44

Sports — Elite Athletes

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Good nutrition is crucial in any athlete's quest to reach peak performance. At all levels of competition, whether for a local recreational league championship or in preparation for the Olympics, athletes seem to be constantly searching for ways to improve their performance and gain a competitive edge. This often includes trying the latest dietary fad or nutritional supplements. However, dietary strategies for training and competition should address the athlete's need for nutrients as influenced by age, fitness, level of competition and intensity of training, environment, time of competition, duration of play, amount of time between competitions, and type of activity. Moreover, an effective diet for the athlete also includes the same general dietary recommendations as for the non-athlete, and these are intended to promote good health.

Although a healthy diet and body can clearly contribute to better performance, this section will not focus on general nutrition guidelines to eating for good health; this is comprehensively addressed in other sections. This section will review several basic nutrition principles and other current nutrition issues as they relate to athletic performance. The following recommendations are based on established results from research in adults competing in certain sports or participating in exercise activities. While there has been extensive research on nutrition and exercise performance in adults, such studies on children and adolescents are lacking.

Much of the following information and guidelines related to preparing for competition, competition, and recovery are also generally appropriate for training and practice sessions. The unique metabolic demand characteristics and environmental circumstances associated with the myriad activities classified as sports makes it nearly impossible to address all athletes' nutritional concerns for achieving peak performance. Individual preferences also play a role. Therefore, this section focuses on selected general nutritional aspects that are applicable for a variety of athletes, especially those who engage in long-duration, endurance-based events.

A Balanced Diet

The primary dietary concern for all athletes should be to generally avoid the known nutritional risk factors associated with health problems and to follow nutritional guidelines that will help promote good health. A diet that provides excess or deficient energy, saturated fat, or alcohol or chronic vitamin and/or mineral deficiencies or excesses should be avoided by anyone interested in good health or good athletic performance. A good diet is one that supports normal growth and development, regulates metabolism, maintains normal menstrual status, and provides adequate energy during training and competition. By following any of the various scientifically based food guides, such as the United States Food Guide Pyramid,[1] athletes, coaches, and parents can achieve appropriate variety, proportions, and balance in their daily dietary planning such that an adequate regular intake of all the essential nutrients is not left to chance.

Carbohydrates

Bread, cereal, rice, pasta, fruits, and vegetables are all good primary sources of carbohydrate that should be regularly included in any athlete's diet. Sport drinks and sport bars are also effective in helping to meet the athlete's carbohydrate needs. It is generally recommended that 55 to 70% of an athlete's daily energy comes from carbohydrates. However, this recommendation may not always be appropriate or practical, particularly if the daily total energy requirement is very high. A better guideline for the athlete in training or during competition would be to ingest at least 7 grams of carbohydrate per kilogram of body weight each day, and up to 10 grams of carbohydrate per kilogram if daily training or competition is intense and lasts for several hours or more.[2,3] This is equivalent to at least 490 grams (or 1960 kcalories) from carbohydrates for a 70-kg person, and would represent roughly 65% of a 3000-calorie daily diet. This relative amount should provide enough dietary carbohydrate to adequately replenish muscle and liver glycogen each day under most circumstances.

Before they are absorbed into the blood, dietary carbohydrates are reduced by digestion to single sugar units (the monosaccharides: glucose, fructose, and galactose). Glucose is the body's primary fuel for energy. Fructose (the very sweet sugar of fruit which is also found in soft drinks and some sport drinks) and galactose (part of lactose or milk sugar) are converted to glucose prior to use as an energy source. Foods that elicit a large and rapid rise in blood glucose are categorized as having a high glycemic index.[4] These foods (Table 44.1) provide a rapid and readily utilizable energy source.[5] Other carbohydrate-rich foods provide glucose at a slower rate due to differences in rates of digestion, absorption, and metabolism. Fructose, for example, is not actively absorbed by the intestine but is absorbed via the less efficient facilitated diffusion. Consumption of large quantities of fructose may slow down fluid absorption and cause a feeling of gastrointestinal distress, particularly during exercise.[6]

Fats

The general recommendation for dietary fat intake is 20 to 30% of total daily energy intake.[7] Further, saturated fats should account for less than 10% of each day's energy supply. Not only is fat needed for many biological functions, fat (as fatty acids) can be an effective metabolic fuel for working trained muscle. Hence, fat provides considerable energy during many sport activities.[2,8,9] Fortunately, most athletes have enough body fat to support their

TABLE 44.1

Glycemic Index (Number in Parentheses) of a Variety of Foods. The index was calculated using glucose as the reference. Average serving size is used; data are from Foster-Powel, K., and Brand Miller, J., *Am. J. Clin. Nutr.* 62: 871S; 1995.

High	Medium	Low
Glucose (100)	Banana (53)	Fructose(23)
Sucrose (65)	Orange juice (57)	Apple, raw (36)
Honey (73)	Potato chips (54)	Soy beans (18)
Bagel (white flour) (72)	White rice (56)	Lentils (29)
Ready-to-eat cereal (70-90)	Spaghetti, white (41)	Peach, raw (28)
Carrots (71)	Bread, mixed grain (45)	Ice Cream, rich (27)
Graham crackers (74)		Skim milk (32)
Potatoes (83)		Yogurt (33)
Raisins (64)		
Jelly beans (80)		
White bread (70)		
Sport drinks, high glucose (70)		

performance energy requirement for fat, and fat intake during or just prior to exercise is not necessary or appropriate.

Some athletes regularly exceed the recommendations for daily fat intake. This may be for convenience or preference, but, for those involved with extensive competition or training that carries a recurring high energy demand, it is often a practical means to help maintain body weight. This practice is fairly common[10-13] among many athletes and has been promoted as being beneficial.[14] As long as the daily energy need is met the athlete is not in chronic positive energy balance, then from a performance point of view, this periodic use of a high-fat diet is appropriate. From a long-term health perspective, the risks associated with such a diet with fit, very active athletes have not yet been studied. Presumably, however, excessive fat intake might adversely affect certain diet-related risk factors for coronary heart disease, even in a fit population.[9,15,16]

Protein

The need for extra protein in an athlete's diet has been a topic of considerable debate. The general recommendation for daily protein intake has been 0.8 grams of high quality protein per kilogram of body weight (about 10 to 15% of daily energy intake).[7] However, a growing body of research[17-20] suggests that many athletes may need more protein than non-athletes.

During and immediately after strenuous exercise, there is an increase in protein breakdown. This is followed by an increase in protein synthesis during the recovery period. This suggests that more dietary protein is needed to maintain body protein mass and/or to support increases in muscle size and muscle energy-producing components. Current thought[17-20] for endurance athletes suggests an intake of 1.2 to 1.8 grams of protein per kilogram of body weight per day. Given the strong endurance component and physiological demands of many competitive sports, athletes involved in extensive regular training and competition may require this much protein each day to maintain protein balance. Body builders and power lifters, for example, could require up to 2.0 grams of protein per kilogram of body weight each day. Such an increase in dietary protein is likely already met by the typical diets that athletes usually consume. Unless an athlete is inappropriately restricting energy, protein supplements are generally not needed — particularly not to the extent that many resistance training athletes ingest regularly.[20-22] There are instances such as when traveling to competition events (especially abroad, where the foods available may be unacceptable to the athlete) and when the travel/competition time is extensive, that sufficient nutrient intake may be challenged or in question. Here, a protein-fortified drink or an energy bar can be a convenient and effective food source to augment the athlete's diet.

Carbohydrate and Fat: Primary Energy Sources

Many factors contribute to the energy expenditure of an athlete during competition or during training. Modestly, 600 to 800 kcalories per hour would not be difficult for many adults to achieve while engaging in sports such as basketball or tennis — and this could readily be much higher with activities such as long distance running or marathon swimming. In fact, large, well-trained athletes might expend up to 10,000 kcal in a single day if the intensity and duration of activity is high.[23]

During continuous endurance activities and other long-duration sports, the metabolic emphasis shifts to utilizing more carbohydrate and proportionately less fat, as the intensity of exercise and overall energy expenditure increase.[2,3] This is necessary because carbohydrate can supply energy for muscle contraction at a much faster rate than fat. However, the intermittent nature of many sports reduces the duration of a continuous high demand for energy within any specific muscle group during and between play. Consequently, even during intense activities such as singles tennis or basketball, fat is used to supply considerable energy throughout the course of the match or game.[24]

Importantly, using fat for energy still requires a continual simultaneous breakdown of glucose. Therefore all athletes, regardless of the intensity of activity, will eventually feel the effects of depleting glycogen stores if the event is long and carbohydrate is not consumed during the activity. Carbohydrate sufficiency can be further challenged in hot environments. As the temperature goes up, the rate of carbohydrate usage can also increase;[27] thus, fatigue can occur more rapidly without regular and adequate carbohydrate intake.

During the latter part of competition, protein could become a more significant contributor in meeting an athlete's energy demands, especially if the pre-event and during-competition dietary carbohydrate intake is inadequate.[20,28] There are ways to reduce potential protein utilization for energy through ensuring sufficient carbohydrate intake and availability. Protein breakdown produces amino acids that in turn are deaminated and used for energy. This, however, puts an additional burden on the body, because the amino group must be converted to urea and excreted.

Effects of Endurance Training on Carbohydrate, Fat, and Protein Utilization

As previously noted, many competitive sports have a significant endurance component. Regularly participating in these sports or other endurance-enhancing exercise or activities (such as bicycling or running) will cause many specific changes in an athlete's body that will positively affect performance.[29,30] A comprehensive discussion of these enhancements is beyond the scope of this section. However, several adaptations relating to the use of nutrients for energy during competition are worth noting.

As a result of regular endurance training and the associated increase in muscle mitochondrial number and activity, there will be an increase in the muscle enzymes that are used for glucose oxidation as well as for glucose conversion to glycogen and for glycogenolysis.[31,32] This, along with other changes that improve the delivery and use of oxygen in the muscles (e.g. an increase in capillary density), permits a more efficient use of carbohydrate for energy.[2] With endurance training there is also an increase in fatty acid uptake and oxidation by the muscle fibers, due to the training-induced increase in mitochondrial number and an induction of the enzymes involved in this process. These are important considerations for an athlete who consequently might not have to rely on blood glucose as much and deplete glycogen stores as readily as a lesser-trained individual — again, fatigue could be delayed, even during high-intensity competition. At the same time, these changes could indirectly defer an undesirable increased reliance on protein for energy as carbohydrate stores are diminished.[28] Some research[34] shows that training results in an enhanced ability and tendency to use protein for energy during exercise. This could supplement the use of glucose and fatty acids as metabolic fuel, and potentially delay fatigue.

Precompetition Nutrition

The nutritional state of the athlete before competition can have a significant impact on performance.[25,35] Many precompetition nutritional strategies are designed to ensure adequate hydration. Appropriate fat, protein, mineral, and vitamin intake are also important, but, because of the metabolic nature of most sports, the other primary precompetition nutritional concern for athletes is adequate carbohydrate intake. How to ensure that carbohydrate stores are maximized prior to competition is the focus of this section.

Ideally, before competition begins, an athlete's carbohydrate stores (muscle and liver glycogen) should be full. The emphasis on precompetition dietary carbohydrates ought to begin at least by the previous evening. The evening meal is typically when the majority of daily energy intake occurs. Moreover, a progressive increase over several days in carbohydrate intake and a concomitant decrease in training duration and intensity just before the start of an event can optimize an athlete's glycogen stores prior to competition.[2]

The immediate precompetition meal is often more of a challenge. Here, the goal is to eat a well-balanced meal with an emphasis on carbohydrate-rich foods and fluids. The recommended energy intake depends, in part, on the competition schedule. In general, the meal size should be moderate. By the time competition begins, the athlete's stomach should be relatively empty, but without feelings of hunger. Prior to competition (three to four hours) a variety of nutritious, easily digestible, nondistress-causing (e.g., low fiber) solid foods can be consumed.[2,36] Based on a person's body weight, a general guideline is to consume approximately 4 to 5 grams of carbohydrate per kilogram of body weight with this meal. This means that a 70-kilogram athlete could consume 280 to 350 grams of carbohydrate. This meal should be low in fat and protein, since too much of either could reduce gastric emptying time. Various fluids (e.g., water, juice, milk, and sport drinks) can be consumed with the precompetition meal, so long as alcohol and excessive caffeine are avoided.

The precompetition meal depends on the time of the competition within the context of the athlete's usual meal pattern. Whatever meal or combination it is, the athlete should not completely skip other regularly scheduled meals. For example, if a game, match, or race is to begin in the early or middle afternoon, a good-sized early breakfast (emphasizing carbohydrates) should be eaten, followed by a smaller precompetition lunch during the late morning or midday. Alternatively, if the competition begins 3 to 4 hours after a precompetition breakfast or lunch, the athlete should eat an additional small (1 to 1.5 grams of carbohydrate per kilogram of body weight), easily digestible carbohydrate snack about 1 to 1.5 hours prior to the start of the event.[2,36] A combination such as 500 ml of a sport drink along with a sport bar or other solid carbohydrate food works well to "top off" carbohydrate stores and body water.

A common problem encountered at some events arises when an early morning competition is scheduled — say, for 8 or 9 a.m. Athletes, parents, and coaches often wonder how to manage breakfast. In this case, it's usually best to have a smaller-than-usual breakfast, again with an emphasis on carbohydrates and easily digestible foods, at least 90 minutes before competition begins. Commercial high-carbohydrate, low-fat liquid meals work well here, because they have less bulk and are easily digested and absorbed. Then, during competition, it will be important to consume a carbohydrate-electrolyte drink throughout, because the body's stored carbohydrate levels will be initially somewhat lower at the outset, and the supplemental carbohydrate will likely have a more readily prominent role in providing energy and deferring hunger.[25]

Whether because of scheduling, preference, or precompetition anxiety, many athletes simply do not consume enough energy before they compete. Inadequate precompetition energy intake and perhaps partially depleted carbohydrate stores can result in premature fatigue.[36]

Another common mistake is to neglect regular fluid and carbohydrate intake during the precompetition warmup session. Such an oversight, especially if it is compounded by a warmup that is too long and consists of excessive exercise, might increase the likelihood that the athlete will begin competition unnecessarily fatigued, dehydrated, and carbohydrate-depleted. Thus, it is important that appropriate rates of fluid and carbohydrate intake be followed during the precompetition warmup as well as during competition. If carbohydrate is not consumed during the warmup period, a small carbohydrate snack after warmup could be sufficient; its content and size depends on how much time is available before competition begins.

Nutrition during Competition

Carbohydrate and fat are the primary energy sources used during sport participation and training activities.[2] Yet, because an athlete's body fat supply is not going to run out in the course of competition, carbohydrate and water are the only principal nutrients that need to be consumed while competing (aside from multi-day or ultra-endurance events).[2,25,37-39] In some situations, salt intake during competition has a more significant role in maintaining fluid balance, but generally it is not a major dietary concern for most athletes while they compete.

Even if an athlete eats well prior to competition, after 60 to 90 minutes of intense exercise, liver and muscle glycogen stores will likely be significantly decreased.[2] Further, the ability to maintain blood glucose and meet the muscles' demand for energy may be seriously challenged. Lack of carbohydrate can be prevented by periodically ingesting carbohydrate during the activity.[25] The amount of supplemental carbohydrate depends on factors such as precompetition dietary status, body weight, environment, and intensity of exercise or play. The body can generally utilize up to 60 grams per hour.[36] This can be provided by a liter of a carbohydrate-electrolyte drink.[25] A number of commercial sport drinks are designed to rapidly deliver carbohydrate and water to maximize performance. Carbohydrate-electrolyte sport drinks can provide energy in the form of carbohydrate. These have been shown to delay the onset of fatigue and perception of effort, increase voluntary fluid intake, and provide electrolytes which help to maintain mineral and fluid balance.[2,25,36,39-42] Moreover, some carbohydrate-electrolyte drinks may be absorbed a little faster than water. Any of these factors can be an important contributor to maintaining performance, especially when competing in a hot environment. In fact, supplemental energy intake may be more readily beneficial during competition in the heat, since glycogen utilization tends to occur more rapidly as body temperature rises.[27] Furthermore, the positive performance effects of carbohydrate and water ingestion during long-term exercise are additive.[43] In other words, appropriate carbohydrate and water consumption (e.g., as a sport drink) during exercise is better than carbohydrate or water consumption alone. Those sport drinks designed for consumption during exercise have a carbohydrate concentration of 5 to 8%. Each liter contains 50 to 80 grams of carbohydrate. Research shows that higher carbohydrate concentrations (i.e., >10%) delay emptying of the stomach, which in turn delays water and carbohydrate from getting into the bloodstream.[40,42]

During the first hour or so of exercise, liver and muscle glycogen often support most of the body's demand for glucose.[2] Thus, from a standpoint of providing energy, the supplemental carbohydrate from a sport drink may not have much of an effect on performance, especially if an athlete's carbohydrate stores are fully replenished at the start of competition. However, it may still be best to drink a carbohydrate-electrolyte drink (perhaps at a diluted concentration at first) from the onset of exercise, even though glycogen stores may not be low. This will help to maintain blood glucose levels and may enhance fluid absorption.[36,39] Moreover, ingesting carbohydrate throughout the early stages of competition might have a sparing effect on some of the body's carbohydrate stores.[36]

Often, athletes drink more than one liter during each hour of exercise in an attempt to offset very high rates of fluid loss from sweating. Exclusive use of a sport drink (even if the carbohydrate content is in the 5 to 8% range) in these situations might not be well tolerated (and may be detrimental) because of the overall excessive amount of carbohydrate that would be ingested. As an alternative, many athletes drink a sport drink and plain water during competition. This combination permits the desired amount of fluid replenishment without taking in too much carbohydrate. At first, the emphasis can be on water consumption. As the competition continues, the athlete can make a progressive transition toward consuming more carbohydrate when he rehydrates.[38] Similarly, eating too large a snack (such as fruit or a sport bar) during competition, while regularly drinking a sport drink at the same time, might also delay stomach emptying and fluid delivery, again, because of the excessive carbohydrate intake. Ingesting a high amount of fructose (liquid or solid) could also cause gastrointestinal distress, since fructose is absorbed more slowly from the intestine compared to other carbohydrates in sport drinks, such as glucose, sucrose, or glucose polymers.[25] However, a small, easily digestible, high-glycemic index snack (e.g., crackers, raisins, jelly beans, etc.) may provide additional needed energy late in the activity.

Postexercise Nutrition

After exercise, an athlete's primary nutritional interest should be the restoration of lost fluid, electrolytes, and carbohydrate.[36,37,39,44] How immediate and aggressive this effort needs to be depends on how much carbohydrate was used (roughly suggested by how intense and long the activity was), how much sweat was lost, and, most importantly, when the next competitive activity will begin.

Sometimes, with sports such as tennis, an athlete must compete more than once on a given day. If the next activity is scheduled to begin shortly after the completion of the first (e.g., within 1 to 2 hours), rehydration and carbohydrate intake (about 50 to 100 grams or 1 to 1.5 grams of carbohydrate per kilogram of body weight) should begin immediately (i.e., within 15 minutes of the end of the match).[2,36] High-carbohydrate sport drinks, along with sport bars, gels, and other carbohydrate-rich foods with a high glycemic index (e.g., bagels, crackers, certain ready-to-eat cereals, white bread, and jelly beans), are good choices. These will facilitate the rapid restoration of muscle glycogen more than high-fructose foods or meals with an emphasis on low glycemic index carbohydrate sources (e.g., flavored yogurt, apples, oranges, pasta, and mixed-grain bread).[5] Notably, some research[45] suggests that a carbohydrate and protein combination might be better than just carbohydrate for rapid glycogen resynthesis. If convenience is a priority, certain commercial high-carbohydrate sport drinks and sport bars are available that could provide appropriate amounts of carbohydrate and protein for this purpose. Otherwise, various combinations of breads, cereals, and dairy products, for example, can provide similar ratios of carbohydrate and protein. During the next activity, regular consumption of carbohydrate may be necessary at an earlier stage to maintain blood glucose, provide energy, and defer hunger, since the short between-activity recovery period may not have been long enough to adequately replenish liver and muscle carbohydrate stores.

When preparing for a second competitive activity that begins four to five hours or more after the completion of the first, athletes should generally follow the precompetition meal guidelines described earlier; however, many athletes would rather not eat a large meal between same-day events, even if there is plenty of time. Thus, if smaller quantities of food are preferred, 50 to 100 grams of carbohydrate, for example, ingested immediately after exercise, and again every two hours, can be an effective method for replenishing (at least partially) one's carbohydrate stores. Having more time to accomplish this task means that an athlete can choose from a wider variety of foods (low, medium, and high glycemic index). However, it is generally a good idea to consume some rapidly absorbed carbohydrates and fluid (i.e., high glycemic index) right after exercise, so that glycogen and hydration status will be more promptly and completely restored for the next activity.[5,39]

If an athlete is not scheduled to compete again until the next day or later, appropriate regularly scheduled meals and snacks (according to the above guidelines) should provide enough of the necessary nutrients to nutritionally recover from the previous exercise and adequately prepare for the next competition.

Nutrition and Fatigue

From a nutritional standpoint, fatigue during sports and exercise occurs when there is an inadequate supply of carbohydrate and/or a diminished ability to use all available sources (i.e., carbohydrate, fat, and protein) to produce energy at a fast enough rate to meet the body's muscular demands. At this point, the fatigued athlete can no longer continue competing at the desired level of intensity.

Following the initiation of exercise, an athlete's blood glucose level tends to increase in response to a variety of hormonal influences (i.e., cortisol and glucagon) designed to mobilize carbohydrate. Without supplemental carbohydrate intake during the rest of the exercise period, a continued high rate of glucose utilization in the muscles will eventually lead to a much greater reliance on blood glucose for energy, which will, in turn, quickly deplete liver glycogen stores. As exercise continues, blood glucose progressively decreases.[2,33,46] Pre-exercise carbohydrate status, of course, plays a role in how readily this occurs. However, with high-intensity competition and repeated long bouts of muscle activity combined with progressive dehydration, the active muscles' use of energy will be accelerated such that carbohydrate will be utilized at an even faster rate. Eventually, carbohydrate availability will be diminished to the point that performance will be severely hindered.[36,38] This is why regular carbohydrate and fluid intake during difficult and long sport and exercise activities is so important, especially in hot environmental conditions. Moreover, if carbohydrate is not consumed during an extended bout of exercise, there may be a significant increase in the conversion of protein to glucose in order to meet the continued demand for energy. This could lead to a lower concentration of the branched-chain amino acids (BCAA) in the blood, which could act as another contributory factor in an athlete's sense of fatigue (see Nutritional Ergogenic Aids in this section).[47,48]

Fluid Balance

When an athlete is involved with any vigorous physical exercise or sport activity, a considerable amount of heat is produced, which will cause body temperature to rise. And although athletes normally have several inherent means for dealing with this (e.g., convection or radiated heat loss), sweating is typically the most effective and utilized method for dissipating heat during exercise, especially in hot weather. However, long-term, extensive sweating can pose a significant fluid balance challenge for athletes.[49]

If fluid balance and thermoregulation are not effectively managed during competition and an athlete progressively dehydrates and becomes overheated, the athlete will fatigue prematurely and possibly lose the race, game, or match. More severely, heat exhaustion, heat cramps, or, at worst, heat stroke may ultimately ensue.[50]

In warm to hot conditions, most adult athletes will lose between 1 and 2.5 liters of sweat during each hour of intense competition or training.[37,39,51,52] Even more impressive, sweat rates over 3.5 liters per hour have been observed with some well-conditioned, world-class athletes competing in very hot and humid climates.[53] During extended competition or training sessions, it would therefore not be difficult for many athletes to lose 10 or more liters of fluid.

The degree to which one sweats depends on a number of factors, including the environmental heat stress (i.e., temperature, humidity, and solar radiation) and the intensity of exercise — as an athlete works harder, sweating rate increases to offset the progressive rise in core body temperature as a result of a higher metabolic rate.[49,54] Acclimatization is another factor. Athletes who have been training and playing in a hot climate for several weeks or more (and thus, are acclimatized to the heat) may sweat more compared to those who are not accustomed to such conditions. The same goes for cardiorespiratory fitness.

Such training can improve sweat gland function and increase plasma volume, which can help to maintain a higher sweating rate.[54] One must keep in mind that a higher sweating rate is a good adaptation, because it gives an athlete a thermoregulatory advantage, although, at the same time, more extensive sweating will be a greater challenge to offset with fluid intake, especially during competition.

Sweat is mostly water, but it also contains a number of other elements found in the blood, including a variety of minerals in varying concentrations. The major mineral ions found in sweat are sodium (Na^+) and chloride (Cl^-), although the concentration varies with a number of factors. For example, well-conditioned athletes who are fully acclimatized to the heat often have sweat sodium concentrations in the range of 5 to 30 mmol per liter (i.e., 115 to 690 mg of sodium per liter of sweat), whereas heat non-acclimatized athletes typically lose much more sodium through sweating (e.g., 40 to 100 mmol or 920 to 2300 mg per liter). Still, some athletes can have a relatively high concentration of sodium in their sweat, no matter how fit or heat acclimatized they are, which again suggests a strong genetic influence. Sweat sodium and chloride concentrations also vary with sweating rate. As sweating rate goes up, the concentration of these minerals in sweat usually increases as well.[55-57]

Without adequate salt replacement, the cumulative effect of such electrolyte losses can bring about a progressive sweat-induced sodium deficit after several days of playing or training in the heat. This can readily lead to incomplete rehydration, poorer performance, and heat-related muscle cramps,[58] and possibly put an athlete at a higher risk for developing heat exhaustion. In contrast, potassium (K^+) and magnesium (Mg^{2+}) sweat losses, for example, are typically much lower.[56] In fact, athletes will generally lose 3 to 10 times as much sodium as potassium during exercise. With regard to calcium and trace minerals such as iron and zinc, their concentrations in sweat are also very low; however, repeated extensive sweating can lead to a deficit of one or more of these elements.[59-61] Such deficits will not have a direct effect on fluid balance per se, but a chronic dietary deficiency of any one of these nutrients (i.e., not enough consumed to offset sweat and other excretory losses) can clearly have a negative impact on overall health and performance.

Unfortunately, it is also a challenge, and often impossible, to keep up with extensive sweating rates over the course of an entire race or match. Therefore, it is critical that athletes prepare and manage as best they can by following a predetermined and comprehensive hydration plan before, during, and after competition.

Heat-related muscle cramps (heat cramps) often occur during prolonged exercise when there have been previous extensive and repeated fluid and sodium losses. Such is often the case in a tennis tournament, for example, especially by the time a player reaches a later round. Drinking plenty of water helps, but to completely restore fluids, the salt lost through sweating must be replenished as well.[62,63] Importantly, any plan for increasing dietary salt intake should be individually designed and include appropriate and adequate fluid intake. For most people with normal blood pressure, however, a slightly excessive salt intake will not likely pose a health threat.[64]

If sufficient carbohydrates and electrolytes are provided by food, then water alone can serve as a primary or sole precompetition beverage. However, other fluids such as milk, juice, and sport drinks can be used as well, and their consumption should be encouraged as part of a well-balanced dietary plan. Alcohol and excessive tea, coffee, and other caffeine-containing beverages should be avoided, as they can accelerate fluid loss.[65,66] An athlete should be able to urinate, and the urine should be fairly clear or light-colored. This can be interpreted as a good indication of adequate precompetition hydration.[67] As previously stated, before competition begins an athlete's carbohydrate (i.e., glycogen) stores should be at or near capacity. Besides providing a readily available source of energy, muscle glycogen also has a fair amount of water stored with it. Thus, by replenishing carbohydrates (even partially), an athlete can improve hydration status as well.

Ideally, athletes should ingest, during competition, enough fluid, electrolytes, and carbohydrate to fully support all circulatory, metabolic, and thermoregulatory requirements, and to offset all fluid losses so that normal body water status (i.e., euhydration) is maintained. But even with relatively short periods of competition (e.g., less than 75 minutes), it is not unusual for some athletes to end up with a significant body water deficit (i.e., a net loss near or greater than 2% of their precompetition body weight).[51,56] In fact, because many athletes often begin competition or training dehydrated to some degree,[51,58] a post-exercise body water deficit may be even worse than is indicated solely by one's pre- and post-exercise body weight difference. Also, because thirst is not a rapidly responding indicator of body water loss, there may not be a sufficient stimulus to consume enough fluid in the exercise or post-exercise period.[68] For some athletes, there could be a fluid deficit of more than 1 liter before thirst is distinctly perceived. During exercise, sweating rates can readily exceed 1.5 liters per hour. Few athletes can comfortably consume this much fluid to replace such a loss. Moreover, it is likely that such a high rate of fluid intake would readily exceed maximal gastric emptying and intestinal absorption rates.[39,42]

After competition, athletes must rehydrate. Plain water alone will rehydrate an athlete to a point, but it also readily prompts increased urine production and potentially a premature elimination of the thirst drive.[63] Excessive water intake for several hours or more can lead to severe problems related to hyponatremia.[69,70] Unless adequate sodium and chloride are replaced, rehydration will remain incomplete. [62,63] Fluid ingestion after prolonged exercise needs to be greater than the volume of fluid that was lost via sweating, because during the rehydration process there is still an obligatory production of urine, whether or not rehydration is complete. [62] Athletes should also keep in mind that alcohol and caffeine can reduce the rate and amount of postexercise plasma volume restoration and net fluid retention.[62,71]

Nutritional Ergogenic Aids

Advocates of today's growing and seemingly endless selection of nutritional ergogenic (work-enhancing) aids promote these products with promises such as enhanced energy, increased strength, power, and lean body mass, more endurance, better performance, and faster recovery. Because many athletes are constantly in search of anything that will provide a competitive advantage, it's understandable why such claims can be so tantalizing. But do the products work? Are the latest supplements just what some athletes need to perform better? To date, very few nutritional ergogenic supplements have lived up to their claims. More importantly, some have been found to actually impede optimal performance. On the other hand, as a result of well-controlled experimental studies, certain products have shown some promise as being effective ergogenic aids. Too often, however, the purported benefits of new supplements are based on unsubstantiated claims or testimonials, poor research or research findings taken out of context, or simply misinformation. Several currently popular and well-studied nutritional ergogenic aids are discussed here, with particular mention of their appropriateness for most sports.

Creatine

Creatine monohydrate has become one of the most popular "performance-enhancing" nutritional supplements in use today, and for good reason. Supportive preliminary evidence associated with creatine supplementation includes increased one-repetition maximum performance (i.e., how much weight a person can lift one time, such as with a bench press or squat) and peak power, as well as enhanced rowing performance and repetitive sprint performance in experimental swimming, running, and cycling bouts of exercise. In addition, many studies have demonstrated increases in body weight.[72]

Does such laboratory data mean that creatine supplementation will enhance performance during sports? Will the same effects be shown with highly trained and conditioned athletes as have been demonstrated with moderately trained or untrained individuals? Is creatine supplementation appropriate for the physiological demands of many sports? Are the observed weight gains actual gains in muscle or mostly fluid retention? And what about the long-term effects and health risks associated with continued supplementation? The answers to these questions are not known at this point.

Creatine is a natural compound made by the body from two amino acids, arginine and glycine. It is also present in fish, meat, and other animal products. During very brief, explosive-type exercise, the muscles' capacity to adequately meet the high demand for energy is largely dependent on the availability of phosphocreatine (PC), a high-energy compound found in muscle. It has been thought that by increasing the amount of creatine in the muscles, more PC will be readily available to provide energy at a faster rate during very high-intensity exercise.

Reports of increased muscle creatine and PC levels, enhanced performance, and desirable changes in body composition have been inconsistent and remain somewhat equivocal. Regarding potential gains in muscle protein, proven and more effective ways exist to gain the necessary lean body mass required for most sports. And, importantly, the long-term consequences and health risks associated with continued creatine supplementation have not yet been comprehensively examined. Potential negative effects on the kidneys, heart, liver, fluid balance, and thermoregulatory capacity, for example, should be carefully studied. Lastly, given the specific loading patterns and metabolic demands on individual muscle groups during many types of sport activities, the muscle creatine and PC levels are probably (without supplementation) already more than adequate in most well-conditioned athletes. At present, creatine supplementation for most athletes does not appear to be justified.

A recent consensus statement written for the American College of Sports Medicine on oral creatine supplementation provides a comprehensive review of the current creatine literature as well as a critical evaluation of its potential health effects and clinical application.[72]

Medium-Chain Tryglycerides

To increase the availability and oxidation of fats during exercise in an attempt to spare carbohydrate and improve performance, several dietary fat supplements have been suggested for athletes.[9] From this category, medium-chain tryglycerides (MCTs) are one of the ergogenic aids used by athletes today because of the professed ability of MCTs to enhance energy levels, fat metabolism, and endurance.[73] Once ingested, MCTs leave the stomach and are absorbed from the intestine in much the same way as are other triglycerides.[48] Thus far, MCTs or other fat-loading techniques have not been shown to affect the rate of carbohydrate oxidation or improve performance. There have also been a number of reports of gastrointestinal complaints and problems associated with MCT ingestion.[48] Therefore, despite the need for fat in an athlete's diet and the important role of fat in providing energy during competition for many sports, fat loading prior to play or fat supplementation during competition are not currently validated or recommended procedures for most athletes.

Sodium Bicarbonate

During very high-intensity exercise, there is an increasing concentration of hydrogen ions (H^+) in the muscle cells as a result of a continuous rapid production of lactic acid. A high level of H^+ will rapidly lead to fatigue. Unless there is something to offset the growing concentration of H^+, there will soon be a decrease in muscle force output, a lower production of energy, and a resultant decrease in performance, even in the presence of adequate carbohydrate supplies. Fortunately, sodium bicarbonate, which is naturally present in the body, buffers a portion of the H^+ associated with the accumulating lactic acid during anaerobic exercise. This helps to delay fatigue. Would augmented sodium bicarbonate levels do a better job in delaying the onset of fatigue during high-intensity exercise by helping to buffer more lactic acid? Probably. Will ingested bicarbonate enhance an athlete's overall performance during all sports? Probably not.[74,75]

The intermittent nature and overall moderate intensity of many sports precludes the necessity for a great reliance on anaerobic carbohydrate metabolism during competition. Consequently, lactic acid production is seldom very high.[46] Thus, sodium bicarbonate supplementation would not be very helpful for such activities, since these athletes do not need to compensate for a large accumulation of H^+. It likely rarely occurs. On the other hand, certain sports that are characterized by high lactic acid production may be better tolerated with an enhanced capacity to neutralize the accompanying decrease in pH within the intracellular environment of the active muscles. Ingestion of buffering agents such as sodium bicarbonate may provide a performance advantage during these activities.[75]

Branched-Chain Amino Acids

When carbohydrate is in short supply, there is a greater reliance on protein for energy. This can lead to lower circulating levels of the branched-chain amino acids (BCAA); i.e., leucine, isoleucine, and valine. Moreover, during prolonged exercise, there is an increase in the concentration of free fatty acids in the blood, which leads to higher levels of free tryptophan (another amino acid). The resultant effect will be a higher free tryptophan:BCAA ratio. This is thought to be an important factor in the development of fatigue, especially during endurance activities. When free tryptophan enters the brain it is converted to serotonin; high amounts of this neurotransmitter may be associated with fatigue.[48,76] Many athletes could conceivably be susceptible to fatigue related to lowered

BCAA levels and increased free tryptophan, particularly during lengthy competitions.[47] Would BCAA supplementation help to alleviate this situation by maintaining higher levels of BCAA in the blood? As one might expect, some researchers have shown improved performance with BCAA supplementation, and others have demonstrated no change in performance.[48,76] Although BCAA might in theory be helpful in delaying the onset of fatigue during long periods of exercise or competition, especially if carbohydrate stores are significantly diminished, adequate carbohydrate intake prior to and during competition could achieve the same effect by reducing the amount of free fatty acids released and minimizing any potential increase in the free tryptophan:BCAA ratio. Furthermore, BCAA supplementation could lead to higher levels of ammonia in the blood, which would accelerate fatigue.[76]

Vitamins and Minerals

Vitamin and mineral supplements are widely used by athletes, often in great excess, not only to maintain health, but also with the hope that performance will be enhanced as well.[77] Likewise, selected mineral supplementation such as increased chromium, vanadium, and boron intake has been purported to increase muscle mass, despite a lack of research evidence.[21]

B-complex vitamin supplements are particularly popular, likely because of their important role as coenzymes in helping carbohydrate and fat to be used for energy. Logically, it seems that B-complex supplementation would be, in theory, helpful in enhancing the utilization of these nutrients during many sports and exercise activities. However, despite the essential role of these and other vitamins in a variety of physiological processes, including energy metabolism, unless an athlete has a vitamin deficiency, vitamin supplementation will not enhance athletic performance. In fact, excessive intake of the fat-soluble vitamins (A, D, E, and K) can have a toxic effect. Although extra water-soluble vitamin (B-complex and C) intake will mostly end up being excreted in urine, excessive intake of these vitamins can have toxic effects as well. Additional vitamin C and E intake, however, might be worth considering. Both of these vitamins have been shown to have beneficial antioxidant and other health-related properties. Moreover, there is evidence that athletes may need more vitamin C compared to those who do not exercise regularly, and additional vitamin E intake may reduce exercise-related muscle tissue damage.[77]

Minerals are necessary for growth, metabolism, and a variety of other physiological processes. Like vitamins, an athlete's mineral requirements generally can be easily met by a well-balanced diet, although certain minerals may need special attention with some people. These typically include calcium and iron, and sometimes zinc. In addition, excessive and repeated sweating may cause a progressive sodium deficit.[55-58] Calcium and iron deficits can be encouraged by inadequate energy intake (which often includes low intake of protein and dairy products), other dietary influences, and excessive sweating. In women, menstrual bleeding can further challenge iron status. But, unless an athlete is restricting energy intake, mineral status is usually not a problem. As a guide, all athletes should regularly eat foods rich in calcium and iron (e.g., meat, chicken, fish, milk, yogurt, dark, leafy green vegetables, whole-grain breads and fortified cereals, etc.); this will likely ensure adequate intake of these and most other minerals. Importantly, arbitrary excessive mineral supplementation can also have deleterious effects on health and can interfere with the absorption of other minerals.[77]

For many athletes, it is sometimes a challenge to maintain a well-balanced diet, especially when traveling and competing.[78] Therefore, to prevent a potential vitamin or mineral deficiency, it is safe and probably prudent to regularly take a one-a-day multi-vitamin/mineral supplement that provides no more than 100% of the Recommended Dietary Allowance (RDA)[7] for any one vitamin or mineral. Slightly higher amounts of vitamins C and E can be supplemented, although it is probably better to obtain these through careful food selection (e.g., fruits, vegetables, legumes).

Summary

Proper nutrition is important in any athlete's quest to reach peak performance. When integrated with proper training and adequate rest, a well-balanced diet, coupled with a dietary strategy that optimizes hydration status and fuel availability in the pre-competition, and recovery periods will greatly enhance an athlete's opportunity to be a regular winner anywhere he or she competes. Table 44.2 summarizes the key performance-related competition points for the elite athlete.

TABLE 44.2

Nutrition-Related Problems and Recommendations for the Elite Athlete

Water

Many athletes begin play or training dehydrated to some degree.
During training or competition, sweat losses can be extensive — 1-2.5 liters per hour or more!
Any water deficit can have a negative effect on an athlete's performance and wellbeing. A progressive water deficit (from sweating and inadequate fluid intake) can cause:
- Increased cardiovascular strain
- Decreased temperature regulation capacity
- Decreased strength, endurance, and mental capacity

Many athletes do not rehydrate adequately after training or competition.

Recommendations

Drink plenty of fluids (e.g., water, juice, milk, sport drinks) throughout the day.
Drink regularly during training and competition — typically, older adolescents and adults can comfortably consume up to 48 ounces (~1.4 liters) per hour.
After training or competition, drink about 150% of any remaining fluid deficit.

Electrolytes

Athletes lose far more sodium and chloride (salt) from sweating than any other electrolyte.
Sodium and chloride losses are greater with higher sweating rates.
Sodium and chloride losses (via sweating) tend to be less when an athlete is acclimatized to the heat.
Sodium deficits can lead to incomplete rehydration and muscle cramps.
To completely rehydrate, an athlete must replace the sodium and chloride that was lost through sweating.
Excessive rapid water consumption, combined with a large sweat-induced sodium deficit, can lead to hyponatremia.

Recommendations

When an athlete competes or trains in a hot environment, adding salt to the diet (or eating high-salt foods) can help to prevent a sodium deficit and maintain/restore hydration. Good sodium and chloride sources include:
- Salt: 1/4 teaspoon (or 1.5 grams) has 590 mg of sodium
- Salted pretzels

TABLE 44.2 *(Continued)*

Nutrition-Related Problems and Recommendations for the Elite Athlete

Tomato juice
Salted sport drinks (or Pedialyte®)
Soup, cheese, tomato sauce, pizza, and many processed foods

Carbohydrates

Adequate carbohydrate intake is crucial to optimal performance in most sports.
Carbohydrate utilization is greater as intensity of exercise increases and when an athlete competes or trains in the heat.
Even if an athlete eats well prior to competition, after 60 to 90 minutes of intense exercise, glycogen stores will likely be significantly decreased and the ability to maintain blood glucose and meet the muscles' demand for energy may be seriously challenged, which could lead to fatigue.

Recommendations

Generally, 7 to 10 grams of carbohydrate per kilogram of body weight (~500 to 700 grams per day for a 155 lb athlete) is appropriate for periods of intense training or competition.
Athletes should consume about 30 to 60 grams of carbohydrate per hour during training and competition.
Foods and sport drinks with a high glycemic index can be particularly effective for providing rapid carbohydrate energy or restoration during and after competition or training.

Lastly, all athletes differ in what foods and which nutritional strategies they can tolerate and that will enhance their performance. New foods, drinks, or other dietary protocols should be experimented with well prior to any important event.

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