PAN
Physical Activity and Nutrition | 2021;25(2):020-025

OPEN ACCESS
https://doi.org/10.20463/pan.2021.0011

Review

Received: 2021/06/03, Revised: 2021/06/21, Accepted: 2021/06/28, Published: 2021/06/30

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Vitamin D in athletes: focus on physical performance and musculoskeletal injuries

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[Purpose] The aim of this review was to discuss the effects of vitamin D on physical performance and musculoskeletal injuries in athletes and provide information on the field applications of vitamin D.

[Methods] A systematic review was conducted to identify studies on vitamin D in athletes that assessed serum vitamin D levels, vitamin D and physical performance, vitamin D and musculoskeletal injuries, and practical guidelines for supplementation of vitamin D.

[Results] Several studies reported that a high proportion of athletes had vitamin D insufficiency or deficiency. Low serum levels of vitamin D in athletes were more pronounced in winter than in other seasons, and indoor athletes had lower serum vitamin D levels than outdoor athletes. Low vitamin D levels have been demonstrated to have negative effects on muscle strength, power, and endurance; increase stress fractures and other musculoskeletal injuries; and affect acute muscle injuries and inflammation following high-intensity exercises. Therefore, periodic assessment and monitoring of vitamin D levels are necessary in athletes; the recommended serum level of 25(OH)D is > 32 ng/mL and the preferred level is > 40 ng/mL (-1). In those with low levels of vitamin D, exposure to sunlight and an improved diet or supplements may be helpful. Particularly, 2000–6000 IU of supplemental vitamin D3 can be consumed daily.

[Conclusion] Vitamin D is a potential nutritional factor that can significantly affect physical performance and musculoskeletal injuries in athletes. The importance and role of vitamin D in athletes should be emphasized, and the current levels of vitamin D should be assessed. Therefore, it is essential to periodically evaluate and monitor serum vitamin D levels in athletes.

[Key words] athlete, musculoskeletal injury, physical performance, stress fracture, supplementation, vitamin D

INTRODUCTION

Nutrition is an important factor for athletes in optimizing their physical performance for training and competitions as well as restoring homeostasis in the body. Therefore, various food products and supplements are required to satisfy their nutritional needs[1,2]. Adequate nutrition supplies materials for energy and building the body as well as bioelements and vitamins that affect metabolic processes and have regulatory functions[2]. However, despite the adequate intake of food and supplements, athletes may still develop deficiencies of certain nutrients, which can negatively affect their physical performance and risk of injuries[3].

Vitamin D is a nutrient that has recently gained increasing attention in sports nutrition[4]. It is synthesized in the skin and produced in the body following exposure to sunlight for 15–20 min. It can also be absorbed through the intake of protein-rich foods, such as egg yolk, fish, and dairy products[4]. Previously, vitamin D was demonstrated to be an essential nutrient in calcium homeostasis[5]. However, recent studies have demonstrated that vitamin D can contribute to signaling gene response, protein synthesis, hormone synthesis, immune responses, and cell turnover and regeneration[6].

According to some studies, a high proportion of athletes have vitamin D deficiency[7]. It has been reported that such deficiency can affect strength or endurance[8,9] and increase the risk of injuries[7,10,11]. Carswell et al.[8] reported that vitamin D levels were positively correlated with endurance and that lower vitamin D levels could impair endurance. Geiker et al.[9] demonstrated that muscle strength was significantly higher in male swimmers with sufficient serum vitamin D levels. Bauer et al.[12] reported that vitamin D deficiency in handball players may increase their risks of musculoskeletal injuries and infections. Rebolledo et al.[7] stated that National Football League (NFL) players commonly have insufficient levels of vitamin D and that players with a history of lower extremity muscle strain and core muscle injuries are more likely to have vitamin D insufficiency. Therefore, several studies have suggested the necessity of assess-

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ing and supplementing vitamin D in athletes. Żebrowska et al.[13] reported that vitamin D supplementation can have positive effects on serum 25(OH)D levels in athletes who underwent endurance exercise training. Abrams et al.[14] reported that vitamin D supplementation could increase strength in athletes with vitamin D insufficiency and that increased vitamin D levels were associated with a lower rate of injuries and improved physical performance in sports. Additionally, Larson–Meyer[15] suggested that, since low vitamin D levels can affect the overall health and training efficiency of athletes, serum vitamin D levels must be evaluated regularly to ensure that adequate levels of serum 25(OH)D levels are maintained.

Therefore, vitamin D is a potential nutrient that can negatively affect physical performance and musculoskeletal injuries in athletes[9,12,14]. Consequently, coaches, trainers, and athletes need to assess vitamin D levels and identify its sources to improve and maintain physical performance and prevent injuries. This review discusses the effects of vitamin D on physical performance and musculoskeletal injuries in athletes based on previous findings and provides information on the field applications of vitamin D.

VITAMIN D LEVELS IN ATHLETES

The normal range of serum vitamin D is 30–50 ng/mL (75–125 nmol/L) or 40–60 ng/mL (100–150 nmol/L). Additionally, levels of 20–30 ng/mL (50–75 nmol/L) and < 20 ng/mL (< 50 nmol/L) are termed vitamin D insufficiency and deficiency, respectively[16]. Generally, vitamin D levels are determined by measuring serum 25(OH)D concentrations; 30 ng/mL is the cut-off to distinguish between vitamin D sufficiency and insufficiency[5,17]. Several studies have assessed vitamin D levels in various types of athletes and reported that a high proportion of athletes have vitamin D insufficiency or deficiency[18-24]. Bezuglov et al.[18] reported that 42.8% of 131 young male soccer players had low serum vitamin D levels (< 30 ng/mL). Hamilton et al.[20] demonstrated that 84% of 3,422 professional soccer players in Qatar had serum vitamin D level < 30 ng/ml and that 12% of the players were severely deficient in vitamin D (<10 ng/mL). Grieshober et al.[19] reported that hypovitaminosis D is common in National Basketball Association players and that 32.3% and 41.2% of professional basketball players had vitamin D deficiency (<20 ng/mL) and insufficiency (20–30 ng/mL), respectively. Furthermore, in a large cohort study of the National Collegiate Athletic Association Division 1 college athletes, Villacis et al.[23] reported that more than one-third of the players had abnormal vitamin D levels. Potential causes of such low vitamin D levels in athletes include race, decreased synthesis of vitamin D by the skin from sunlight, and insufficient dietary intake of vitamin D[25,26].

Other studies have also suggested that athletes have lower levels of vitamin D in winter than other seasons. Galan et al.[27] stated that soccer players did not have enough vitamin D in mid-winders and that two-thirds of the players had vitamin D insufficiency in early February. Todd et al.[22] reported that athletes tended to have low vitamin D levels and serum vitamin D levels < 50 nmol/L were more common in them, especially in winter. Furthermore, Morton et al.[21] demonstrated that serum vitamin D levels in Premier League soccer players decreased between August and December. Particularly, vitamin D insufficiency (< 50 nmol/L) was observed in 65% of the total athletes assessed in winter. Vitale et al.[28] reported that serum vitamin D levels were the highest in summer in Italian alpine skiing athletes. Additionally, Yang and Lee[24] demonstrated that 80% of young athletes in Korea had vitamin D insufficiency and that vitamin D levels were low, especially in winter.

Yang and Lee[24] also reported that indoor athletes had lower vitamin D levels than outdoor athletes. This finding is also consistent with those of Farrokhyar et al.[5] and Valtueña et al.[29]. In a systematic review and meta-analysis of vitamin D levels in athletes, Farrokhyar et al.[5] observed that vitamin D levels were also affected by the region where the athletes trained and that the risk of vitamin D insufficiency was significantly increased in indoor sports athletes. Similarly, Valtueña et al.[29] demonstrated that in elite athletes in Spain, vitamin D levels were higher in those who trained outdoors than those in those who trained indoors. The most likely cause of low vitamin D levels in winter or indoor athletes is an insufficient synthesis of vitamin D due to a lack of exposure to sunlight[24].

VITAMIN D AND PHYSICAL PERFORMANCE

Several studies have demonstrated that vitamin D insufficiency is significantly related to physical performance, especially power and strength, in soccer players[20,30,31]. Hamilton et al.[20] reported that professional soccer players with severe 25(OH)D deficiency had lower peak torque values in the non-dominant leg compared with those with vitamin D levels > 30 ng/mL. Koundourakis et al.[30] demonstrated that low vitamin D levels were significantly correlated with physical performance, including vertical jump, countermovement jump, and sprint time, irrespective of the competition level in male soccer players. Other studies evaluated the effects of vitamin D levels on the strength and power of athletes participating in combat sports, such as judo and Taekwondo. Książek et al.[31] demonstrated that decreased serum 25(OH)D levels in Polish elite judoists were positively correlated with left-hand grip strength, muscle power that was assessed on vertical jump, and total work in the left and right knee extensors at an angular velocity of 60°. Additionally, Seo et al.[32] reported that in 15–18-year-old Taekwondo athletes, serum 25(OH)D levels were positively correlated with the mean power output and relative mean power output.

Several mechanisms have been suggested to explain the effects of vitamin D on muscle function (i.e., strength and power). The activated form of vitamin D has been reported to exert biological effects by binding to vitamin D receptors found in most human extra-skeletal cells, including skeletal muscle[31]. The number of nuclear vitamin D receptors in cells is related to muscle function; therefore, vitamin D may

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potentially affect muscle protein synthesis, neuromuscular control, and type II muscle fibers[33]. Particularly, neuromuscular control and type II muscle fibers are important factors that can result in high force and rapid muscle contraction[34]. Other studies have demonstrated that vitamin D can contribute to calcium transport from the sarcoplasmic reticulum and increase the efficiency and number of calcium-binding sites that are involved in muscle contraction, thereby improving muscle function[35,36].

Vitamin D may also affect endurance[37]. Koundourakis et al.[30] suggested a significant positive correlation between vitamin D levels and VO_2 max in soccer players. In another study on the relationship between vitamin D and physical performance in healthy recreational athletes in Austria, Zeitler et al.[38] demonstrated that low vitamin D levels in athletes decreased the submaximal physical performance measured on a treadmill ergometer. Furthermore, Jastrzębska et al.[39] reported that VO_2 max was improved by 20% in soccer players who had a significant increase in serum vitamin D levels after taking vitamin D supplements for 8 weeks. However, the mechanism underlying the effects of vitamin D on endurance is currently unclear. One possible mechanism is that vitamin D may increase the affinity of hemoglobin for oxygen in the blood[40].

VITAMIN D AND MUSCULOSKELETAL INJURIES

Several studies have demonstrated that serum vitamin D levels are associated with musculoskeletal injuries[41,42]. Ammerman et al.[41] investigated serum vitamin D levels in female patients diagnosed with lower extremity injuries and reported that 60.8% and 77.4% of those with overuse and acute injuries had low vitamin D levels, respectively. Furthermore, 76.5% of patients with ligament and cartilage injuries, 71.0% of patients with patellofemoral problems, 54.6% of patients with muscle/tendon injuries, and 45.0% of patients with bone stress injuries had low vitamin D levels. Smith et al.[42] assessed the prevalence of vitamin D deficiency in patients with a low-energy fracture of the foot or ankle. They reported that 35/75 patients had serum vitamin D < 30 ng/mL and 10 patients had serum vitamin D < than 20 ng/mL, which suggested that hypovitaminosis D was common in patients with foot or ankle injuries. Additionally, serum vitamin D levels were significantly lower in patients with fractures than the levels in those with ankle sprains.

Similar findings have been observed in athletes. Rebolledo et al.[7] observed that 50% of NFL players had lower extremity muscle strain or core muscle injuries, which suggested that such injuries were significantly related to low serum vitamin D levels. Furthermore, it suggested that inadequate vitamin D levels could increase the risk of hamstring injuries. Particularly, vitamin D deficiency has been demonstrated to increase the incidence of stress fractures among musculoskeletal injuries in athletes[43-45]. Knechtle et al.[43] reported that vitamin D deficiency was a risk factor for stress fractures in athletes. Shimasaki et al.[45] demonstrated that fifth metatarsal stress fractures were 5.1 and 2.9 times higher in athletes with 25(OH)D levels of 10 and 20 ng/mL, respectively. In a recent study, Millward et al.[44] reported that the rate of stress fractures in athletes with low vitamin D levels was 12% higher than that in those with normal vitamin D levels, which suggested that correcting low levels of serum vitamin D in athletes may reduce the risk of stress fractures.

Considering the basic functions of vitamin D, the potential mechanism of low serum vitamin D levels leading to an increased incidence of stress fractures in athletes may be easily understood. Vitamin D is important for bones because it contributes to their mineralization and calcium regulation[5]. Low serum vitamin D levels cause a significant decrease in calcium absorption from the intestines, which increases the parathyroid hormone levels and, consequently, leads to the activation of osteoclasts that break down the collagen matrix of bones[46]. Therefore, various preventive measures are important to maintain and restore the normal levels of vitamin D and prevent stress fractures in athletes. Sikora–Klak et al.[47] recommended vitamin D supplements to treat athletes with vitamin D insufficiency and deficiency. In a recent study, Williams et al.[26] demonstrated that vitamin D supplements significantly reduced the incidence of stress fractures from 7.51% to 1.65% in athletes with vitamin D insufficiency or deficiency. Although more studies are required to better understand the effects of vitamin D supplements, these studies suggest that vitamin D supplements may be effective in reducing stress fractures.

Other studies have reported that vitamin D can have significant effects on acute muscle injuries induced by high-intensity exercises as well[48,49]. Barker et al.[48] reported that high pre-exercise serum 25(OH)D levels were associated with rapid recovery of muscle strength after muscle injury from high-intensity exercises. Furthermore, Pilch et al.[49] recently suggested that vitamin D supplementation can significantly reduce muscle injury caused by high-intensity eccentric exercises. However, the studies by Barker et al.[48] and Pilch et al.[49] were not conducted in athletes. Similar results were observed in the other athletes. Żebrowsk et al.[13] demonstrated that 3 weeks of vitamin D supplementation significantly increased serum 25(OH)D levels in athletes participating in ultra-marathons. This subsequently decreased the serum levels of troponin, myoglobin, creatine kinase, and tumor necrosis factor (TNF)-α, and the post-supplementation increased serum levels of 25(OH)D were negatively correlated with serum myoglobin and TNF-α levels.

Such effects of vitamin D may be mediated by its anti-inflammatory and antioxidative activities. Willis et al.[50] assessed the relationship between vitamin D levels and pro-inflammatory and anti-inflammatory cytokines in endurance athletes; they reported that low serum vitamin D levels were associated with increased concentrations of TNF-α. In a recent study, Ferrari et al.[51] demonstrated that high vitamin D levels were associated with low reactive oxygen species in Italian professional league soccer players. In some studies, vitamin D reduced the production of pro-inflammatory cytokines (interleukin-6, interferon-γ, interleukin-2, and TNF-α)

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and increased the production of anti-inflammatory cytokines (transforming growth factor, interleukins-4, -10, and -13)[15,50]. Furthermore, vitamin D was effective in reducing the oxidative stress induced by high-intensity exercises[52]. Generally, high-intensity exercises induce inflammation and oxidative stress through muscle injuries, which subsequently lead to significant increases in the serum levels of troponin, myoglobin, creatine kinase, and TNF-α[53,54]. However, in contrast, some studies have reported that vitamin D supplementation had no effect on exercise-induced skeletal muscle injuries despite increasing vitamin D levels in athletes[55,56]. Therefore, the effects of vitamin D supplementation warrant further investigations.

PRACTICAL APPLICATIONS OF VITAMIN D IN ATHLETES

Vitamin D deficiency must be treated by correcting the lifestyle to restore normal blood vitamin D levels, which is fundamental in maintaining or restoring the physical performance and musculoskeletal health of athletes[57]. Therefore, sports nutritionists and physicians must regularly evaluate serum vitamin D levels in athletes with recommended 25(OH)D levels of > 32 ng/mL and preferably > 40 ng/mL (-1)[15].

The efforts required to restore normal vitamin D levels may vary between athletes according to their current levels of 25(OH)D. Generally, regular and safe exposure to sunlight and/or foods and supplements rich in vitamin D are recommended[6]. Vitamin synthesis requires approximately 30 min of daily exposure to the sun as well as sufficient intake of vitamin D-rich foods, such as salmon, sardines, herring, and red meat[4,58]. However, exposure to sunlight and dietary intake may not be sufficient for vitamin D synthesis[4]; in such cases, vitamin D supplements may be helpful[4]. Wyon et al.[59] reported that 2,000 IU of daily vitamin D supplementation for 4 months in elite classical ballet dancers not only improved their isometric strength and vertical jump but also reduced injuries. In a more recent study, Michalczyk et al.[60] reported that 6,000 IU of daily vitamin D supplementation for 6 weeks after 10 days of exposure to the sun in professional soccer players with vitamin D insufficiency significantly increased their blood levels of 25(OH)D, which was associated with improved physical performance in 5-m sprint tests. Athletes must also be provided with accurate information on vitamin D supplements. Previous studies have suggested different ranges of vitamin D supplementation. Generally, 2000–6000 IU of daily vitamin D is recommended for athletes[39,60-62]. Recent studies have suggested that athletes may require supplementation of more than 10,000 IU of vitamin D in certain cases[11,63]; however, further studies are required to assess the effects of mega-dose vitamin D in athletes.

Among the different types of vitamin D supplements, vitamin D3 is recommended[64,65]. Both vitamin D2 and D3 can increase the serum levels of 25(OH)D; however, vitamin D3 is more effective than vitamin D2[22,65]. Vitamin D has lower stability, bioavailability, and absorption than vitamin D3[64]. Chiang et al.[66] demonstrated that vitamin D2 supplementation had no effect on muscle strength, whereas vitamin D3 improved muscle strength.

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