Nutrition and exercise--a consensus view

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The ability to perform exercise is impaired if the diet is inadequate. Conversely, performance may be improved by appropriate dietary manipulation. The primary need for the diet of athletes in training is to meet additional nutrient requirements imposed by the training load. Many athletes consider that a high protein diet is essential to stimulate muscle growth and promote repair. Evidence shows that hard exercise increases the protein requirement, but athletes eating a varied diet in sufficient quantity to meet their energy demands will obtain adequate protein. Carbohydrate is the main fuel used by the muscle in hard exercise, and carbohydrate intake must be sufficient to enable the training load to be sustained. During each strenuous training session, 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. It is recommended for athletes in training that carbohydrate should account for 60-70% of total energy intake, but the type of carbohydrate consumed is not crucial. With regular training, there must be an increased total energy 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 micronutrients. Possible exceptions are iron and calcium, especially when energy intake is restricted to control body weight. There is no good evidence to suggest that specific supplementation with any of these dietary components is necessary or that it will improve performance. Attention must be paid, however, to ensure an adequate water intake during training: dehydration will reduce performance. The body does not adapt to dehydration.

Consumption of a high-carbohydrate diet for the few days before competition with a reduction in the training load can double the muscle glycogen content and is generally known to be effective in increasing endurance performance. There is some evidence that the muscle glycogen content may also influence performance in events lasting only a few minutes. A high muscle glycogen content may be important when repeated sprints at near maximum speed have to be made. 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. The primary aims must be to ingest a source of energy, usually carbohydrate, and fluid for replacement of water lost as sweat. Carbohydrate-electrolyte (sodium) drinks are the most effective way of achieving this. Each athlete must establish by trial and error the most suitable dietary programme for training and competition.

Introduction

The ability to perform exercise will be impaired if the diet is inadequate, although the concept of dietary inadequacy may be quite different for an individual who exercises regularly compared to a sedentary individual. Conversely, performance may be improved by dietary manipulation, but we still have an incomplete understanding of how best to control diet to optimise sports performance. This discussion will focus on the effects of diet on competitive sports performance, as this is the area where we have most information. The general implications, however, apply to all activities where there is a need for optimum exercise performance. The recommendations to sportsmen and women are also broadly in line with the recommendations for a healthy diet for the general population. This paper is loosely based on an international consensus conference held under the auspices of the International Olympic Committee at Lausanne, Switzerland, in February 1991 and subsequently published[1]. Detailed discussion of the individual topics covered here will be found in that publication, together with a comprehensive reference list.

At the highest level of sports competition, where competitors are predisposed to success by genetic endowment and have undergone the most rigorous training, the difference between first and last is small, and nutritional intervention may make the difference between success and failure. It is not surprising therefore that sportsmen and women generally are concerned about their diet, although this concern is not always matched by a knowledge of basic nutrition. Some of the dietary practices followed by athletes in pursuit of success are sound, but others have no beneficial effect and may even be harmful. As in other areas of nutrition, these ideas are often encouraged by those who stand to gain financially from sales of dietary supplements.

Two distinct aspects 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 in the immediate pre-competition period and during competition

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itself. Considering the range of activities encompassed by the term sport and the variation in the characteristics of the individuals taking part, it is not surprising that the nutritional requirements vary. For non-competitive activities, and for the individual who exercises for recreational and health reasons, the daily diet forms part of a lifestyle which may be quite different from that of the competitive athlete, but the nutritional implications of exercise participation apply equally, albeit to different degrees.

The primary need for the diet of the athlete in training is to meet the additional nutrient requirement imposed by the training load. In sports involving prolonged strenuous exercise on a regular basis, participation has a significant effect on energy balance. Metabolic rate during running or cycling, for example, may be 15-20 times the resting rate, and such levels of activity may be sustained for several hours by trained athletes. Even the sprinter, whose event lasts only a few seconds, may spend several hours per day in training.

Evidence suggests that the metabolic rate may remain elevated for at least 12 and possibly up to 24 hours if the exercise is prolonged and close to the maximum intensity that can be sustained; this has been disputed, and it is unlikely that metabolic rate remains elevated for long periods after more moderate exercise[2]. If body weight and performance levels are to be maintained, the high rate of energy expenditure must be matched by a high energy intake. Available data for most athletes suggest that they are in energy balance within the limits of the techniques used for measuring intake and expenditure. This is to be expected as a chronic deficit in energy intake would lead to a progressive loss of body mass. However, data for women engaged in sports where a low body weight, and especially a low body fat content, are important, including events such as gymnastics, distance running and ballet, consistently show a lower than expected energy intake. There is no obvious physiological explanation for this finding other than methodological errors in the calculation of energy intake and expenditure, but it seems odd that these should apply specifically to this group of athletes. Many of these women do, however, have a very low body fat content: a body fat content of less than 10% is not uncommon in female long distance runners. Secondary amenorrhoea possibly related more to the training regimen than to the low body fat content, is common in these women, but is usually reversed when training stops[3].

Athletes engaged in strength and power events have traditionally been concerned with achieving a high dietary protein intake in the belief that this is necessary for muscle hypertrophy. In a survey of American college athletes, 98% believed that a high protein diet would improve performance. While it is undoubtedly true that a diet deficient in protein will lead to loss of muscle tissue, there is no evidence to support the idea that excess dietary protein will drive the system in favour of protein synthesis. 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. Exercise, whether it is long distance running, aerobics or weight training, will cause an increased protein oxidation compared with the resting state.

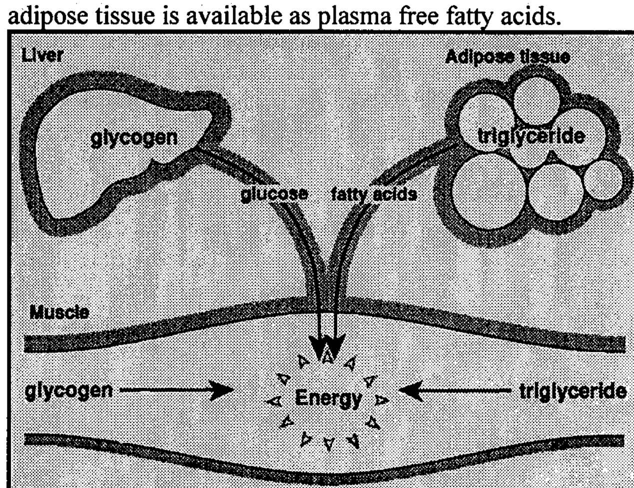
Although the contribution of protein oxidation to energy production during the exercise period may decrease to about 5% of the total energy requirement, compared with about 10-15% (the normal fraction of protein in the diet) at rest, the absolute rate of protein degradation is increased during exercise[4]. This leads to an increase in the minimum daily protein requirement, but this will be met if a normal mixed diet adequate to meet the increased energy expenditure is consumed (Table 1). In spite of this, however, many athletes ingest large quantities of protein-containing foods and expensive protein supplements. Daily protein intakes of up to 400 grams are not unknown in some sports. 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[5]. The recommended diet for athletes may even contain a lower than normal proportion of protein on account of the increased total energy intake.

Table 1. Energy intake and protein intake for a diet containing 12-15% protein

70 kg athlete (typical male)	
	12 MJ (3000 Cal) = 90 - 112g protein = 1.3 -1.6g/ kg
	20 MJ (5000 Cal) = 150 - 188g protein = 2.1-2.7g/ kg
60 kg athlete (typical female)	
	8 MJ (2000 Cal) = 60 - 75g protein = 1-1.3 g/ kg
	12 MJ (3000 Cal) = 90 - 112g protein = 1.5-1.9 g/ kg

The energy requirements of training are largely met by oxidation of fat and carbohydrate. The body's stores of carbohydrate, in the form of liver and muscle glycogen, and of fat, in the form of triglyceride stored in the muscle and in adipose tissue will contribute to varying degrees to energy production during exercise (Figure 1).

Figure 1. Energy sources available to the exercising muscle. Both fat and carbohydrate are stored within the muscle and are immediately available. Carbohydrate from the liver glycogen stores is transported to the muscles as blood glucose, and fat from the triglyceride stores of adipose tissue is available as plasma free fatty acids.



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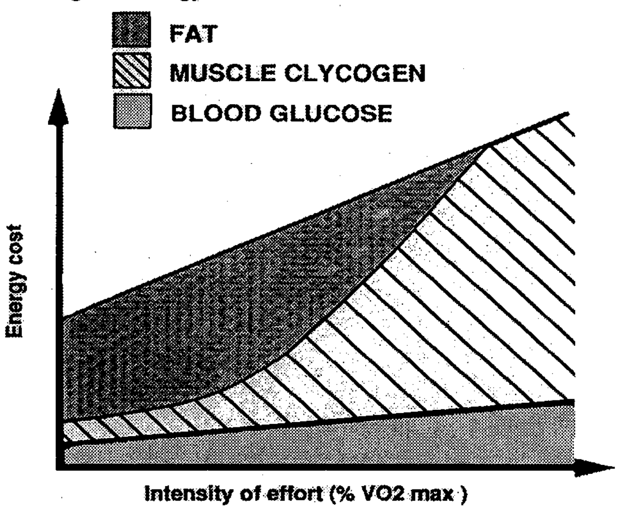
The higher the intensity of exercise, the greater the reliance on carbohydrate as a fuel: at an exercise intensity corresponding to about 50% of an individual's maximum oxygen uptake (V02max), approximately two thirds of the total energy requirement is met by fat oxidation, with carbohydrate oxidation supplying about one third. If the exercise intensity is increased to about 75% of V02max, the total energy expenditure is increased, and carbohydrate is now the major fuel. 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 energy requirement can be met by fat oxidation. Where the intention is to reduce body fat content, as in the case of many who exercise on a recreational basis, the exercise intensity should be high enough to result in a substantial increase in the metabolic rate, but not so high as to cause the majority of the energy demand to be met by carbohydrate oxidation. The effects of exercise intensity on metabolic rate and on the contributions of fat and carbohydrate metabolism to energy metabolism is illustrated in Figure 2.

Figure 2. Effects of exercise intensity on the metabolic rate and on the contributions of different metabolic fuels to meeting this energy demand.



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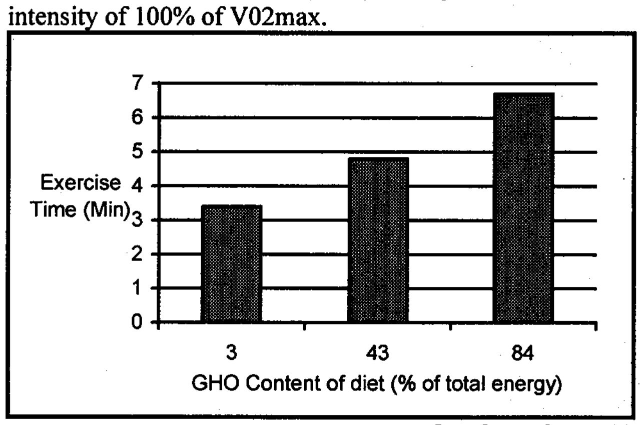
The primary need, therefore, is for carbohydrate intake to be sufficient to enable the training load to be sustained at the high level necessary to produce a response. During each strenuous training session, substantial depletion of the glycogen stores in the exercising muscles[6] and in the liver[7] 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. Any athlete training hard on a daily basis can readily observe this. If a low carbohydrate diet, consisting mostly of fat and protein, is consumed after a day's training, it will be difficult to repeat the same training load on the following day.

Feeding a high-fat, low-carbohydrate diet for prolonged periods has been shown to increase the capacity of muscle to oxidise fat and hence improve endurance capacity in the rat, but may not be effective in man. Similarly, short term fasting increases endurance capacity in the rat, but results in a decreased exercise tolerance in man. The training diet, therefore should be high in carbohydrate, preferably with a large proportion in the form of complex carbohydrates rather than simple sugars[8]. This suggestion conforms with the recommendations of NACNE that carbohydrates provide 50% of dietary energy intake. It has been shown that 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 if the carbohydrate content was only 40%, a progressive fall in muscle glycogen content was observed. A dietary carbohydrate intake of 500-600g was necessary to ensure adequate glycogen resynthesis. These high levels of intake are difficult to achieve without consuming large amounts of simple sugars. Most athletes find that they can only satisfy the requirement for carbohydrate by eating confectionery and sweet snacks between, or even instead of, meals[8].

Figure 3. Effects on the carbohydrate content of the diet on the ability to perform high intensity exercise, measured as the time to exhaustion in a cycle ergometer test at an intensity of 100% of V02max.



Data from reference 14.

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. A diet which may be considered inadequate for a sedentary individual consuming 4MJ per day, may meet the requirements of an athlete taking 12-15 MJ/day. Indeed without resorting to sweets, snacks and convenience foods, such a high intake may be difficult to achieve. There is, however, no evidence that this pattern of eating is harmful. For the individual who has to fit an exercise programme into a busy day, it is inevitable that changes to eating patterns must be made, but these need not compromise the quality of the diet. When the energy expenditure is very high, carbohydrate-rich drinks and snacks become an essential part of the diet[9].

The use of dietary supplements, especially of vitamins, but also including a wide range of substances classified as ergogenic aids, is widespread among athletes, but the evidence does not generally support any beneficial effect of supplementation[10]. Possible exceptions may occur where the normal diet is inadequate, in low body weight sports such as women's gymnastics there is a real possibility of chronic mild malnutrition, but these are exceptional situations which should be easily recognised. One supplement which does appear to be an exception is creatine, and creatine supplements are now commonly used by athletes in events where a high power output is required.

There is good evidence that supplementing the diet with creatine at a dose of 20-30g per day for a period of 5-6 days will result in an increase in the muscle content of creatine phosphate and that this will increase the ability to perform short bursts of high intensity exercise[11].

The only nutritionally significant exceptions to the generalisation about dietary supplements may be iron[12] and, in the case of very active women, calcium[13]. Highly trained endurance athletes commonly have low circulating haemoglobin levels, although total red cell mass may be elevated due to an increased blood volume. This may be considered to be an adaptation to the trained state, but 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 has been reported to increase bone mineral density in women, and this may be a significant benefit of exercise for most women. Hard training, however, may reduce circulating oestrogen levels and hence accelerate bone loss. For these athletes, an adequate calcium intake should be ensured, although calcium supplements themselves will not reverse bone loss while oestrogen levels remain low. Restoration of normal menstrual function is, however, associated with a gain of bone mass[3].

There is no doubt that the ability to perform prolonged exercise can be substantially modified by dietary intake in the pre-exercise period. 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 prior to the exercise task, and the day of exercise itself.

Dietary manipulation to increase muscle glycogen content in the few days prior to 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 one week prior to 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[8].

There is now a considerable amount of evidence that it is not necessary to include the low-carbohydrate glycogen depletion phase of the diet for endurance athletes. All that is necessary is to reduce the training load over the last 5 or 6 days before competition and to simultaneously increase the dietary carbohydrate intake. This avoids many of the problems associated with the more extreme forms of the diet. Although an increased pre-competition muscle glycogen content is undoubtedly beneficial, there is a faster rate of muscle glycogen utilisation when the glycogen content itself is increased, thus nullifying some of the advantage gained.

Consumption of a high carbohydrate diet in the days prior to competition may also benefit competitors in games such as rugby, soccer or hockey, although it appears not to be usual for these players to pay attention to this aspect of their diet. Karlsson and Saltin showed that players starting a soccer game with low muscle glycogen content did less running, and much less running at high speed, than those players who began the game with a normal muscle glycogen content. It is common for players to have one game in midweek as well as one at the weekend, and it is likely that full restoration of the muscle glycogen content will not occur between games unless a conscious effort is made to achieve a high carbohydrate intake.

Although this glycogen loading procedure is generally restricted to use by athletes engaged in endurance events, there is some evidence that the muscle glycogen content may influence performance in events lasting only a few minutes[14]. A high muscle glycogen content may be particularly important when repeated sprints at near maximum speed have to be made. At major athletics championships, the sprinter who competes in the 100m and 200m as well as in the relay may be required to run as many as 8 or 9 races within a rather short space of time. Short term high-intensity exercise can also be improved by ingestion of alkaline salts prior to exercise to enhance the buffering of the protons produced by anaerobic glycolysis[14].

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. The primary aims must be to ingest a source of energy, usually in the form of carbohydrate, and fluid for replacement of water lost as sweat[15]. 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. It is often reported that exercise performance is impaired when an individual is dehydrated by as little as 2% of body weight, and that losses in excess of 5% of body weight can decrease the capacity for work by about 30%. Sprint athletes are generally less concerned about the effects of dehydration than are endurance athletes. The capacity to perform high intensity exercise which results in exhaustion within only a few minutes has been shown to be reduced by as much as 45% by prior prolonged exercise which resulted in a loss of water corresponding to only 2.5% of body weight. Smaller, but substantial, reductions in performance occurred after administration of diuretics or after sweat loss in a sauna. Although there is little opportunity for sweat loss during sprint events, athletes who travel to hot climates are likely to experience chronic dehydration.

The composition of drinks to be taken during exercise should be chosen to suit individual circumstances. 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. Although consumption of a high-carbohydrate diet in the days prior to exercise should reduce the need for carbohydrate ingestion during exercise in events lasting less than about 2 hours. It is not always possible to achieve this-- competition on consecutive days, for example, may prevent adequate glycogen replacement between exercise periods. In this situation, more concentrated glucose drinks are to be preferred. These will supply more glucose thus sparing the limited glycogen stores in the muscles and liver without overloading the body with fluid. In many sports there is little provision for fluid replacement. Participants in games such as football or hockey can lose large amounts of fluid, but replacement is possible only at the half-time interval. Until very recently, the opportunities for drinking during long road races were severely restricted, but the rules have now been relaxed to allow more frequent intake.

In the post-exercise period, replacement of fluid and electrolytes can usually be achieved through the normal dietary intake. If there is a need to ensure adequate replacement before exercise is repeated, extra fluids should be taken and small amounts of table 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.

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营养与运动—— 一个一致的看法

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摘要：

膳食、营养与运动表现的关系十分密切。但必需注意到有两种运动膳食，即训练膳食及比赛（包括赛前）膳食。传统上认为从事中高强度项目的运动员应食用高蛋白膳食以便肌肉增粗。但实际上过量的膳食蛋白并不能增加蛋白质合成。训练时的热量需要主要靠脂肪和碳水化合物来提供，如运动强度大，则碳水化合物应为主要的能量来源。因此，运动膳食的基本要求是碳水化合物必须充足。在耐力运动员比赛前数日进行膳食调查以增加肌糖元以被广泛采用，即在赛前换成高碳水化合物膳食，而不进行剧烈活动。以证明，赛前数日摄入高碳水化合物膳食对橄榄球、足球等项目有益。糖元增加措施不限于耐力运动员，对于田径运动员也很重要。另外，水分和电介质的补充也很重要。比赛过程中所用饮料的成份（葡萄糖、钾、镁、钙）应认真选择以适合不同情况。

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