Vitamin E and athletic performance

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Vitamin E has been of interest to sports people for many years, with reports of its dietary supplementation in the 1950s. In the last decade there has been a resurgence in the interest in the relationship between vitamin E and athletic performance and animal studies have demonstrated that endurance is reduced in vitamin E deficiency. Much of the recent research has centred around the antioxidant properties of vitamin E and it seems that these properties are in part responsible for the improvement of aerobic power of humans at medium to high altitude venues following supplementation of the vitamin. However, there have been no similar reports relating to sea-level performance. On the other hand, one recent study has indicated that supplementation of vitamin E to athletes consuming the recommended daily intake (RDI) elicited a reduction in indicators of muscle damage following an exercise bout. Furthermore, vitamin E is implicated in maintenance of both optimal immune function and optimal blood viscosity, both factors being important in athletes' ability to train and compete, but it remains to be seen whether supplementation over the RDI has any beneficial effects. So, there seems little doubt that vitamin E deficiency will impair athletic performance and there is also some evidence that supplementation of vitamin E on top of the RDI may provide some advantage for the intensely training athlete, especially those training at altitude.

Introduction

A 1922 report identified a fat-soluble factor as preventing foetal resorption in animals fed a rancid lard diet[1]. They named the factor tocopherol, 'tocos' meaning offspring and 'phero' to bring forth. This early experiment and later confirmation by others formed the basis for determination of the biological activity of the various tocopherols. The tocopherols were accepted as 'vitamin E' in 1925. The significance of foetal resorption clearly overshadowed the series of studies on the antioxidant properties of the tocopherols initiated by Olcott and Emerson[2] and followed up by other workers through to the early '60s. The profile of vitamin E enjoyed an upsurge when Cureton[3] and Cureton and Pohndorf[4] reported that vitamin E and wheat germ oil improved performance in training athletes and middle-aged subjects respectively. The momentum was maintained during the early '60s when it was found that certain metabolites of α-tocopherol restored the fertility of vitamin E deficient rats[5,6].

There was considerable interest in the use of vitamin E at the Mexico City Olympic Games in 1968, supposedly to compensate for the effects of the reduced oxygen pressure. The latter interest probably arose through reports that vitamin E administration enhanced the survival of animals exposed to acute hypoxia[7,8]. The general ergogenic implications of vitamin E supplementation were reinforced again some 20 years ago, by several animal studies in which induced vitamin E deficiency states resulted in decreased oxidative phosphorylation[9,10], decreased creatine phosphate activity[11,12] and decreased NAD/NADP succinate-cytochrome-c reductase activity and ATP production[13]. These findings prompted the hypothesis that vitamin E acts to optimise orientation of cytochromes b and c for electron transfer[14]. Furthermore, animal studies suggested that training induced the same type of muscle damage as vitamin E deficiency (Aikawa et al., 1984) and vitamin E deficient rats exhibited a 40% reduction in running endurance[16].

The more recent findings that vitamin E is associated with maintenance of the structural and functional integrity of biological membranes[17,18], seems to provide a plausible explanation for the pro-oxidative metabolic effects associated with the vitamin. Clearly, if vitamin E deficiency induces lipid peroxidation of sarcoplasmic reticular vesicular suspensions, this will adversely affect the efficiency of the CA^{++} transport system and Ca^{++}/ATPase activity[19], with resultant diminished muscular work capacity.

Consequently, research over the last decade relating vitamin E and exercise has targeted the antioxidant properties of vitamin E in relation to protection of muscle fibre and red cell membrane during bouts of intense exercise. The exercise protocol used as the challenge has typically been metabolically stressful cycling or running, presumably to maximize production of reactive oxygen species and associated oxidative damage. However, some authors have hypothesized that mechanically, rather than metabolically damaging exercise (such as downhill treadmill running or other exercise involving predominantly eccentric muscle contraction) may, through its influence on the immune system, also stimulate the production of free radicals as the neutrophils' respiratory burst is brought into play[20].

Vitamin E supplementation and athletic performance

When considering the relationship of a nutrient with performance, there are, as usual with such studies, two separate questions that need to be addressed. The first is whether dietary vitamin E is essential to the development of peak fitness or performance of the athlete. The second question is whether those athletes involved in strenuous training can benefit from supplementation of the vitamin at levels higher than the RDI. Put another way, can an athlete consuming the RDI for vitamin E, with plasma vitamin E concentration between 5–10 mg/l, benefit further by increasing their plasma concentration?

As mentioned earlier, the first published study of vitamin E supplementation and athletic performance arose in 1954 in the *American Journal of Physiology*[3] and obviously excited coaches and athletes with a finding that supplementation improved laboratory cycling and running performances over training alone. Swimmers, in particular, responded to this research, but from what we can gather, a large proportion of other serious athletes took vitamin E as a supplement until the early to mid-70s[21]. Anecdotal support for the common use of vitamin E supplementation comes from Terry Gathercole, Australian Institute of Sport swimming coach and former champion swimmer. He and his Australian team colleagues used to routinely take α-tocopherol tablets through training and competition periods. Interestingly, during the 1956 Olympics Gathercole recalls a visit from Professor Thomas Cureton, author of the first study with athletes and vitamin E[3], at which time Cureton took notes on each swimmer's supplementation programme.

In the '70s five groups tried to reproduce the early findings but failed to detect any advantage of vitamin E supplementation[22-26]. None of these studies incorporated blood measures of vitamin E status, which would have been useful given the notable unreliability and lack of compliance in athletes involved in studies of this nature[27,28].

Recently, there have been investigations of the effect of several months of multivitamin supplementation, which included vitamin E, on a variety of components of athletic performance[28-31]. Apart from some trends in one or two aspects of fitness, the authors were not able to support the hypothesis that vitamin E (or multivitamin supplementation) for athletes consuming the RDI, has any beneficial (or deleterious) effect on performance. Two aspects of the latter studies are worth noting, however. Firstly, plasma vitamin E levels did not rise after 3 months and 6 months of vitamin/mineral supplementation[29,31]. The authors suggested that absorption of vitamins E and A may have been impaired in the multivitamin preparations, as these vitamins have been reported to mutually inhibit absorption[32]. Secondly, it has been explained that as elite athletes seek improvement in fractions of 1%[33] – the design of performance studies is rarely of the sensitivity to detect these small improvements. Indeed, it has been estimated that more than 200 athletes may be needed in both treatment and placebo groups to detect a 10 second difference in a 4 minute event[34].

Animals are easier to manage experimentally than humans, but we are, of course, faced with difficulties of interpretation of the findings of animal studies in relation to humans. Nevertheless, the endurance capacity of vitamin E deficient rats is reduced dramatically, even when they are supplemented with vitamin C[35]. Further, the authors have demonstrated that the reduction in endurance capacity of the rats was not related to mitochondrial activity in skeletal or heart muscle.

Vitamin E supplementation and performance at high altitudes

Three studies provide good evidence that vitamin E supplementation does improve performance at medium to high altitudes (2000–5000m). The first suggestion in this regard came from a study of a group of prominent long distance runners[36] who received 300mg α-tocopherol daily for 44 days, significantly raising serum vitamin E concentration. The experimental group was found to perform better than the control group in a race at 5000m altitude and the authors reported lower blood lactate accumulation in the supplemented group. A few years later, in a double blind cross-over design, it was demonstrated that 1200 IU/day vitamin E for 6 weeks improved the capacity for aerobic work at both 1524m and 4572m simulated altitudes, by 9% and 14% respectively[37]. More recently, there was an investigation of the aerobic fitness adaptations of mountaineers on expedition in the Himalayas[38]. Two groups of mountaineers were given daily multivitamin capsules, one with vitamin E, the other without 2 × 200mg d-α-tocopherol per day. Anaerobic threshold measures (using the lactic acid accumulation in response to power output) were performed as the mountaineers proceeded on a 10 week expedition around 5000m. In contrast with the placebo group, improvements in fitness were demonstrated in the supplemented group. Furthermore, pentane exhalation, considered to be a measure of lipid peroxidation, was doubled in the first 4 weeks in the placebo group, but was unchanged in the vitamin E group.

These studies provide sound evidence that vitamin E supplementation improves performance under conditions of chronic hypoxia. Apparently, reactive oxygen species are produced in greater quantities when metabolism and oxygen consumption are increased[38], and in man the metabolic rate can be increased from 300ml O_2/min at rest to 6500ml O_2/min in endurance athletes. In addition, it seems that we may also be subjected to an increased stress from free radicals on exposure to hypoxic environments, given the better adaptations of vitamin E supplemented humans to physical exercise at high altitude. On the other hand, the so-called hyper-oxidative state of the intensely exercising person may also be viewed as 'relative hypoxia'; hypoxic at the working tissue level because the demand for maximal power is not always met by the oxygen transport capacity of the circulation. This results in involvement of anaerobic glycolysis, and lactic acid accumulation in whole blood can rise to 25mmol/l in intensely exercising athletes whilst pH drops below 7.0. Recent studies have demonstrated that the blood of even elite athletes can be progressively desaturated with oxygen at these extremely high rates of power output[40], so, if vitamin E supplementation does help man at altitude, then it might be argued that it could also help intensely-exercising athletes at sea-level where muscle cells may also be under hypoxic stress.

A further implication of the vitamin E studies at altitude for sea-level performance is that athletes utilize altitude training to seek improvements at sea level. Based on the evidence above, it might be speculated that if altitude-induced adaptations are beneficial for sea-level competition then these adaptations might also be enhanced through supplementation of vitamin E at altitude.

Vitamin E and performance modulators

There is a further relationship between studies of the effect of vitamin E and altitude on performance. For years, physiologists have been investigating the effect of medium altitude training (2000–2500m) on sea level athletic performance. For altitude training and vitamin E supplementation alike, numerous coaches and athletes claim it is beneficial despite the fact that scientifically controlled experiments have not borne this out[41]. Given the problems mentioned above of using absolute athletic performance as a criterion for a treatment's effectiveness[34], studies of vitamin E and altitude training share inherent difficulties when it comes to indicating effects on performance. It would then seem a more sensible approach to investigate vitamin E's efficacy (and perhaps altitude training's) in modifying aspects which might contribute to better performance.

(a) Vitamin E and muscle membrane damage

Vitamin E is clearly an effective biological antioxidant, with the potential ability to protect cellular membranes from oxidative damage by free radicals[42,43]. Athletes' training capacity is limited by their ability to recover between training sessions. Such limitations in recovery are due in part to muscle tissue damage, and associated general soreness and fatigue. Consequently, it has been hypothesized that vitamin E, the antioxidant may have a beneficial role to play[44].

A recent study at the Australian Institute of Sport has uncovered some interesting findings[45]. This double blind, cross-over, placebo controlled study, demonstrated that 4 weeks of supplementing runners with 1000 IU of α-tocopherol resulted in a significant increase in both plasma and red cell membrane concentrations of vitamin E. Individual response to a 40 minute run at 3mM blood lactate concentration (quite strenuous exercise) revealed that the supplemented runners had significantly lower blood creatine kinase (CK) concentrations, this being generally interpreted as attenuation of muscle fibre damage. What is more, where blood tocopherol level was plotted against CK concentration, vitamin E levels below 10mg/l were associated with sharply increased CK concentration. The curve suggested that a blood level of greater than 10 mg/l is necessary to offset the sharp increase in CK level. All of the supplemented subjects were measured with plasma tocopherol concentrations greater than 10mg/l, whilst half of the unsupplemented subjects had concentrations less than 10mg/l. These data may be interpreted as evidence that supplementation of vitamin E levels greater than that achieved by diet alone may be beneficial to the recovery of intensely training athletes, irrespective of the fact that trained runners appear to adapt, at least partially, to their oxidative stress by natural increases in tissue antioxidant status[46]. Such natural adaptation may not always eventuate. Studies in rats,[47-49] suggest that chronic intense training, whilst producing mitochondrial proliferation, leads to a decrease in the vitamin E concentration in muscle.

The Institute of Sport study is not without problems in interpretation. Whilst muscle enzyme 'leakage' has been proposed as an index of muscle damage, this interpretation has been questioned[20]. In an attempt to explain a higher blood CK concentration in a vitamin E supplemented group of older people aged more than 55 years (in contrast to younger subjects) the authors referred to two alternative hypotheses for muscle enzyme release following exercise. Both were based on transient membrane permeability changes resulting either from reversible membrane pore function[50] or through activated neutrophil release of lipoxygenase products, the activity of which has been previously modulated with vitamin E[51].

In any case, the escape of the large CK molecule does represent a loss of 'functional integrity' of the muscle cell, related to muscle soreness, and would appear to correlate negatively with an athlete's recovery from a training session. These findings of reduced CK efflux in supplemented athletes may therefore be of advantage to athletes irrespective of the precise mechanism of raised blood CK concentrations.

(b) Vitamin E and red cell damage

Reduced plasma ferritin concentrations can be a consequence of prolonged increased physical training, as indicated by the haematological study of highly trained rowers[52]. Numerous studies have indicated low serum ferritin in endurance trained athletes[53]. Whilst subject to some uncertainty, serum ferritin levels are believed to be well correlated with bone marrow iron stores in athletes[54]. However, there is new evidence that the serum ferritin level of athletes is not necessarily related to their dietary iron intake, but more to their energy output[55]. If superoxide production increases in proportion to metabolic rate, it is possible that lipid peroxidation may result in increased day-to-day haemolysis of athletes[39]. This premise is supported by findings of higher proportions of blood reticulocytes in athletes, indicating increased red cell turnover[56]. The importance of vitamin E is indicated from the peroxide haemolysis test[57]: erythrocytes possess decreased ability to withstand peroxidative stress from hydrogen peroxide when vitamin E levels in the blood are decreased. Herein lies another possible antioxidant role of vitamin E, in protection of the red cell membrane and potential reduction of iron loss through excretory pathways. On the other hand, it may be argued that increased red cell turnover and a resulting younger population of cells is advantageous to the athlete given the more favourable physiological and rheological properties of younger red cells[58].

(c) Vitamin E and endocrine activity

Of further interest in the Australian Institute of Sport study[45] is the finding that the ratio of blood testosterone/cortisol concentrations at 24 hours post exercise was significantly higher in the supplemented group. The ratio has been utilized as an indication of recovery from intense exercise (as these hormones influence muscle anabolism/catabolism respectively). The physiological significance of this finding needs to be further investigated, but it does provide more evidence that vitamin E supplementation at multiples of the RDI may be of benefit to athletes. Also, through the enhanced testosterone concentrations, the relationship of vitamin E supplementation to the human reproductive system is hinted at in humans, seven decades after the first findings of its influence on the reproductive process in laboratory animals.

(d) Vitamin E and blood viscosity

Blood viscosity is related not only to health[59], but to performance in athletes. In another recent report from the current author's laboratory[60] it was demonstrated that performance of elite rowers was best when their whole blood viscosity was lowest within the normal range. It is also of advantage to athletes involved in high level aerobic exercise to maximize their haematocrit, and accordingly their oxygen transport per unit volume of blood. However, as a rule the higher the haematocrit, the higher the blood viscosity, but vitamin E may help to optimize blood viscosity. For example, erythrocyte filterability and hence deformability of vitamin E supplemented mountaineers was unchanged under the hypoxic stresses of a high altitude expedition, in contrast to a placebo group whose erythrocyte filterability fell significantly[61]. Vitamin E supplementation is also effective in reducing platelet adhesion[62], important to patients with thrombo-embolic disease, and with possible implications for athletes in optimizing whole blood viscosity, but as yet unstudied in this regard.

(e) Vitamin E and immune function

Studies concentrating on neutrophil function in athletes as well as untrained subjects indicate that, whilst moderate physical activity can enhance this 'first line of immune defence', intense and/or high volume training can depress neutrophil microbicidal capacity[63]. A variety of studies concerning various other aspects of immune function provide general support for this premise[64]. Bearing in mind this constant threat to intensely training athletes, any method by which optimal immune function can be preserved will aid performance indirectly by facilitating illness-free training of higher quality and quantity.

Vitamin E supplementation has improved immune response in some animal experiments. In fact, it has been suggested that the dietary vitamin E requirement of rats for optimal immune function is greater than that required to prevent experimentally enduced muscle fibre and red cell oxidative damage[65]. A postulated mechanism of action is through inhibition by vitamin E of the synthesis of immunosuppressive prostaglandins from arachidonic acid[65,66].

Studies in humans also implicate vitamin E with immune function. The neutrophilia observed after eccentric exercise was dampened in older people, but restored to a level similar to younger people after 48 days of supplementation at 400 IU/day[20]. No effect of vitamin E supplementation on immune function was demonstrated, however, in younger subjects. In another study of healthy adults aged 60 years and over, supplementation of 800mg of vitamin E/day for 30 days improved certain indicators of immune function including a skin hypersensitivity test and response of lymphocytes to a T-cell mitogenic agent[67].

Although vitamin E seems to have an immunomodulatory role, its influence on young people, particularly athletes, is unclear and warrants further investigation.

Final comments

Vitamin E is implicated with athletic performance through:

(a) its role as an antioxidant, particularly at the site of the muscle and possibly the red cell membrane

(b) enhancing physical performance at altitude – altitude training being a form of training undertaken by numerous international athletes in preparation not only for events staged in the mountains, but also for sea level athletic performance as well.

Vitamin E may also contribute to athletic performance through:

(c) optimizing blood viscosity, especially as the rheology of an athlete is related to performance as well as health, and

(d) its role in immune function, especially as intense exercise and chronic training has been linked with down-regulation of normal immune function.

There seems little doubt that vitamin E deficiency will diminish physical work capacity. There is also evidence to suggest that supplementing vitamin E to plasma levels above those normally achieved by diet alone, can benefit the intensely training athlete.

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維生素E與運動員的成績

摘　要

多年來運動員已對維生素E感到興趣，在１９５０年代已有膳食補充維生素E的報告。過去十年，維生素E與運動員成績的關系再次引起興趣，同時動物實驗已證明維生素E缺乏時耐力減退。很多最近的研究集中圍繞在維生素E的抗氧化特征，似乎補充維生素E后，這些特征可部分改善人在中等和高地的需氧能力。但是仍未有海平面的類似報告。另一方面，最近一個研究指出。給進食ＲＤＩ的運動員補充維生素E可減少運動比賽后的肌肉損傷。再者，維生素E可維持最理想的免疫功能和血液黏度，這兩個因素對運動員訓練和完成能力是重要的。雖然，是否超過ＲＤＩ的補給量會帶來任何好處，這事尚待證明，但作者指出，補充維生素E在ＲＤＩ的上限將對強烈訓練的運動員有利，特別是那些在高地受訓練的運動員。