Sports nutrition: an overview

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Nutritional interventions have the potential to influence the outcome of athletic competition where opponents are closely matched. Sound dietary habits can also influence the adaptations that occur in response to training. This article summarizes some of the strategies that the athlete can use to enhance performance.

Sportsmen and -women, from the player in the Saturday afternoon pub football team to the elite Olympic performer, recognize that the food they eat can influence how they perform. For some of these athletes, nutrition is seen as a way of compensating for a lack of talent, training and motivation, even though it is clear that diet alone is not the road to successful performance in sport. At the elite end of the spectrum, however, where all the competitors have the genetic potential to succeed and where all have undergone the most rigorous preparation, attention to diet can make the difference between success and failure.

For those whose participation in physical activity is to gain the health benefits that come from regular exercise or simply for enjoyment, nutrition is an important part of the lifestyle package associated with good health and performance. Control of body mass, and more especially of body fat content, ranks high among the concerns of these individuals on account of the close association between increasing adiposity and various disease states.

Two distinct aspects of the athlete's diet must be considered; the first is the diet in training which must be consumed on a daily basis for a large part of the year, and the second is the diet before and during competition. The traditional concern among athletes has been with dietary preparations for competition, but there is a growing awareness that nutrition can affect the processes by which the body adapts to the training stimulus. The most important aspect of the athlete's diet is that it allows consistent hard training to be performed, because it is only from such training that improvements in performance result. In most sports, the number of major competitions in the year is small, and peak performance must be achieved only a few times each year. Cycling is an exception, and the top cyclists may compete on 100 days per year (Jeukendrup et al, 2000). In some team games (e.g. football, basketball), competition is frequent, but peak effort cannot be produced on every occasion.

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NUTRITION FOR TRAINING

In sports involving prolonged strenuous exercise on a regular basis, participation has a significant effect on energy expenditure (Maughan and Piehl Aulin, 1997). Even for events which last only a few seconds, such as sprinting or weightlifting, the top performers may spend several hours per day in training, resulting in very high levels of energy expenditure and a need for a correspondingly high level of energy intake. It must be appreciated, however, that not all athletes will incur high energy expenditures, and some may be in energy balance on low food intakes (Deakin and Inge, 1994).

Exercise increases the rate of energy expenditure during the exercise period itself, but the metabolic rate may remain elevated for at least 12 and possibly up to 24 hours afterwards if the exercise is both prolonged and intense. The effect of this sustained elevation of metabolic rate will be to further increase the energy cost of training. The recreational exerciser, whose aim is often to reduce body mass, is unlikely to benefit from this effect because the duration and intensity of exercise will normally be too short for it to be significant. The elite athlete who trains once or more per day at the limits of the tolerable load will incur an additional energy cost which may be unwelcome.

Macronutrient requirements

Protein requirements: A diet deficient in protein will lead to loss of muscle tissue, but there is no evidence that excess dietary protein will drive the system in favour of protein synthesis (Lemon, 1991). Excess protein will simply be used as a substrate for oxidative metabolism, either directly or as a precursor of glucose, and the excess nitrogen will be lost in the urine. A normal mixed diet which meets the increased energy expenditure should be adequate to meet protein needs, but many athletes ingest large quantities of protein-containing foods and expensive protein supplements. Daily protein intakes of 3–4 g/kg body mass are not unknown in some sports, especially in body building and strength training events (Burke and Inge, 1994). Disposal of the excess nitrogen is theoretically a problem if renal function is compromised, but there does not appear to be any evidence that excessive protein intake among athletes is in any way damaging to health (Lemon, 1991). The recommended diet for athletes, especially those in endurance events, may contain a lower than normal amount of protein (when expressed as a percentage of total energy intake), as the total energy demand is increased to a greater extent than the protein requirement.

Although there may not be a major effect on the requirement for protein, there is accumulating evidence that providing amino acids to the muscle during and after exercise can promote the remodelling of muscle tissue that is an integral part of the process of adaptation to training. A fall in the intracellular amino acid concentration is observed after hard resistance training carried out in the fasted state, and this will restrict the rate of protein synthesis (Tipton and Wolfe, 2001). Ingestion of protein or amino acids immediately after exercise can prevent this fall and promote muscle protein synthesis, but no long-term studies have yet been conducted to establish if these effects result in an improved adaptation of the muscle to the training stimulus (Tipton and Wolfe, 2001).

Carbohydrate requirements: The energy requirements of training are largely met by oxidation of fat and carbohydrate, with only a very small contribution from protein oxidation. The higher the intensity of exercise, the greater the reliance on carbohydrate as a fuel: at an exercise intensity corresponding to about 50% of an individual's maximum oxygen uptake (VO_2max), approximately two thirds of the total energy requirement is met by fat oxidation, with carbohydrate oxidation supplying about one third. If the exercise intensity is increased to about 75% of VO_2max, the total energy expenditure is increased, and carbohydrate is now the major fuel (Romijn et al, 1993).

The primary need, therefore, is for the carbohydrate intake to be sufficient to enable the training load to be sustained at the high level necessary to produce a response. During each strenuous training session, substantial depletion of the glycogen stores in the exercising muscles and in the liver takes place. If this carbohydrate reserve is not replenished before the next training session, training intensity must be reduced, leading to corresponding decrements in the training response.

Recovery of the muscle and liver glycogen stores after exercise is a rather slow process, and will normally require at least 24–48 hours for complete recovery (Piehl, 1974). The rate of glycogen resynthesis after exercise is determined largely by the amount of carbohydrate supplied by the diet (Ivy, 2000), and the amount of carbohydrate consumed is of far greater importance for this process than the type of carbohydrate. Carbohydrate foods (at least 50–100 g carbohydrate) should be consumed as soon as possible after the end of training, as the rate of glycogen synthesis is most rapid at this time (Ivy, 2000). Although the type of carbohydrate is less crucial than the amount consumed, there may be some benefit from ingesting high glycaemic index foods (such as bread, rice, confectionery or sports drinks) at this time if rapid restoration of muscle glycogen is a critical issue (Coyle, 1991).

Fat requirements: If carbohydrate is not available, or is available in only a limited amount, the intensity of the exercise must be reduced to a level where the greater part of the energy requirement can be met by fat oxidation. A high carbohydrate diet (70% of energy intake as carbohydrate) enabled runners who were training for 2 hours per day to maintain muscle glycogen levels, whereas a progressive fall in muscle glycogen content was observed with a 40% carbohydrate diet (Costill, 1988). Although it seems obvious that the ability to train at high intensities will be impaired if a high carbohydrate diet is not consumed, there is limited experimental evidence from studies on humans to support this (Williams, 1998).

Short-term fasting increases endurance capacity in the rat but results in a decreased exercise tolerance in man (Gleeson et al, 1988). Studies where subjects have trained on high fat diets have shown that a high carbohydrate diet during a period of training brings about greater improvements in performance, even when a high carbohydrate diet is fed for only a few days to allow normalization of the muscle glycogen stores before exercise performance is measured (Kiens and Helge, 1998). A further disadvantage of training on a low carbohydrate diet is the potential for an increased risk of injury and of increased susceptibility to minor infectious illness (Nieman and Pedersen, 1999).

The training diet therefore should be high in carbohydrate, with perhaps 60% or more of total energy intake coming from carbohydrate. A daily dietary carbohydrate intake of 500–600 g may be necessary to ensure adequate glycogen resynthesis during periods of intensive training, and for some athletes, the amount of carbohydrate that must be consumed on a daily basis is even greater (Coyle, 1991).

The carbohydrate requirement is determined primarily by training volume and intensity, but body size is also an important factor, so expressing the requirement in grams per kg body mass per day might be the best option. A daily requirement of about 8–10 g/kg body mass is likely in periods of hard training. These high levels of intake are difficult to achieve without consuming large amounts of simple sugars and other compact forms of carbohydrate, as well as increasing the frequency of meals and snacks towards a 'grazing' eating pattern. Athletes may find that sugar, jam, honey and high sugar foods, such as confectionery, as well as carbohydrate-containing drinks, such as soft drinks, fruit juices and specialist sports drinks, can provide a low-bulk, convenient addition of carbohydrate to the nutritious food base (Clark, 1994).

Micronutrients

With regular strenuous training, there must be an increased total intake to balance the increased energy expenditure. Provided that a reasonably normal diet is consumed, this will supply more than adequate amounts of protein, minerals, vitamins and other dietary requirements. There is no good evidence to suggest that specific supplementation with any of these dietary components is necessary or that it will improve performance. Food choices that may not meet the micronutrient needs of a sedentary individual consuming 4 MJ/day may meet the requirements of an athlete taking 12–15 MJ/day.

Exceptions to the generalization about dietary supplements may be iron (Eichner, 1986) and, in the case of very active women, calcium (Clarkson, 1991). Endurance athletes commonly have low circulating haemoglobin levels, although total red cell mass may be elevated because of an increased blood volume. Hard training may result in an increased iron requirement, and exercise tolerance is impaired in the presence of anaemia. Low serum folate and serum ferritin levels are not associated with impaired performance, however, and correction of these deficiencies does not influence indices of fitness in trained athletes. Moderate exercise will increase bone mineral density in women, but hard training may reduce circulating oestrogen levels and accelerate bone loss. An adequate calcium intake should be ensured, although calcium supplements themselves will not reverse bone loss while oestrogen levels remain low.

NUTRITION FOR COMPETITION

The ability to perform prolonged exercise can be substantially modified by dietary intake in the pre-exercise period, and this becomes important for the individual aiming to produce peak performance on a specific day. The pre-exercise period can conveniently be divided into two phases: the few days before the exercise task and the day of exercise itself.

Dietary manipulation to increase muscle glycogen content in the few days before exercise has been extensively recommended for endurance athletes following observations that these procedures were effective in increasing endurance capacity in cycle ergometer exercise lasting about 1.5–2 hours. The suggested procedure was to deplete muscle glycogen by prolonged exercise about 1 week before competition and to prevent resynthesis by consuming a low carbohydrate diet for 2–3 days before changing to a high carbohydrate diet for the last 3 days during which little or no exercise was performed. This procedure can double the muscle glycogen content and is effective in increasing cycling or running performance, measured as the time for which a given workload can be sustained (Williams, 1998). All that is necessary is to reduce the training load over the last 5 or 6 days before a competition and to simultaneously increase the dietary carbohydrate intake. Consumption of a high carbohydrate diet in the days before a competition may also benefit competitors in team games and in events lasting only a few minutes.

There is scope for nutritional intervention during exercise only when the duration of events is sufficient to allow absorption of drinks or foods ingested and where the rules of the sport permit food intake. The primary aims must be to ingest a source of energy, usually in the form of carbohydrate, and fluid for the replacement of water lost as sweat (Maughan, 1994). High rates of sweat secretion are necessary during hard exercise in order to limit the rise in body temperature which would otherwise occur. If the exercise is prolonged, this leads to progressive dehydration and loss of electrolytes. Fatigue towards the end of a prolonged event may result as much from the effects of dehydration as from substrate depletion. The composition of drinks to be taken during exercise should be chosen to suit individual circumstances (Maughan, 1994). During exercise in the cold, fluid replacement may not be necessary as sweat rates will be low, but there is still a need to supply additional glucose to the exercising muscles.

In the post-exercise period, replacement of fluid and electrolytes can usually be achieved through the normal dietary intake. Restoration of water balance is not achieved, however, unless the electrolytes lost in sweat (especially sodium) are also replaced. If there is a need to ensure adequate replacement before exercise is repeated, extra fluids should be taken and additional salt (sodium chloride) might usefully be added to food. The other major electrolytes, particularly potassium, magnesium and calcium, are present in abundance in fruit and fruit juices. Mineral supplements are not normally necessary.

NUTRITIONAL SUPPLEMENTS

Recurring sales figures for a wide range of specialist supplements demonstrates the widespread interest in any component which has the potential for improving exercise performance. Nutritional supplements used by elite athletes generally fall into one of two categories: those that are banned by the governing bodies of sport and those that have no effect on performance. A small number of supplements have a role to play in supporting consistent intensive training and in strategies for improving performance in competition, but these should not detract from the need for athletes to address basic nutrition issues. **HM**

Conflict of interest: Professor Maughan has received research support from a number of companies involved in nutrition, including Mars, Quaker, Unilever, GlaxoSmithKline, IDV, Orchid Drinks, Sandoz Nutrition.

Burke LM, Inge K (1994) Protein requirements for training and ‘bulking up’. In: Burke LM, Deakin V, eds. *Clinical Sports Nutrition.* McGraw-Hill, Sydney: 124–50

Clark K (1994) Nutritional guidance to soccer players for training and competition. *J Sports Sci* **12** (Special Issue): S43–S50

Clarkson PM (1991) Minerals: exercise performance and supplementation. *J Sports Sci* **9** (Special Issue): 91–116

Costill DL (1988) Carbohydrates for exercise: dietary demands for optimal performance. *Int J Sports Med* **9:** 1–18

Coyle EF (1991) Timing and method of increased carbohydrate intake to cope with heavy training, competition and recovery. *J Sports Sci* **9** (Special Issue): 29–52

Deakin V, Inge K (1994) Training nutrition. In: Burke LM, Deakin V, eds. *Clinical Sports Nutrition.* McGraw-Hill, Sydney: 16–37

Eichner ER (1986) The anemias of athletes. *Physician Sportsmed* **14:** 122–30

Gleeson M, Greenhaff PL, Maughan RJ (1988) Influence of a 24-hour fast on high-intensity cycle exercise performance in man. *Eur J Appl Physiol* **57:** 653–9

Ivy JL (2000) Optimization of glycogen stores. In: Maughan RJ, ed. *Nutrition in Sport.* Blackwell, Oxford: 97–111

Jeukendrup AE, Craig NP, Hawley JA (2000) The bioenergetics of world class cycling. *J Sci Med Sport* **3:** 414–33

Kiens B, Helge JW (1998) Effect of high-fat diets on exercise performance. *Proc Nutr Soc* **57:** 73–5

Lemon PWR (1991) Effect of exercise on protein requirements. *J Sports Sci* **9** (Special Issue): 53–70

Maughan RJ (1994) Fluid and electrolyte loss and replacement in exercise. In: Harries M, Williams C, Stanish WD, Micheli LJ, eds. *Oxford Textbook of Sports Medicine.* Oxford University Press, New York: 82–93

Maughan RJ, Piehl Aulin K (1997) Energy needs for physical activity. In: Simopoulos AP, Pavlou KN, eds. *World Rev Nutr*: Vol 82. Karger, Basel: 18–32

Nieman DC, Pedersen BK (1999) Exercise and immune function. *Sports Medicine* **27:** 73–80

Piehl K (1974) Time course of refilling of glycogen stores in human muscle fibres following exercise-induced glycogen depletion. *Acta Physiol Scand* **90:** 297–302

Romijn JA, Coyle EF, Sidossis LS et al (1993) Regulation of endogenous fat and carbohydrate metabolism in relation to exercise intensity and duration. *Am J Physiol* **265:** E380–91

Tipton KD, Wolfe RR (2001) Exercise, protein metabolism and muscle growth. *Int J Sport Nutr Exerc Metab* **11:** 109–32

Williams C (1998) Diet and sports performance. In: Harries M, Williams C, Stanish WD, Micheli LJ, eds. *Oxford Textbook of Sports Medicine.* 2nd edn. Oxford University Press, Oxford: 77–97

KEY POINTS

- Exercise performance is influenced by the composition of the preceding diet. In spite of this, however, many elite athletes have no clear idea of the nutritional demands of their sport and often pursue practices which are unhelpful.
- Energy intake should be appropriate for the level of energy expenditure after taking account of the requirements for growth and the need to change body mass or fat content.
- A high carbohydrate intake is necessary to meet the demands of intensive training, and carbohydrate supplementation before competition may also be beneficial.
- If a varied diet is eaten in an adequate amount, it is extremely unlikely that deficiencies of protein or of any of the micronutrients will arise. There may be a need to pay attention to the intake of iron, and possibly also of calcium, especially in female athletes and anyone on an energy-restricted diet.
- Water intake must be increased to meet the increased losses which occur through sweating, and carbohydrate–electrolyte drinks may be beneficial if consumed during events lasting longer than about 40 minutes.
- Dietary supplements are not recommended.