Antioxidant and Vitamin D supplements for athletes: Sense or nonsense?

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Antioxidant and Vitamin D supplements for athletes: Sense or nonsense?

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Abstract
The idea that dietary supplements can improve athletic performance is popular among athletes. The use of antioxidant supplements is widespread among endurance athletes because of evidence that free radicals contribute to muscle fatigue during prolonged exercise. Furthermore, interest in vitamin D supplementation is increasing in response to studies indicating that vitamin D deficiency exists in athletic populations. This review explores the rationale for supplementation with both antioxidants and vitamin D and discusses the evidence to support and deny the benefits of these dietary supplements. The issue of whether athletes should use antioxidant supplements remains highly controversial. Nonetheless, at present there is limited scientific evidence to recommend antioxidant supplements to athletes or other physically active individuals. Therefore, athletes should consult with their health care professional and/or nutritionist when considering antioxidant supplementation. The issue of whether athletes should supplement with vitamin D is also controversial. While arguments for and against vitamin D supplementation exist, additional research is required to determine whether vitamin D supplementation is beneficial to athletes. Nevertheless, based upon the growing evidence that many athletic populations are vitamin D deficient or insufficient, it is recommended that athletes monitor their serum vitamin D concentration and consult with their health care professional and/or nutritionist to determine if they would derive health benefits from vitamin D supplementation.

Keywords: Exercise, free radicals, fatigue, antioxidants, vitamin D

Introduction
Many athletes are interested in using dietary supplements because of the perception that these additives can improve athletic performance (Huang, Johnson, & Pipe, 2006; Maughan, Depiesse, & Geyer, 2007). Although many diverse dietary supplements are available, the use of antioxidant supplements is common among endurance athletes because of evidence that free radicals promote muscle fatigue during prolonged exercise. Moreover, interest in vitamin D supplementation has increased recently due to reports suggesting that vitamin D deficiency exists in some athletes, particularly those that participate in indoor sports (e.g. basketball) (Constantini, Arieli, Chodick, & Dubnov-Raz, 2010; Halliday et al., 2011; Lehtonen-Veromaa et al., 1999; Lovell, 2008). Furthermore, recent reviews on vitamin D and muscle performance suggest that vitamin D deficiency impairs muscular performance and that vitamin D supplementation can potentially improve athletic performance (Bartoszewska, Kamboj, & Patel, 2010). Collectively, these reports have increased the awareness of the need for vitamin D among athletes and stimulated interest in supplementation.

This review discusses the rationale for supplementation with antioxidants and vitamin D, and highlights the evidence to support (or deny) the benefits of these dietary supplements.

Antioxidants and the athlete
The following sections provide an overview of both free radicals and antioxidants. We also discuss the physiological link between free radicals and muscle fatigue during exercise. Finally, we present arguments both for and against antioxidant supplementation in...
Overview of free radicals and antioxidants

Free radicals (hereafter referred to as radicals) are molecules (or fragments of molecules) that contain one or more unpaired electrons in their outer orbital (Halliwell & Gutteridge, 2007). An unpaired electron results in molecular instability, thus radicals are highly reactive molecules that can promote oxidative damage to cellular components (i.e. proteins, lipids, and DNA). This radical-induced damage is commonly referred to as “oxidative stress” and oxidation of cellular constituents can lead to cell dysfunction and, in extreme cases, cell death. Also, note that the label “reactive oxygen species” (ROS) is a general term that refers not only to oxygen-centred radicals but also includes non-radical but reactive derivatives of oxygen (e.g. hydrogen peroxide) (Halliwell & Gutteridge, 2007). The damaging effects of reactive oxygen species can be negated in cells by antioxidants and in the context of this review, antioxidants will be defined as any substance that significantly delays or prevents oxidative damage of a target molecule (Halliwell & Gutteridge, 2007).

It is well established that physical exercise results in increased radical and ROS production in active skeletal muscles. Indeed, several reports indicate that exercise-induced radical production is responsible for oxidative damage to cells and contributes to muscular fatigue during prolonged exercise (Powers & Jackson, 2008). The source of muscle ROS production during exercise remains an active area of research and a highly debated topic. Historically, it has been believed that mitochondria are the dominant source of ROS production in contracting skeletal muscles. However, growing evidence suggests that mitochondria are not an important source of reactive oxygen species in exercising muscles and that xanthine oxidase or NADPH-oxidase may play a more important role in exercise-induced ROS production in muscle (Powers & Jackson, 2008).

Given that cells produce radicals, it is not surprising that all cells contain an endogenous antioxidant system composed of both enzymatic and non-enzymatic antioxidants. Moreover, dietary antioxidants (e.g. vitamin C and vitamin E) cooperate with the endogenous antioxidant defence systems to form a united antioxidant network in muscle fibres. This cooperative interaction between endogenous antioxidants and dietary antioxidants has fuelled the argument that antioxidant supplementation will boost the muscle fibre’s ability to scavenge reactive oxygen species and protect against exercise-induced oxidative damage.

Muscle fatigue is commonly defined as a reduction in the ability of a muscle to generate force. Exercise-induced muscle fatigue is a multi-factorial process and the specific causes of fatigue can vary widely. Nonetheless, growing evidence indicates that radical production in skeletal muscles contributes to fatigue during prolonged submaximal exercise (i.e. events lasting >30 min) (Reid, 2008). As mentioned previously, ROS production increases in contracting skeletal muscles and low levels of reactive oxygen species play an essential role in the regulation of muscle force production. Although a low level of reactive oxygen species in skeletal muscle is required for optimum force production, excessive reactive oxygen species can induce oxidative damage to muscle proteins and diminish muscle force production. Indeed, well-controlled animal studies indicate that scavenging radicals via antioxidants can protect skeletal muscles against oxidative damage and also delay fatigue during prolonged submaximal exercise (Powers & Jackson, 2008; Reid, 2008). In contrast, antioxidant scavengers are not effective in delaying muscle fatigue in animals performing high-intensity exercise (Powers & Jackson, 2008; Reid, 2008).

Do radicals contribute to exercise-induced muscular fatigue in humans? The answer to this question remains a matter of debate, but a growing number of studies suggest that acute administration of the antioxidant N-acetylcysteine delays human muscle fatigue during prolonged submaximal exercise. Specifically, N-acetylcysteine is a thiol-based antioxidant and its administration can delay muscular fatigue in humans during submaximal exercise tasks (e.g. electrically stimulated limb muscle, voluntary cycling exercise, and repetitive handgrip exercise) (Kelly, Wicker, Barstow, & Harms, 2009; Matuszczak et al., 2005; McKenna et al., 2006; Reid, Stokic, Koch, Khawli, & Leis, 1994). At present, it is unclear whether N-acetylcysteine retards human muscle fatigue during exercise close to or above maximum oxygen uptake (e.g. 85–90% \( \dot{V}O_{2\text{max}} \)) (Kelly et al., 2009; Medved et al., 2003; Medved, Brown, Bjorksten, & McKenna, 2004). In contrast to the findings that acute N-acetylcysteine administration can delay muscle fatigue during prolonged submaximal exercise, there is little evidence that other more commonly used antioxidant supplements (e.g. beta carotene, vitamin E, and/or vitamin C) can improve human exercise performance (Powers, DeRuisseau, Quindry, & Hamilton, 2004). Based upon current evidence, it appears that N-acetylcysteine supplementation can increase performance during prolonged exercise in humans, but there is limited evidence to support the
concept that supplementation with vitamin C, vitamin E or beta carotene can improve human performance.

The fact that working skeletal muscles produce radicals has motivated many athletes to use antioxidant supplements in hopes of preventing exercise-induced radical damage and/or muscular fatigue. However, whether or not antioxidant supplements are helpful or harmful to the athlete remains a highly debated topic. We next summarize the arguments for and against antioxidant supplementation in athletes and other physically active individuals.

Arguments to support antioxidant supplementation in athletes

Advocates of antioxidant supplementation in athletes provide three primary arguments in favour of this practice. First, supporters argue that rigorous exercise training results in increased production of reactive oxygen species in skeletal muscles, thus antioxidant supplements are required to protect muscle fibres against oxidative damage (Schroder, Navarro, Mora, Galiano, & Tramullas, 2001; Schroder, Navarro, Tramullas, Mora, & Galiano, 2000). Supporters also argue that most common antioxidant supplements are not toxic even at relatively high levels of supplementation. Therefore, antioxidant supplementation is not likely to do harm and, in theory, antioxidant supplementation has the potential to be beneficial. Nonetheless, the merit of this statement continues to be debated among investigators in the field of redox biology and skeletal muscle.

A second argument to support antioxidant supplementation for athletes is that radicals have been shown to promote muscle fatigue in some types of exercise (Reid, 2008). Indeed, the evidence that some antioxidants (i.e. N-acetylcysteine) can improve human endurance performance provides motivation for many athletes to enrich their diets with antioxidants supplements. Many supplement companies have used the scientific reports that N-acetylcysteine improves performance and delays fatigue to encourage athletes to supplement with antioxidants. Indeed, the possibility that antioxidant supplementation can delay fatigue and improve endurance performance remains one of the strongest arguments in favour of antioxidant supplementation.

Finally, there is one circumstance that clearly supports the use of antioxidant supplements in athletes. Specifically, dietary recall studies reveal that some athletes do not consume a well-balanced diet, and therefore these individuals can be deficient in antioxidant intake. This is a reasonable supposition that is supported by studies investigating the nutritional habits of specific athletic populations (Machefer et al., 2007; Rankinen et al., 1998; Schroder et al., 2000). Therefore, for athletes that do not consume a well-balanced diet, antioxidant supplementation appears reasonable to bring them to the recommended levels of key antioxidant vitamins.

Arguments against antioxidant supplementation in athletes

Several lines of reasoning argue against antioxidant supplementation. First, although prolonged and/or intense exercise can promote oxidative stress in the active muscles, it is important to recognize that exercise-induced oxidative stress is a transient phenomenon and there is no evidence that exercise-induced radical production in skeletal muscle is detrimental to human health. Furthermore, regular exercise training promotes increased enzymatic and non-enzymatic antioxidants in muscle fibres resulting in improved endogenous protection against exercise-mediated oxidative damage (Criswell et al., 1993; Powers, Nelson, & Hudson, 2010). Therefore, this increase in endogenous antioxidants may be sufficient to protect against excessive exercise-induced oxidative damage and antioxidant supplementation is not required. Moreover, if an athlete maintains a diet that meets energy needs and is nutritionally well balanced, it is feasible that the athlete does not require supplementary antioxidants above those contained in the diet.

Perhaps the strongest argument against antioxidant supplementation for athletes and other active individuals is that emerging evidence indicates antioxidant supplementation may impair muscle function or retard some important exercise-induced adaptations in skeletal muscle (Coombes et al., 2001; McClung et al., 2010). For example, growing evidence indicates that exercise-induced production of reactive oxygen species serves as a signal to promote the expression of numerous skeletal muscle proteins, including antioxidant enzymes, mitochondrial proteins, and heat shock proteins (Hamilton et al., 2003; Powers & Jackson, 2008; Sen, 2001). Furthermore, two recent reports indicate that antioxidant supplementation with high levels of vitamins E and C (i.e. ~16 times higher than the recommended dietary allowance for adults) can blunt the training adaptation to exercise (Gomez-Cabrera et al., 2008; Ristow et al., 2009). These recent developments call for a very careful analysis of the use of antioxidants in athletes engaged in training.

A final argument against antioxidant supplementation in athletes is that the available data do not support the concept that antioxidant supplementation is beneficial to human health. For example, a meta-analysis of 68 randomized antioxidant supplement trials (total of 232,606 human participants)
concluded that dietary supplementation with beta carotene, vitamin A, and vitamin E does not improve health outcomes and may increase mortality (Bjelakovic, Nikolova, Gluud, Simonetti, & Gluud, 2007). These authors also concluded that the roles of vitamin C and selenium on human mortality are unclear and require further study before a recommendation can be rendered.

**Summary and conclusions: Antioxidant supplementation in athletes**

The question of whether athletes should use antioxidant supplements remains an important and highly debated topic. Arguments for and against antioxidant supplementation exist and additional research will be required to firmly establish whether antioxidant supplementation is beneficial or harmful to athletes. However, at present there is limited scientific evidence to recommend antioxidant supplements to athletes or other physically active individuals. In fact, the current evidence suggests that athletes should use caution when considering supplementation with high doses of antioxidants. Therefore, based on the available evidence, we conclude that athletes should not use antioxidant supplements but should focus on consuming a well-balanced, energetically adequate diet that is rich in antioxidant-containing foods (i.e. whole grains, fruits, vegetables, nuts, and seeds).

**Vitamin D and the athlete**

Here we provide an introduction to the biochemical functions of vitamin D and discuss the arguments for and against vitamin D supplementation in athletes. We also consider calcium intake and supplementation in the context of vitamin D. We begin with an overview of the health benefits of vitamin D.

**Overview of vitamin D**

Vitamin D is not technically a vitamin but is a group of secosteroids that have endocrine and paracrine functions. Although vitamin D is found in the diet, physiological need can be met through endogenous synthesis upon exposure of the skin to ultraviolet-B radiation (UV-B, 290–315 nm). Ultraviolet-B exposure initiates a series of metabolic reactions that result in the conversion of 7-dehydrocholesterol, present in the membrane of epidermal and dermal cells, into vitamin D3 (cholecalciferol) (Holick, 2004). Endogenous vitamin D3 and vitamins D2 (ergocalciferol) and D3 obtained from the diet are subsequently hydroxylated to 25(OH)D, which is the main circulating or storage form. Further conversion to the biologically active form, 1,25-dihydroxyvitamin D (1,25(OH)2D) by the kidney occurs under the direction of parathyroid hormone when serum calcium or phosphorus concentrations are low (Holick, 2004).

Vitamin D is essential for maintaining normal calcium metabolism and a major purpose of vitamin D is to increase intestinal calcium absorption. Research, for example, has found that only 10–15% dietary calcium is absorbed in the vitamin D-deficient state, whereas 30–35% is absorbed when vitamin D status is sufficient (Heaney, Dowell, Hale, & Bendich, 2003; Holick, 2004). Adequate vitamin D and calcium are also essential for bone health (Panda et al., 2004). Low calcium intake (Myburgh, Hutchins, Fataar, Hough, & Noakes, 1990) together with reduced vitamin D status (Ruohola et al., 2006) have been associated with decreased bone density and increased risk for stress fractures, particularly in amenorrheic athletes (Wolman, Clark, McNally, Harries, & Reeve, 1992).

Aside from this classic function, vitamin D also regulates the expression of over 1000 genes in a variety of tissues (Cannell, Hollis, Sorenson, Taft, & Anderson, 2009). Furthermore, vitamin D has been shown to be an important regulator of inflammation and immunity, partially via up-regulation of immune proteins and anti-inflammatory cytokines and down-regulation of inflammatory cytokines (Larson-Meyer & Willis, 2010). In skeletal muscle, vitamin D has been reported to play an important role in calcium handling, protein synthesis, and muscle cell proliferation/growth (Ceglia, 2009; Hamilton, 2010).

Recent reviews conclude that vitamin D deficiency is at epidemic levels for all age groups worldwide (Holick, 2004; Willis, Peterson, & Larson-Meyer, 2008; Zittermann, 2003). Importantly, vitamin D deficiency has been linked to numerous disorders including osteoporosis, several types of cancer, hypertension, and autoimmune diseases (Cannell, Hollis, Zasloff, & Heaney, 2008; Holick, 2004; Larson-Meyer & Willis, 2010; Zittermann, 2003) and increased risk of stress fracture (Ruohola et al., 2006) and season illness (Halliday et al., 2011).

**Sources of vitamin D and calcium**

The newly revised recommended dietary allowance (RDA) for vitamin D in adults is 600 IU (Ross, Taylor, Yaktine, & Del Valle, 2010). Several minutes (5–30) of direct sun exposure several times a week between 10.00 and 14.00 h on the arms and legs during spring, summer, and fall is often adequate to prevent vitamin D deficiency in young adults (Holick, 2007). In fact, vitamin D produced from skin exposure is the predominant source of circulating vitamin D in humans (Cannell et al., 2008). However, vitamin D can also be supplied via the diet.
from limited natural sources, including fatty fish, egg yolks, and sun-dried mushrooms. Although some countries, including the USA and Canada, add vitamin D to milk, margarine, ready-to-eat cereals, and other selected products, the modern diet in most of the world lacks sufficient vitamin D. This suggests that when sun exposure is limited, vitamin D status is likely to be compromised.

In contrast to vitamin D, the RDA for calcium (i.e. 1000 mg for adults aged 19–50 years, 1200 mg for adults older than 50 years, and 1300 mg for children younger than 18 years) can easily be obtained from the diet. Athletes can meet calcium requirements by including several servings of dairy products or 8–10 servings of calcium-containing plant foods daily (Messina, Melina, & Mangels, 2003). Non-dairy foods that are rich in well-absorbable calcium include sardines, low-oxalate green leafy vegetables (broccoli, kale, Chinese cabbage and collard, mustard, and turnip greens), calcium-set tofu, fortified soy and rice milks, textured vegetable protein, tahini, certain legumes, fortified orange juice, and blackstrap molasses (Messina et al., 2003). Laboratory studies have determined that the calcium bioavailability of most of these foods is comparable to cow’s milk, which has a fractional absorption of about 32% (Weaver, Proulx, & Heaney, 1999; Zhao, Martin, & Weaver, 2005). The exceptions include soymilk fortified with tricalcium phosphate, most legumes, nuts, and seeds, which have a fractional absorption in the range of 17–24% (Zhao et al., 2005). Foods such as spinach, Swiss chard, beet greens, and rhubarb are not well-absorbed sources of calcium due to their high oxalate or phytate content. Athletes not meeting their calcium intake may consider calcium plus vitamin D supplementation as a short-term option but should work towards consumption of calcium-rich foods daily.

**Assessment of vitamin D status**

Clinically, the inactive form of circulating vitamin D, 25(OH)D, is used as a measure of vitamin D status. The definition of the optimum serum concentration of vitamin D, however, remains controversial. Nonetheless, most experts agree that a serum 25(OH)D concentration below 50 nmol · L\(^{-1}\) (20 ng · mL\(^{-1}\)) indicates deficiency, while a concentration below 80 nmol · L\(^{-1}\) (32 ng · mL\(^{-1}\)) should be considered insufficient (Larson-Meyer & Willis, 2010; Willis et al., 2008). While 25(OH)D concentrations between 100–250 nmol · L\(^{-1}\) (40-100 ng · mL\(^{-1}\)) are considered optimal (Cannell & Hollis, 2008; Hollis, 2005), there is little scientific evidence to support what is deemed as optimal (Larson-Meyer & Willis, 2010). In fact, the new US RDA for vitamin D was based only on bone health with the assumption that 25(OH)D concentrations >50 nmol · L\(^{-1}\) are adequate (Ross et al., 2010). However, the newly revised RDA of 600 IU is below the 800–2200 IU recommended by researchers (Cannell & Hollis, 2008; Heaney, 2005; Holick, 2007) to optimize overall health and maintain serum 25(OH)D concentrations in the sufficient to optimal range. Overall, the lack of scientific agreement regarding the serum concentrations of vitamin D that are deemed optimal for health and physical performance remains an impediment for sports nutritionists.

Due to vitamin D’s classic role in calcium homeostasis and its impact on skeletal muscle, several important questions regarding vitamin D status in athletes have emerged. For example, how many athletes are low in vitamin D? Do athletes need to supplement with vitamin D and can vitamin D supplementation improve performance? In the following sections we provide arguments both for and against vitamin D supplementation in athletes.

**Arguments to support vitamin D supplementation**

Two major arguments exist to support vitamin D supplementation in athletes. First, accumulating evidence suggests that athletes may be as much at risk for vitamin D deficiency as is the general population. Second, emerging evidence suggests that supplementation with vitamin D may improve health and athletic performance. A summary of these two suppositions follows.

Contrary to the large number of studies regarding vitamin D deficiency in the general population, limited studies have investigated vitamin D status in athletic populations. Nonetheless, a growing number of studies suggest that many athletes are at risk for vitamin D deficiency (Table 1). In general, the athletes at greatest risk for vitamin D insufficiency and deficiency are those participating in indoor sports, those residing at higher latitudes (with less opportunity for sun exposure all year round), and those with dark-pigmented skin. For example, a study of Israeli athletes reported that ~94% of basketball players and dancers suffered from vitamin D insufficiency (defined as 25(OH)D <75 nmol · L\(^{-1}\)) (Constantini et al., 2010). In the same study, 48% of outdoor athletes were vitamin D insufficient. Similarly, a study investigating serum 25(OH)D concentrations in Australian elite female gymnasts reported that ~33% of the athletes were vitamin D insufficient (25(OH)D <50 nmol · L\(^{-1}\)) (Lovell, 2008). In another study of East German female gymnasts, 37% of the athletes were found to be vitamin D deficient (25(OH)D <25 nmol · L\(^{-1}\)) (Bannert, Starke, Mohnik, & Frohner, 1991).

Evidence also exists that some outdoor athletes may be at risk for vitamin D deficiency. For example,
a study of young Finnish runners reported that ~68% were vitamin D deficient during the winter; however, by the end of summer blood concentrations of vitamin D increased to sufficient concentrations (Lehtonen-Veromaa et al., 1999). Another example of a seasonal variation in vitamin D concentration of athletes residing at higher latitudes has been reported in the USA. Similar to the Finnish study, most athletes evaluated did not exhibit sufficient serum 25(OH)D concentrations during early fall and spring months but blood 25(OH)D concentrations were markedly lower and insufficient in the winter months (Halliday et al., 2011). Finally, a recent study performed in Qatar reported that ~91% of the athletes evaluated were 25(OH)D deficient (<50 nmol L\(^{-1}\)) (Hamilton, Grantham, Racinais, & Chalabi, 2010). These findings are somewhat surprising given that Qatar is a relatively sunny location (latitude ~25°30'N). The authors report, however, that the majority of outdoor training was completed after sunset because of the environmental heat and social factors in Qatar. The results indicate that simply living in a sunny environment does not ensure adequate vitamin D synthesis. Indeed, clothing, regular sunscreen use, skin pigmentation, ageing, time of day of training, season, cloud cover, and latitude can dampen the effect of sun on vitamin D production by compromising the quantity of UV-B radiation absorbed by the skin.

The second major argument used to support vitamin D supplementation in athletes is that vitamin D supplementation may improve athletic performance (in those who are deficient). The belief that vitamin D (or UV-B exposure) can positively impact athletic performance has an extensive history. For example, long before reports were published detailing the prevalence of low vitamin D among athletes, it was believed the exposure to UV-B radiation was ergogenic. In the late 1920s, German swimmers were irradiated with UV radiation from a sunlamp prior to competition (Cannell, 2009). Coinciding with these observations, a report suggested that distance running performance is improved during summer compared with winter months (Hiruta, Ishida, & Miyamura, 1990; Kristal-Boneh, Froom, Harari, Malik, & Ribak, 2000; Svedenhag & Sjodin, 1985). Together, these observations have led to speculation that vitamin D supplementation improves athletic performance.

Although the aforementioned studies have provided fuel for the concept that low vitamin D concentrations may impair athletic performance, the literature contains limited experimental studies that demonstrate a positive benefit of vitamin D supplementation on athletic performance in athletes. Nonetheless, two recent studies evaluated the relationship between muscle strength and or power in British and Chinese adolescent girls (Foo et al., 2009; Ward et al., 2009), who were mostly vitamin D deficient. These studies found a significant positive correlation between serum 25(OH)D concentrations and muscle strength and power.

Table I. Examples of investigations indicating that many athletic populations suffer from insufficient blood concentrations of vitamin D as indicated by serum concentrations of 25(OH)D.

<table>
<thead>
<tr>
<th>Study</th>
<th>Prevalence of low serum 25(OH)D</th>
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<tbody>
<tr>
<td>Constantini et al. (2010)</td>
<td>80% of indoor athletes&lt;sub&gt;a&lt;/sub&gt; (&lt;75 \text{ nmol} \cdot L^{-1})</td>
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<tr>
<td></td>
<td>48% of outdoor athletes&lt;sub&gt;b&lt;/sub&gt; (&lt;75 \text{ nmol} \cdot L^{-1})</td>
</tr>
<tr>
<td>Hamilton et al. (2010)</td>
<td>91% of athletes&lt;sub&gt;c&lt;/sub&gt; (&lt;50 \text{ nmol} \cdot L^{-1})</td>
</tr>
<tr>
<td>Lovell (2008)</td>
<td>33% of athletes&lt;sub&gt;d&lt;/sub&gt; (&lt;50 \text{ nmol} \cdot L^{-1})</td>
</tr>
<tr>
<td>Bannert et al. (1991)</td>
<td>37% of athletes&lt;sub&gt;e&lt;/sub&gt; (&lt;25 \text{ nmol} \cdot L^{-1})</td>
</tr>
<tr>
<td>Halliday et al. (2011)</td>
<td>Fall 9.8% of athletes&lt;sub&gt;f&lt;/sub&gt; (&gt;50 \text{ nmol} \cdot L^{-1}) but (&lt;80 \text{ nmol} \cdot L^{-1})</td>
</tr>
<tr>
<td></td>
<td>Winter 2.4% of athletes&lt;sub&gt;f&lt;/sub&gt; (&lt;50 \text{ nmol} \cdot L^{-1})</td>
</tr>
<tr>
<td></td>
<td>Spring 16% of athletes&lt;sub&gt;f&lt;/sub&gt; (50 \text{ nmol} \cdot L^{-1}) (&lt;80 \text{ nmol} \cdot L^{-1})</td>
</tr>
<tr>
<td>Lehtonen-Veromaa et al. (1999)</td>
<td>Winter 67.7% of athletes&lt;sub&gt;f&lt;/sub&gt; (&lt;37.5 \text{ nmol} \cdot L^{-1})</td>
</tr>
<tr>
<td></td>
<td>Summer 1.6% of athletes&lt;sub&gt;f&lt;/sub&gt; (&lt;37.5 \text{ nmol} \cdot L^{-1})</td>
</tr>
</tbody>
</table>

<sup>a</sup>Males and females aged 10–30 years, Israel; dancing, basketball, swimming, Tae Kwon Do, judo, gymnastics, table tennis.
<sup>b</sup>Males and females aged 10–30 years, Israel; tennis, soccer, running, triathlon, sailing.
<sup>c</sup>Males aged 13–45 years, Qatar; professional-junior level sports in soccer, soccer referees, track and field, handball, shooting, squash, cycling, martial arts, bodybuilding.
<sup>d</sup>Females aged 10–17 years, Australia; elite gymnasts.
<sup>e</sup>Male and females aged 8–27 years, East Germany; competitive gymnasts.
<sup>f</sup>Males and females aged 10–17 years, Finland; runners, dancers, non-athletes.
and jumping height and velocity, muscle force, muscle power, (Ward et al., 2009), and hand grip strength (Foo et al., 2009). Another study indirectly linked to long-term performance benefits found that 8 weeks of supplementation with 800 IU of vitamin D plus 2000 mg calcium in female Navy recruits reduced the incidence of stress fracture (Lappe et al., 2008). Taken together, these studies are consistent with the concept that athletes deficient in vitamin D could benefit from vitamin D supplementation.

Arguments against vitamin D supplementation

Arguments against vitamin D supplementation in athletes are focused on two issues: (1) lack of scientific evidence to support that vitamin D is ergogenic; and (2) risk of vitamin D toxicity. In regard to the strength of the scientific evidence to support the case that vitamin D supplementation improves athletic performance, the lack of well-designed supplementation trials in athletes means that a clear answer is not available.

In reference to the concern over vitamin D toxicity, it should be recognized that vitamin D is a fat-soluble vitamin and that excessive intake by overzealous athletes who feel “more is better” could result in toxicity (defined as a serum 25(OH)D concentration > 737 nmol·L\(^{-1}\) in the presence of hypercalcaemia). Vitamin D toxicity can result in nausea, vomiting, poor appetite, constipation, weakness, and weight loss (Chesney, 1989), as well as lead to mental confusion, cardiac rhythm irregularities (Favus & Christakos, 1996), and calcification of soft tissues. However, it is important to mention that intoxication from excess supplementation is extremely rare, and that most of the reported toxicity cases were due to inadvertent ingestion of excessively high supplemental doses many of which were due to manufacturer error (Klontz & Acheson, 2007). Doses of 10,000 IU·day\(^{-1}\) for up to 5 months have not been shown to cause toxicity (Vieth, 2004). According to the new “tolerable upper limit” for Vitamin D, daily doses of vitamin D up to 4000 IU·day\(^{-1}\) have been established as safe in almost all populations (Ross et al., 2010), but less is known concerning habitual supplementation > 4000 IU·day\(^{-1}\).

An important final point – worthy of further research – is that there may be significant individual differences in the response of vitamin D supplementation to the rise in 25(OH)D concentrations. Provocative evidence suggests that these differences are related to common genetic variants in vitamin D binding protein (VDBP). This protein binds to vitamin D and its metabolites and carries them to target tissues (Foo et al., 2009). This is potentially important to athletes because it is not known how VDBP variants influence toxicity or performance responses to supplementation.

Summary and conclusions: Vitamin D supplementation in athletes

The question of whether vitamin D supplementation should be recommended for athletes remains controversial. There are proponents for and against vitamin D supplementation and additional research is essential to establish whether vitamin D supplementation is beneficial to athletes. Currently, there is little scientific evidence that vitamin D supplementation improves performance in athletes that are not vitamin D deficient. Nonetheless, based upon the evidence that many athletic populations are vitamin D deficient or insufficient, it is recommended that athletes monitor their serum vitamin D concentrations and consult with their health care professional and/or nutritionist to determine if they would derive health benefits from vitamin D supplementation. On the other hand, all athletes should strive to consume the RDA for calcium.

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Vitamin D deficiency is endemic in Middle Eastern sportsmen. Vitamin D insufficiency alters blood redox status but does not alter contraction-induced fatigue or recovery. Experimental Physiology, 95, 222–231.


Antioxidants, vitamin D, and the athlete


