowfield et al. 1993).

The type of carbohydrate consumed during recovery may also have an influence on the rate of muscle glycogen resynthesis and subsequent performance. Burke and colleagues (1993) reported that muscle glycogen resynthesis after recovering for 24 h from prolonged exercise was greater when their subjects consumed a recovery diet containing a high-glycemic-index carbohydrate (HGI) when compared to a low-glycemic-index carbohydrate (LGI) diet. Although they did not assess the exercise capacity of their subjects after the 24-h recovery period, it is reasonable to expect that a greater endurance capacity would have been achieved with the greater glycogen stores following the HGI diet (Burke et al., 1993).

In contrast to the results of Burke et al. (1993), Stevenson et al. (2005a) found that treadmill run time to exhaustion was 12 min longer and fat oxidation was higher after a LGI recovery diet than after a HGI diet (Stevenson et al., 2005a). The greater rate of fat oxidation during the run to exhaustion after the LGI recovery diet presumably compensated for the lower pre-exercise glycogen stores. It is also interesting to note that the runners reported that they never felt hungry on the LGI diet, even after the overnight fast prior to the run to exhaustion the following day. But they were hungry when they consumed the HGI recovery diet that was matched for energy and macronutrient composition with the LGI diet. Therefore, it may be more effective to consume HGI
carbohydrates for the first few hours after exercise and then switch to LGI carbohydrate meals for the remainder of the recovery period. In this way, the HGI carbohydrate may better contribute to the most rapid early period of glycogen resynthesis, whereas the LGI carbohydrate may continue to provide energy as well as the sensation of satiety. In addition, an evening meal containing LGI carbohydrate depresses the spike in blood glucose in response to a standard HGI breakfast the following morning and so may enhance fat oxidation during subsequent exercise (Stevenson et al., 2005b). Additional research is needed to determine the mix of carbohydrates that maximizes glycogen restoration and performance.

**Carbohydrate supplementation during 4 hours of recovery: constant-pace exercise.**

Consuming carbohydrate beverages immediately after exercise accelerates muscle glycogen resynthesis, even during a recovery as short as 4 h, but does it make any difference to performance during subsequent exercise? Fallowfield et al. (1995) attempted to answer this question with a group of endurance runners who initially ran on a treadmill at 70% VO2max for 90 min or to fatigue (which ever occurred first). Immediately after the exercise and 2 h later, the subjects drank either a placebo or a sports beverage containing about 1 g of carbohydrate/kg body weight. After a 4-h recovery period, both groups ran to exhaustion at the same treadmill speeds as on the first occasion. The group who drank the sports beverage ran for 22 min longer than the group who drank the placebo (Fallowfield et al., 1995).
FIGURE 2. Run time to exhaustion at 70% VO2max 4 h after running at 70% VO2max for 90 min or until fatigue, whichever came first. One group drank a sports beverage (6.9% carbohydrate), whereas the other group drank a placebo beverage (Fallowfield et al., 1995).

Interestingly, ingesting large amounts of carbohydrate immediately after exercise may not be more beneficial than a moderate amount. For example, Wong and Williams (2000) gave a group of runners 50 g of carbohydrate in a 6.5% carbohydrate-electrolyte beverage immediately after 90 min of treadmill running (70% VO2max) and then rehydrated them by providing either water or the carbohydrate beverage in sufficient quantity to cover 150% of the body weight lost during the initial run. Surprisingly there was no difference in run times to exhaustion when the runners consumed 175 g or 50 g of carbohydrate during the 4-h recovery period (Wong & Williams, 2000). Yet there was a greater increase in muscle glycogen concentration during the 4 h of recovery when the runners ingested the larger amount of carbohydrate (Tsintzas et al., 2003). These results are somewhat paradoxical because it would be reasonable to expect a greater improvement in exercise capacity after a treatment that causes a greater increase in muscle glycogen stores. Nevertheless, postexercise ingestion of a well-formulated sports beverage does improve endurance capacity during subsequent exercise, but more information is needed to be able to prescribe the optimal amounts of beverage for each athlete.

Should protein be added to carbohydrate supplements? Insulin has a positive influence on glycogen resynthesis. Adding protein and some amino acids to carbohydrate sometimes results in an increase in insulin concentrations to values that are higher than those achieved with an equal amount of carbohydrate (van Loon et al., 2000a; Zawadzki et al., 1992). Ivy and colleagues were among the first to report that consuming a carbohydrate-protein mixture immediately after exercise increased the rate of postexercise muscle glycogen resynthesis beyond that which occurs with carbohydrate alone (Ivy et al., 2002; Zawadzki et al., 1992). The subjects in the early study by Zawadzki et al. (1992) performed prolonged cycling to deplete muscle glycogen and then ingested on three separate occasions either 112g of carbohydrate, or 40.7 g protein or 112 g carbohydrate plus 40.7g protein immediately after exercise and then again 2 h later. They found that the rate of glycogen resynthesis during the 4 h recovery was 38% faster after the carbohydrate –protein mixture (Zawadzki et al., 1992). Although the carbohydrate- protein mixture and the carbohydrate were matched for carbohydrate they were not matched for total energy which may have had some contribution to the differences in the glycogen resynthesis rates. In a subsequent study Ivy and colleagues (2003) compared the influence of ingesting a carbohydrate-protein mixture with a sports beverage on endurance capacity during a 4 h recovery from prolonged cycling. They reported a 55% greater endurance capacity when their subjects consumed the carbohydrate-protein mixture during the recovery period. However, not only was the amount of carbohydrate in the carbohydrate-protein mixture far greater than the
carbohydrate in the sports drink but the carbohydrate-protein mixture also contained more energy (~330 kcal) and so this study failed to compare 'like with like' (Williams et al., 2003).

Not all authors report that glycogen resynthesis following the ingestion of carbohydrate-protein mixtures immediately after exercise is any better than after consuming energy-equivalent amounts of carbohydrate only (Carrithers et al., 2000; Jentjens et al., 2001; van Hall et al., 2000; van Loon et al., 2000b). Moreover, as described below, several investigators have found that exercise performance after a period of recovery is not improved to a greater extent with carbohydrate-protein mixtures than with carbohydrate alone, especially if the beverages are matched for energy content.

In two similar studies reported by Betts and colleagues (2005b) the investigators used running rather than cycling to examine the influences of a carbohydrate-protein mixture and a matched amount of carbohydrate on endurance running capacity at 85% VO2max 4 h after a 90-min treadmill run at 70% VO2max (Betts et al., 2005b). A 9.3% carbohydrate solution or the same solution supplemented with 1.5% protein were used to provide carbohydrate in the initial study at a rate of 1.2 g/kg/h for both trials. The runners ingested the solutions immediately after the 90-min run and then at 30-min intervals during the 4 h of recovery. Although the solutions ingested were matched for carbohydrate, the carbohydrate-protein mixture contained 17% more energy. There was a large variation in run times to fatigue in both trials but there were no overall differences in endurance capacity (Carbohydrate: 14.5 min vs. Carbohydrate-Protein: 18 min). In this initial study, several of the subjects complained of abdominal discomfort that was probably the consequence of the large amounts of carbohydrate ingested during the recovery period. Therefore, a second study was undertaken using exactly the same exercise and recovery protocols with the same carbohydrate-plus-protein mixture, but on this occasion the runners ingested smaller amounts of carbohydrate (0.8 g/kg/h). Again, there were no significant differences in the run times to fatigue in the two trials (Carbohydrate: 18 min vs. Carbohydrate-Protein: 19.5 min).

In another study, Betts et al. (2005a) used a similar design, but the run to exhaustion after the 4-h recovery was at 70% rather than 85% VO2max to allow longer run times and so make greater demands on the runners’ carbohydrate stores. Six runners completed three trials. In one trial, they ingested a carbohydrate-protein mixture (0.8 g carbohydrate/kg/h plus a whey protein isolate at a rate of 0.3 g/kg/h); in a second trial they ingested the same amount of carbohydrate as in the carbohydrate-protein trial (0.8 g/kg/h); and in the third trial they ingested the carbohydrate equivalent to the energy content of the carbohydrate-protein mixture (1.1 g carbohydrate/kg/h). After 4 h of recovery, the run times to fatigue were significantly longer in the carbohydrate-protein and the energy-matched carbohydrate trials than in the low-carbohydrate trial, i.e., 91 min, 99.9 min, and 83.7 min, respectively. However, there were no
significant differences between the run times to fatigue between the carbohydrate-protein and energy-matched carbohydrate trials (Betts et al., 2005a) nor differences in the rate of muscle glycogen resynthesis (Betts et al., 2006). Millard-Stafford et al. (2005), who used a 5-km time trial run as a performance test, also found no beneficial effect of supplementing a sports drink with protein. In summary, there appear to be no performance advantages of ingesting a carbohydrate-protein mixture compared to an energy-matched carbohydrate solution during a 4-h recovery period following exercise.

There may be indirect benefits to be gained from ingesting a carbohydrate-protein mixture that have yet to be systematically confirmed. For example, some authors reported that the degree of postexercise muscle soreness was generally less when a carbohydrate-protein solution was used when compared to carbohydrate alone (Millard-Stafford et al., 2005). The rationale for such a possible effect is unclear. Of course, consuming a carbohydrate-protein mixture during recovery may influence the post-exercise protein balance by contributing substrate for protein synthesis which has long rather than short term benefits for athletes (Gibala, 2002).

**Carbohydrate supplementation during 24 hours of recovery from “stop-and-go” exercise.**

Although there are many participants in sports that include continuous activities such as distance running, road cycling, and cross-country skiing, there are many more athletes who participate in multiple-sprint or stop-and-go sports such as football, soccer, field and ice hockey, rugby, and tennis. The prolonged, intermittent, high-intensity exercise that is part of these stop-and-go sports reduces muscle glycogen stores and impairs performance, just as is the case in constant-pace exercise (Balsom et al., 1999). For example, the muscle glycogen concentrations of professional soccer players are severely reduced after 90 min of match play (Jacobs et al., 1982; Saltin, 1973). It is well established that those players who begin match play with modest or low glycogen concentrations in their muscles cannot fully engage in the game because of the early onset of fatigue (Saltin, 1973).

In a study on nutrition and soccer-specific fitness, Bangsbo and colleagues (1992) showed that when players consumed a high-carbohydrate diet for 48 h before a series of soccer-specific tests, their endurance capacity during prolonged, intermittent, high-intensity treadmill running was significantly better than when a normal mixed diet was the nutritional preparation for the test.

Using intermittent high-intensity shuttle running as an exercise protocol that mimics the activity patterns common in soccer, Nicholas et al. (1997) examined the influence of different nutritional strategies on exercise capacity during the last 15 min of the 90-min test. All the subjects completed 75 min of the test and then they were required to complete as many 20 meter shuttles while alternating
between sprinting and jogging to the point of fatigue. Endurance capacity was assessed as the shuttle run time beyond 75 min. Recovery of shuttle running capacity was restored after 22 h of recovery when the subjects consumed a recovery diet that provided a carbohydrate intake of 10 g/kg/d (Nicholas et al., 1997). However, when the subjects consumed their normal amount of carbohydrate with additional protein and fat to match the energy intake of the carbohydrate-recovery diet, they were unable to run as long as on the previous day.

**FIGURE 3.** Recovery of endurance capacity during intermittent high-intensity shuttle running 24 hours after the same run. The high-carbohydrate (9 g/kg/d) and mixed recovery diets were isoenergetic (Nicholas et al., 1997).

**Carbohydrate supplementation during 4 hours of recovery from “stop-and-go” exercise.**

Consuming In professional stop-and-go team sports such football, soccer, rugby, field and ice hockey, and basketball, only one game or match is normally played each day. However, in tournaments or championship competitions in some sports, players may have to compete more than once with only a few hours of recovery between matches. In the absence of studies on the nutritional influences on recovery under these circumstances, it appears reasonable to suggest that stop-and-go athletes should implement the same nutritional recommendations offered to endurance athletes. They are advised to ingest a well-formulated sports drink immediately after exercise and at 30-min intervals during the recovery period.
Factors That May Delay Recovery

Glycogen repletion after prolonged heavy exercise will obviously be slower when carbohydrate intake is low or is withheld during recovery (Fournier et al., 2004). Recovery of muscle glycogen may also be delayed when prolonged exercise involves a significant amount of eccentric muscle actions because this type of activity damages muscle membranes and results in delayed-onset muscle soreness (Asp et al., 1998; Costill et al., 1990; O’Reilly et al., 1987). (Eccentric actions are those in which the muscle lengthens as it produces force, e.g., the actions of the elbow flexors as a dumbbell is lowered.) Furthermore, Asp et al. (1998) reported that prior eccentric contractions during leg exercise resulted in a greater reduction in muscle glycogen concentration than in the contralateral limb that performed concentric contractions. The lowered glycogen concentrations following eccentric exercise was accompanied by a marked reduction in power output and endurance capacity during subsequent two-legged concentric exercise. This poorer performance was attributed to the reduction in glycogen concentration and a greater rate of glycogen utilization (Asp et al., 1998).

There is an eccentric component to leg muscle actions during running, and this may explain the slower recovery of muscle glycogen after prolonged running such as in marathon races (Sherman et al., 1983). Muscle glycogen resynthesis was reported to be only 70% of pre-race values two days after a competitive marathon race, in spite of the fact that the runners ate a high-carbohydrate diet (7 g/kg). Muscle glycogen stores were restored to their high pre-race values after seven days of recovery (Asp et al 1997). This information should be used in planning a recovery strategy because athletes who experience delayed-onset muscle soreness may take longer than normal to restore their muscle glycogen stores and endurance fitness.

REHYDRATION

Immediately after exercise most athletes generally prefer to drink fluids rather than to consume solid foods. This choice helps rehydrate the athlete, which is an essential part of the recovery process. The volume, type, and timing of fluid ingested during short recovery periods (e.g., of only a few hours) are important considerations for successful rehydration and subsequent exercise. In order to fully hydrate during short-term recovery, athletes should drink the equivalent of 150% of the volume of body weight lost through sweating (Shirreffs & Maughan, 2000) because of the way the kidneys handle the fluid load. The fluid that is most effective in rehydrating athletes after exercise is a well-formulated sports drink rather than water (Gonzalez-Alonso et al., 1992). Drinking a sports beverage immediately after exercise not only provides fluid, but the carbohydrate helps begin the process of glycogen resynthesis and the sodium in the sports drink promotes retention of the fluid in the body.
It appears that when recovery duration is short, e.g., ~4 h, athletes should drink the appropriate amount of a sports drink (150% of body weight lost) in portions allocated throughout the recovery period; they should not simply consume the beverage as fast as possible. When athletes were allowed to drink the required volume of a sports beverage voluntarily, they consumed most of the volume immediately after exercise, and their endurance capacity during a subsequent exercise session was less than when the fluid intake was ingested throughout the 4-h recovery period as prescribed (Wong et al., 1998).

Although successful rehydration can be achieved within a few hours after a prolonged period of sweating, there are sports in which there is a very limited time to complete this process. In weight-category sports, such as wrestling, boxing, rowing, and equestrian events, achieving a lower than normal body weight in preparation for weight certification usually includes deliberate dehydration. Rehydration during the short period after the weigh-in and before competition may be difficult to achieve but nevertheless must be attempted in order to achieve a successful performance. There is no simple rehydration recommendation appropriate for all circumstances because each sport has its own regulations about time between weigh-in and competition, and athletes have different weight-loss needs. Therefore, after taking into account the requirements of the sport, athletes should seek help to develop a rehydration strategy that will be effective during competition (Walberg-Rankin, 2000).

**SUMMARY**

Restoration of muscle glycogen stores underpins the recovery of endurance capacity for moderate-to-high-intensity exercise. Therefore, eating sufficient carbohydrate following prolonged intense exercise is an essential part of any recovery strategy. The carbohydrate intake required to replace large decreases in muscle glycogen within 24 h is approximately 10 g/kg/d. When the daily carbohydrate intake is less than 4 g/kg/d, it is insufficient to support daily prolonged submaximal exercise (Kirwan et al., 1988; Pascoe et al., 1990). When recovery is of short duration, there is still an advantage to be gained from consuming a sports beverage that can provide the equivalent of 1-1.2 g carbohydrate/ kg/h because this will accelerate glycogen resynthesis, help the rehydration process, and benefit performance during subsequent exercise. When athletes experience soreness after exercise, their recovery may be delayed, not only because of the soreness per se, but also because the rate of glycogen resynthesis may be slower.

**REFERENCES**


BACKGROUND

In most athletic events, muscle glycogen (the storage form of carbohydrate in the body) is the most critical fuel used to produce the energy for movement. As the duration of the exercise increases, it is increasingly likely that muscle glycogen stores will be reduced to the point that the muscles can no longer keep up with the demand for energy. This leads to fatigue.

If the glycogen used up in a training session or a competition is not fully restored before the next day of training or the next competition, exercise performance will probably be impaired.

In addition to glycogen depletion, dehydration is a major factor that can lead to poor performance if uncorrected during recovery by appropriate rehydration strategies.

In simple terms the more demanding the training session or competition, the greater is the amount of dietary carbohydrate needed to replace glycogen stores.
A similar simple guide to rehydration is “Athletes who sweat a lot should drink a lot.”

These guiding principles should be translated into nutritional strategies that take into account the duration of the recovery period, the demands of the previous exercise session and those of the next session/competition. Of course, athletes eat food, not nutrients, so their food choices must be considered if a nutritional recovery strategy is to be effective. The following examples are for athletes who are in an intensive daily training program or are competing daily in tournaments.

**NUTRITIONAL RECOVERY STRATEGIES**

**Recovery Duration: 24 hours**

When completing training sessions in the morning, athletes have the rest of the day to restock their glycogen stores and rehydrate. Immediately after completing the training session, they should consume a sports drink that provides them with the equivalent of about 1 g of carbohydrate/kg body weight (see Table 1) and drink the same amount at hourly intervals up to the time that they have their next meal. The meals for the rest of the day should contain carbohydrate sufficient to bring the total carbohydrate intake for the 24 h to about 8–10 g/kg. For an 80-kg (176 lb) athlete, this would amount to 640-800 g of carbohydrate for the 24 h.

Drinking a sports beverage is not only a convenient way of achieving the recommended carbohydrate intake for the first few hours of recovery, but it will also contribute to rehydration and help maintain fluid balance before the next training session or competition.

**Table 1.** Carbohydrate and fluid needs during recovery.

<table>
<thead>
<tr>
<th>Recovery Duration</th>
<th>Carbohydrate (g/kg body weight)</th>
<th>Fluid Replacement (% body weight lost)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 hours</td>
<td>8-10 g/kg for the day</td>
<td>Drink enough to maintain body weight</td>
</tr>
<tr>
<td>4 hours</td>
<td>0.8-1.2 g/kg each hour</td>
<td>150%</td>
</tr>
<tr>
<td>2-hours</td>
<td>0.8-1.2 g/kg each hour</td>
<td>150%</td>
</tr>
<tr>
<td>Daily training</td>
<td>5-7g/kg each day</td>
<td>Drink enough to maintain body weight</td>
</tr>
</tbody>
</table>

**Recovery Duration: 2-4 hours**

Two-a-day training sessions are often separated by only 4 or 5 hours, so the recovery time is not enough to fully restock the body’s glycogen stores.
Moreover, recovery periods as short as 2 hours are common in wrestling tournaments and in other sports events in which athletes may have to compete several times in a single day. Nevertheless, even in this brief time, athletes can replace a significant amount of glycogen. Therefore, they should consume 0.8-1.2 g of carbohydrate/kg per hour at 30-min intervals to achieve the maximal restoration of muscle glycogen before their next exercise session. The most effective way to accomplish this is to consume a sports drink so that the athlete receives both carbohydrate and fluid. The fluid intake should be equivalent to 150% of the body weight lost during the previous exercise session—determined by recording body weight before and after exercise. This nutritional strategy will ensure the optimal glycogen resynthesis during the short recovery period. Immediately after exercise, fluids rather than solid foods are the athletes’ first choice, but once they have cooled down, then food becomes more attractive. Therefore, easily digestible carbohydrate foods should be consumed, being careful not to eat so much that it causes abdominal discomfort. (This is especially important for runners and less so for cyclists.

In many weight category sports there are intervals of 2 hours or less between weigh-in and the start of competition. Those athletes who use dehydration as a method of ‘making weight’ should use this time to restore fluids and carbohydrate before they compete. A fluid intake equivalent of 150% of body weight loss is recommended and this volume should be ingested in small amounts evenly distributed across the entire precompetition period. Again, a sports beverage would be the first choice of fluid because not only will it help achieve rehydration, it will provide the much needed carbohydrate.

**Daily Training**

Most preseason daily training sessions are not designed to be so heavy that they completely deplete the athlete’s carbohydrate stores. Nevertheless, athletes need to be able to cope with successive days of training in order to improve their fitness as well as learn new skills and stay healthy. Therefore, adopting a recovery strategy that focuses on carbohydrate and fluid replacement should be part of a well-planned training program. During this period of training, athletes have the opportunity to eat a wide range of foods that provide the necessary amounts of carbohydrate. The amount of carbohydrate needed in the recovery period is about 5-7g/kg body weight per day. The same nutritional principles discussed above apply during this type of training period, i.e., the athletes should begin to restock their carbohydrate stores immediately after exercise by consuming some carbohydrate, i.e., about 0.8-1.2 g/kg per hour in order to ‘kick-start’ the glycogen resynthesis process. Finally, if athletes begin a daily training session lighter than they were the day before and they have not restricted their food intake, they may be dehydrated. Therefore, monitoring body weight before and after training provides information about energy balance and acts as a rough guide to the hydration status of the athlete.
SUGGESTED ADDITIONAL RESOURCES

