Role of micronutrients in sport and physical activity

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Many micronutrients play key roles in energy metabolism and, during strenuous physical activity, the rate of energy turnover in skeletal muscle may be increased up to 20–100 times the resting rate. Although an adequate vitamin and mineral status is essential for normal health, marginal deficiency states may only be apparent when the metabolic rate is high. Prolonged strenuous exercise performed on a regular basis may also result in increased losses from the body or in an increased rate of turnover, resulting in the need for an increased dietary intake. An increased food intake to meet energy requirements will increase dietary micronutrient intake, but athletes in hard training may need to pay particular attention to their intake of iron, calcium and the antioxidant vitamins.

For normal health to be maintained, a wide range of vitamins, minerals and trace elements must be present in adequate amounts in the body tissues, and the dietary intake must be sufficient to meet the requirement. Many vitamins and minerals play key roles in energy metabolism, and the adverse effect of deficiencies of these components is well recognised and easily demonstrated. Marginal deficiency states may have little effect on the sedentary individual, but small impairments of exercise capacity may have profound consequences for the serious athlete. Regular intense exercise training may also increase micronutrient requirements, either by increasing degradation rates or by increasing losses from the body. Consequently, there is a great interest shown by athletes in some of these dietary components because of their role in maintaining or enhancing physical performance. There is often, however, a failure to appreciate that it is not inevitably, or indeed even generally, the case that increasing micronutrient in*t*ake to levels above those that are adequate for maintaining health will improve athletic performance.

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Biological functions of vitamins

The use of vitamin supplementation to enhance performance is based on the known biological actions of these compounds, and some important biological functions related to physical activity are summarised in Table 1.

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Table 1 Major biological functions of the vitamins in exercise. Vitamin K is not included in this table, as no specific role for this vitamin in exercise has been identified

Vitamin	Metabolic role
A	Antioxidant function
Thiamin (B_1)	Carbohydrate metabolism
Riboflavin (B_2)	Mitochondrial electron transport (as FAD)
Niacin (B_3)	Multiple metabolic pathways (as NAD and NADP)
Pyridoxine (B_6)	Amino acid synthesis
Folate	Red blood cell synthesis
Pantothenic acid	Oxidative metabolism (as CoA)
Biotin	Biosynthetic reactions
B_{12} (cyanocobalamin)	Red blood cell synthesis
Ascorbic acid (C)	Antioxidant, catecholamine synthesis, tissue repair
D	Calcium homeostasis
E	Antioxidant, prevention of free radical damage

Many vitamins, particularly the water-soluble vitamins, are involved in mitochondrial energy metabolism: it is, therefore, intuitively attractive to believe that supplying additional amounts may be beneficial. Although information on the influence of vitamin supplementation on mitochondrial metabolism appears to be relatively scarce, athletes often see dietary supplements as a form of 'insurance policy' – even when there is no evidence that a deficiency may exist or that intakes above the normal level may be beneficial, it may be as well to take supplements 'just in case'. This practice is generally harmless, except perhaps in the financial sense, but there are some concerns over the possible harmful effects of excessive intakes of the fat soluble vitamins (A, D, E and K) over long periods. The water-soluble vitamins are simply excreted if consumed in amounts in excess of the requirement. By definition, all vitamins must be supplied in the diet if health is to be maintained, but deficiency states are rare in the industrialised countries, and the classical symptoms of deficiency are unlikely to be observed in athletes.

Biological functions of minerals

At least 20 different minerals are required in adequate amounts to sustain normal function of tissues and cells. Many of these are required in only trace amounts, but others must be supplied in greater quantities. Deficiencies of all of these elements are theoretically possible, but, in practice, deficiencies are generally uncommon, with the possible exceptions of iron, calcium and, in some parts of the world, iodine. A balanced diet consumed in amounts sufficient to meet energy requirements will normally supply all the vitamins in the required amounts, but not all athletes have a high energy intake and many do not eat a varied diet.

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There has been much interest in magnesium homeostasis in athletes. Magnesium plays a number of vital roles in the regulation of energy metabolism, acting as a cofactor and activator for a number of enzymes, and is also involved in calcium metabolism and in the maintenance of electrical gradients across nerve and muscle cell membranes. Magnesium is lost in sweat in concentrations that may be higher than those in the blood, leading to concern about magnesium deficiency in athletes losing large amounts of sweat. Magnesium deficiency is often proposed as a cause of exercise-induced muscle cramps, even though there is no experimental evidence to support this hypothesis[1]. In some countries, including Germany, this idea is so fixed that sports drinks intended for athletes invariably have added magnesium, even though the same products are sold in other countries without the addition of magnesium salts. Experimental magnesium deficiency results in a variety of symptoms, but these do not include muscle cramp.

Zinc is also involved as a cofactor in many enzyme reactions, and has many other roles, including promotion of tissue repair processes. Most of the body zinc content of about 2 g is present in muscle (60%) and bone (30%). Low concentrations are present in sweat, and exercise may stimulate urinary loss: this may account for the concern of many athletes, but there is no evidence that these losses are sufficient to cause concern. Small amounts of zinc are present in many foods, including both animal and vegetable products. Copper is another divalent cation with important biological functions including modulation of enzyme activity and also a role in the synthesis of haemoglobin, catecholamines and of some peptide hormones. Once again, deficiencies are rare, as copper is found in a wide range of foods, including shellfish, liver, whole grain cereals, legumes and nuts.

Selenium has an antioxidant function by virtue of forming an integral part of the glutathione peroxidase enzyme, helping to protect cells against the damage that can result from free radicals. There is some evidence to suggest a role for selenium in protecting against some cancers. In regions of the world where the soil is low in selenium, vegetables will have a low selenium content and deficiencies are possible: these are, however, generally well recognised, and appropriate measures for fortification are in place, so this should not affect most athletes.

An adequate dietary iodine intake is essential for synthesis of the thyroid hormones thyroxine (T_4) and tri-iodothyronine (T_3), and thyroid deficiency was formerly common in parts of the world where the availability of iodine is low. Recognition of the role of iodine led to iodination of salt in these regions. In most European countries, intakes are well in excess of requirements, and there is no evidence to suggest a greater requirement in physically active individuals.

A variety of other elements, including cobalt, molybdenum, manganese, chromium and phosphorus, play important metabolic roles and are

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required in the diet in small amounts. Deficiencies of all of these elements are sufficiently rare that the possibility of their being encountered in athletes is negligible. Many of these elements, however, including cobalt, chromium and phosphate, are used as supplements by athletes, although there is no evidence either for an increased requirement or for a beneficial effect of specific supplementation on performance.

A comprehensive review of the role of minerals in exercise performance and of the requirements of athletes is presented by Clarkson[2].

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Dietary micronutrient intake in athletes

With regular strenuous training, there must be an increased total food intake to balance the increased energy expenditure: without this, hard training cannot be sustained for long. Provided that a reasonably varied diet is consumed, this will supply more than adequate amounts of protein, minerals, vitamins and other dietary requirements[3]. There are of course always exceptions – as with the general population, not all athletes eat a varied diet, and some athletes restrict energy intake to maintain low body weight and low levels of body fat. It must be remembered, however, that the results of surveys which show intakes of vitamins and minerals below the RDA in some groups of athletes (most especially female athletes in sports where a low body fat content is considered essential, including ballet dancers, gymnasts, and long distance runners) take no account of the very low body weight of most of these individuals. Indeed the RDAs are so imprecise that there is generally no attempt to relate the requirement to body weight. However, it is likely that the increased energy intake of most athletes will ensure an adequate intake of most essential dietary components.

There is no good evidence to suggest that specific supplementation with any of these dietary components is necessary or that it will improve performance. Deficiencies can only be established by biochemical investigation or by the identification of specific symptoms as mentioned above. Where the presence of a specific deficiency is established, this should be treated wherever possible by directing the individual towards a more appropriate choice of foods to include those with a high content of the deficient component. In almost every case, it is possible to meet requirements from a normal varied diet, and only where clinical signs of an established deficiency are identified should vitamin or mineral supplementation be considered. The only exceptions to the generalisation about the value of dietary supplements in meeting micronutrient needs may be iron and, in the case of very active women, calcium. There is also some experimental support for antioxidant supplementation in some situations.

Iron, haemoglobin and oxygen transport

Iron has a number of functions in the human body, but the principal one is its role – in the form of haemoglobin – in the transport of oxygen from the lungs to the tissues where it is required. A fall in the circulating haemoglobin concentration is associated with a reduction in oxygen carrying capacity and a decreased exercise performance[4]. The body stores some iron in the form of ferritin, and transport around the tissues is accomplished by another protein, transferrin. The first sign of iron deficiency is generally a fall in the circulating ferritin concentration. Anaemia – a low blood haemoglobin concentration – may result from an inadequate iron intake in the diet, but may also be due to inadequate absorption of dietary iron, or to a deficiency of vitamins B_{12} or folate, which are both involved in the formation of new red blood cells. The circulating transferrin level can rise sharply after exposure to any one of a number of stresses, and cannot be used as an index of iron status.

The observation that VO_{2max} can be increased by artificial elevation of the circulating haemoglobin concentration, by use of red cell re-infusion procedures[5,6] and, more recently, recombinant erythropoietin, to enhance performance has focused attention on the possible limitation to oxygen transport imposed by the oxygen carrying capacity of the blood. Although these procedures are, quite properly, banned in athletes, the search for legitimate means of achieving the same end goes on. This explains in part the popularity of altitude training among athletes, as well as the widespread use of iron supplementation. In a controlled study, well-trained subjects received either a sham saline infusion or an infusion of red cells in a double-blind crossover design[7]. Blood volume was unchanged 24 h after re-infusion, but haemoglobin concentration was increased by 9% from 151 to 165 g/l. This was accompanied by a 5% increase in VO_{2max} and a 34% increase in treadmill running endurance time (from 7.2 to 9.7 min).

In view of the apparent importance of the oxygen carrying capacity of the blood for oxygen transport, it seems odd that one commonly observed adaptation to endurance exercise is a decrease in the circulating haemoglobin concentration, commonly referred to as sports anaemia. This is not a true anaemia, however, and the decrease in haemoglobin concentration is a consequence of the disproportionate increase in plasma volume. The total circulating haemoglobin mass is usually increased or at least maintained in the trained state. 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 certainly 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.

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Stimulation of erythropoiesis – the formation of new red blood cells – is apparent within the first day of two of exercise training, and a similarly rapid response is observed on going to altitude. If the body's iron stores are inadequate at this time, there will certainly be some impairment of the process of adaptation. Special attention to dietary iron intake is, therefore, necessary for the sedentary individual who embarks on a strenuous training programme or for the individual, whether sedentary or athletic, who plans to spend some time at an altitude of more than about 1500–2000 m.

Calcium

Osteoporosis is now widely recognised as a problem for both men and women, and an increased bone mineral content is one of the benefits of participation in an exercise programme. Regular exercise results in increased mineralisation of those bones subjected to stress[8] and an increased peak bone mass may delay the onset of osteoporotic fractures; exercise may also delay the rate of bone loss. The specificity of this effect is demonstrated by the unilateral increase in forearm bone density observed in tennis players[9].

In athletes training hard on a regular basis, there is likely to be a decrease in circulating levels of sex steroids in both men and women. Oestrogen plays an important role in the maintenance of bone mass in women, and low oestrogen levels cause bone loss[10]. Many of these women also have low body fat and, because of their low body mass, also have low energy (and calcium) intakes in spite of their high activity levels. All of these factors are a threat to bone health. The loss of bone in these women may result in an increased predisposition to stress fractures and other skeletal injury and must also raise concerns about bone health in later life[11]. It should be emphasised, however, that this condition appears to affect only relatively few athletes. Hard sustained training is a relatively new phenomenon, particularly among female athletes, and it remains to be seen whether the long-term effects are clinically significant.

For these athletes, as for all individuals, and especially for women, an adequate calcium intake should be ensured, although calcium supplements themselves will not reverse bone loss while oestrogen levels remain low. It must be emphasised that, although there is little scope for harmful effects, calcium supplements should only be taken on the advice of a qualified practitioner after suitable investigative procedures have indicated an inadequate intake. The recommended dietary calcium intake varies between countries, but for men the recommended intake is normally about 800 mg/day, and for women about 1200 mg/day. Intakes of as much as 2000 mg/day are sometimes recommended. Even then,

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alternatives to supplementation, specifically alterations in the selection of foods to achieve a higher intake must also be considered, and should be sufficient to meet needs.

Antioxidant nutrients

Athletes engaged in very hard physical training and sedentary individuals participating in unaccustomed exercise show signs of muscle damage in the post-exercise period, and there is evidence of free radical-induced damage to muscle membranes and subcellular structures. There is some evidence for an adaptive increase in antioxidant status in response to regular exercise[12], and this may help protect against further damage. Supplementation of the diet with antioxidant nutrients has been proposed as a possible way of further reducing the harmful effects of exercise. Some studies suggest that the severity of muscle damage — as assessed by circulating levels of muscle-specific proteins — can be reduced by supplementation with large doses of vitamins A, C and E, but the evidence is not entirely convincing, and further information is required before any specific recommendations can be made.

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Key points for clinical practice

1 Regular strenuous exercise increases the demand for energy intake, and a high dietary energy intake will meet the demand for all micronutrients, provided that a varied diet is consumed.

2 Not all athletes have a high energy intake, and the effects of a marginal intake may be more apparent in an active individual than in a sedentary person.

3 Modest levels of exercise stimulate bone mineralisation, but very hard exercise may promote calcium loss, especially in women.

4 Vitamin supplementation is generally unnecessary, but further research into the requirements of athletes for antioxidant nutrients is required.

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