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The Effects of Vitamin D supplementation on Athletic Performance and Injury Prevention

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Context: Vitamin D supplementation has numerous effects on athletic performance and plays a significant role in preventing an athlete's risk of sustaining injury. Vitamin D has an impact on numerous physiological functions such as: bone health, muscle function, inflammatory response, and immune function. An athlete's bone and muscle health are essential for maximum performance and career success. A bone fracture due to vitamin D deficiency can delay an athlete's training and ultimately inhibit obtaining a collegiate scholarship and/or contract. **Objective:** The objective of this review is to investigate current research looking at the effects of vitamin D supplementation on athletic performance and injury prevention as well as optimal doses of vitamin D3 for athletes. **Methods: [INCLUDE METHODS] Results:** A cross sectional study found that more than half of athletic trainers did not view 25-hydroxyvitamin D (25[OH]) testing and vitamin D supplementation as a necessary use of athletic program funds. **Conclusion:** There disagreement over vitamin D in the applied clinical setting. Further studies are needed in which a host of variables are investigated regarding the optimal dosages of vitamin D supplements to athletes. Adequate vitamin D supplementation can be utilized to prevent and reduce risk of frequent injuries among athletes.
Key Words: *Vitamin D, Vitamin D Deficiency, Athletic Performance, Injury Prevention*

INTRODUCTION

Vitamin D is a fat-soluble micronutrient involved in the expression of over 1,000 genes, with roles in angiogenesis, cellular proliferation, differentiation, and apoptosis.[1] In particular, vitamin D has critical effects on bone health, muscle function, inflammation, and immune system function.[2] The importance of vitamin D to the structure and function of bone, muscle, and joint tissue, means that it contributes substantially to the ability of the individual to move effectively in space while safely absorbing and transmitting corresponding force loading (i.e., healthy physical function). While maintenance of physical function across the lifespan is a central component of health and well-being broadly,[3] it is of particular importance to athletes. The health, structural integrity, and functional capacity of the neuro-musculoskeletal system is vital to the ability of athletes to perform physical tasks, both in training environments and in competitive athletic settings, while minimizing injury risk. Thus, there is considerable clinical and practical value in understanding the roles of vitamin D, vitamin D deficiency (VDD), and vitamin D supplementation in the health and performance of athletes.

Evidence suggests that VDD is common in athletes and other highly physically active people.[4-5] Despite a substantial body of research, however, the extent to which it hampers performance and raises injury risk is underappreciated.[6-10] Although there are some dietary sources of vitamin D, they are not especially abundant, and so most of the physiologically active forms of the vitamin must come from de novo synthesis with exposure to ultraviolet (UV) radiation.[11-12] There are numerous barriers to obtaining and synthesizing sufficient vitamin D in athletes,[5] such that supplementation may be crucial to supporting neuro-musculoskeletal health in athletes.[13] There is, however, little in the way of consensus on how to determine vitamin D needs and design supplementation programs, causing confusion for nutritionists, athletic trainers, and other health professionals working with athletes.[10]

The aim of the present study is to present the results of a systematic review of available literature on vitamin D supplementation in athletes, to clarify levels of need, appropriate dosages, and effectiveness of supplementation programs. The review will outline the specific effects of vitamin D supplementation in different domains of athletic performance and injury prevention.

BACKGROUND

Importance of Vitamin D for Athletes

Although a direct effect of physical activity of vitamin D status has not been established,[14] the manner in which athletes use and stress their musculoskeletal tissues may place them at higher risk for the negative consequences of VDD. For example, the athlete's skeleton experiences high levels of loading due to weight-bearing, rapid braking and propulsive forces, and stresses exerted by tendons as they transmit the tension produced by active muscle. The ability of bone to resist these loads without fracture is highly dependent on bone strength, which is related to bone mineral density and calcium content. Given the role of vitamin D in gastrointestinal calcium absorption, VDD is associated with increased risk of fractures among athletes,[6] and other groups engaged in high levels of physical activity such as military recruits.[7,9] Loading of bone also involves loading of joint tissues, and thus, at least in the absence of osteoarthritis, the protective effects of sufficient vitamin D are likely also vital to the integrity of articular cartilage.

In athletes who experience high levels of neuromuscular stimulation and activation, the risk for reduced bone strength may be especially high. Bone not only serves as the structural framework upon which muscle acts, but also provides a reservoir of calcium for other physiological functions.[15] Those other functions include transmission of action potentials from motor neurons to the motor end plate, and facilitating actin-myosin binding in the sarcomere, which are necessary for muscle activity and force production. Again, given the role of vitamin D in gastrointestinal calcium absorption, VDD can result in circulating levels of calcium that are insufficient to support these functions. Under these conditions, VDD leads to elevated circulating parathyroid hormone (PTH) levels, which mobilizes stored calcium in bone in a process called osteoclastogenesis.[1,16] While this process helps maintain circulating calcium levels at a normal range, and thus supports neuromuscular function, it can result in reduced bone mineral density.[16] This process favors short term maintenance of locomotor capabilities (e.g., to avoid a predator or dunk a basketball) at the cost of potential longer-term reductions in bone strength and increased fracture risk. Additionally, chronic VDD is linked to ongoing PTH upregulation, and is thus a risk factor for secondary hyperparathyroidism.[17]

Beyond its role in calcium absorption and mobilization, vitamin D also affects skeletal muscle function in multiple ways. Sufficient levels of vitamin D have been shown to be related to greater muscular power and strength.[18-21] Muscle function is impacted by vitamin D in part through increased calcium uptake in the sarcoplasmic reticulum, and increased calcium binding to troponin to facilitate contractile activity.[22] Vitamin D also contributes to muscular strength and power by increasing the size and number of Type II muscle fibers,[20] and by enlarging myotubes during development.[23] Type II muscle fiber composition has a direct correlation with vitamin D serum levels in the body. VDD individuals present with enlarged interfibrillar spaces that contain infiltration of fat, fibrosis, and glycogen.[1] Vitamin D receptors are found in skeletal muscle. Thus, vitamin D has function in myocytes. Severe VDD results in muscle weakness and myopathy.[24]

Finally, among its many pleiotropic functions, vitamin D also has a significant role in regulating the immune system and anti-inflammatory function,[25] as well as other aspects of preservation of homeostasis within the endocrine system, including steroid hormones, indirectly affecting other functions of the body.[26] Vitamin D regulates immune function by having an important role in the synthesis of cathelicidin, which serves as protection from pathogenic agents such as *Mycobacterium tuberculosis*.[26] The activation of toll-like receptors, which identify molecular signatures of microbial pathogens, is also linked to vitamin D-mediated antimicrobial protein (AMP) production.[27] High-intensity exercise is found to suppress immune function, which increases an athlete's risk of illness, and involves high ventilation rates which can elevate exposure to and load of airborne bacterial and viral pathogens.[27] The most common non-injury illness among athletes is upper respiratory tract infection (URTI): athletes who engage in high-intensity training or competition are at an increased risk of URTI, with a 35%-65% incidence rate during high-intensity training. An athlete having a URTI is correlated with higher frequencies of VDD and is related to a 24% reduction in training volume and compromised physical performance.[27]

Other aspects of homeostasis relating to aerobic metabolism and mitochondrial activity are also linked to vitamin D status. Vitamin D supplementation may decrease hepcidin concentration, which can improve iron status and thus augment physical performance that is primarily dependent on aerobic capacity.[28] Athletes with high vitamin D levels also present with low levels of reactive oxygen species (ROS), suggesting that vitamin D is useful in minimizing the effects of ROS, which correlate with a higher risk of neurodegenerative disorders.[29] With low levels of vitamin D, increase in inflammation, oxidative stress, and concurrent reduction of antioxidants can affect an athlete's health, training, and performance.[30]

Risk Factors for Athlete Vitamin D Deficiency

General Assessment and Treatment

Whether an athlete obtains sufficient vitamin D to support bone and joint resistance to mechanical loading, as well as facilitate high levels of neuromuscular activity, depends on a number of factors.[24] The ranges for vitamin D levels are as follows: Deficiency: concentrations of 25 (OH) D < 25 nmol / L < 10 μg/L, Insufficiency: concentrations of 25 (OH) D between 25-50 nmol/ L 10–20 μg/L, and Normal value: Concentration of 25 (OH) D must be above the 50 nmol / L (> 20 μg/L). There are other studies that suggest the values should be above 75 nmol / L > 30 μg/L.[31] Bioavailable vitamin D and not serum 25(OH)D is associated with Bone Mineral Density in a racially diverse athletic population regardless of age or race. To effectively obtain more accurate results on bioavailable vitamin D, clinicians should use specific assays to calculate vitamin D binding protein and bioavailable vitamin D level concentration.[32] On the other hand, Chiang et al. (2017) suggests that the serum concentration of the active steroid hormone's precursor, 25(OH)D (calcidiol), is the best indicator of vitamin D status because it has a long half-life of 15 days.[33]

There are many significant factors that must be considered when determining the adequate amount of Vitamin D supplementation an athlete should be taking. The National Academy of Medicine states that the Recommended Dietary Allowance (RDA) of vitamin D for healthy North Americans is 600 IU.[5] Rawson et al. (2018) suggests that an athlete should have blood work to determine if they are insufficient or deficient in Vitamin D. Then, they should be forwarded to a physician or sports nutritionist to determine optimal supplementation and if any lifestyle changes need to be warranted.[34]

Sekel et al. (2020) emphasizes that 56% of a total sample of 2,000 athletes from nine different countries have inadequate levels of vitamin D (<80 nmol/L). An athlete having insufficient levels of vitamin D raises specific health concerns and increases an athlete's risk of injuries.[5] It is reported that more than two thirds of programs that are a part of the National Collegiate Athletic Association (Division I) have conducted 25-hydroxyvitamin D [25(OH)D] testing. Only 42% of these programs have used funding to purchase vitamin D supplements. A cross sectional study revealed that more than half of athletic trainers viewed 25(OH)D testing and vitamin D supplements as an unnecessary use of athletic program funds.[10] Leitch et al. (2019) conducted an observational study where 52 female and male Division I collegiate athletes completed an online vitamin D awareness and dietary intake questionnaire. The median intake of vitamin D was 330 IU, which is considered below the RDA. Furthermore, only 23.4% of athletes reported concern for their vitamin D levels and only 28.4% believed they were at risk for VDD.[8] Several different factors likely underlie an athlete's risk for VDD.

Exposure to and absorption of UVB Rays from Sunlight

As the primary source of active vitamin D, variables related to UVB ray exposure and absorption have substantial effects on vitamin D status and thus risk for VDD. These variables include exposure factors such as latitude, seasonality, and whether the athlete competes and trains indoors or outdoors, as well as absorption factors, the most important of which is skin pigmentation (melanin content), but which is also related to athletic apparel and skin coverings. Athletes living above the 40th parallel north commonly exhibit VDD, especially during the winter.[35] Even in the southern United States, below the 40th parallel and where daylight hours and temperatures are more conducive to UVB exposure, Hildebrand et al. (2016) found that only 68% of NCAA athletes were VD sufficient, whereas 23% were insufficient, and 9% were deficient.[36]

A lack of UVB exposure during the winter plays a significant role in athletes having deficient or insufficient vitamin D status,[14] and the level of vitamin D has been shown to be markedly low in adolescent female soccer players during the winter in Sweden.[37] When it is recognized and diagnosed, it may be possible to combat this seasonal decrease in UVB exposure through supplementation. Jung et al. (2018b) found that four weeks of supplementation helped elevate serum 25(OH)D concentration to sufficient levels in taekwondo athletes.[38] The need in winter to compete and train indoors, or cover the skin when performing outdoors, can exacerbate the VDD issue. For example, Swiss elite wheelchair athletes exhibited a higher incidence of vitamin D insufficiency and deficiency during winter when training and competing indoors.[39] Indoor athletes in general, regardless of season, are documented to have inadequate serum 25(OH)D levels, which may put them at risk of suboptimal athletic performance.[5,40]

Finally, even athletes who compete outdoors with minimal skin coverings year-round may differ in their ability to absorb UVB rays, relating to variation in skin pigmentation. Darker skin tones are the product of greater concentrations of epidermal melanin, which in context of high UV radiation exposure (e.g., subtropical and equatorial environments) is protective against Deoxyribonucleic acid (DNA) damage and skin cancer.[41] Because this protective function is tied to inhibition of UV wavelength absorption, people with darker skin tones synthesize vitamin D at a lower rate compared to people with lighter skin tones.[5] This is unlikely to be a problem for people who live at lower latitudes, and thus experience enough sun exposure year round to satisfy requirements for vitamin D synthesis. However, for darker skinned athletes who live, train, and compete at higher latitudes with overall less direct sun and high levels of seasonal variation in day length, skin melanin content becomes a risk factor for VDD. African American athletes require more sun exposure than light-skinned athletes to produce the same amount of vitamin D,[5] and athletes who have high concentrations of melanin need to be exposed to UVB rays ten times longer compared to fair-skinned athletes to generate the same vitamin D stores.[1]

In the same study by Hildebrand and colleagues' (2016) cited above, all of the 9% of southern US NCAA athletes with VDD were classified as non-Caucasian, and thus likely to have elevated skin melanin content.[36] Black professional football players (American football; National Football League, NFL) have a higher rate of VDD than their peers of other races,[6] and may consequentially be at a higher risk for injuries and other issues. Black players are at greater risk of bone fractures compared to white players,[6] and case studies of other athletes also present a link between skin pigmentation, vitamin D status, and the presence of bone pain and stress fractures.[42] Black NFL players also made up the vast majority (78%) of players in a study demonstrating a link between insufficient vitamin D levels and incidence of lower extremity muscle strain and core muscle injury.[43] Even prior to joining a professional team, vitamin D status may be indirectly related to NFL careers—football players with higher vitamin D levels were more likely to obtain a contract with the National Football League.[6] Thus, the vitamin D status of athletes with higher melanin levels should be monitored and remedied throughout their playing careers.

METHODS

This systematic review complied with the guidelines delineated in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The search was limited to the PubMed database, and to articles published from 2015 to 2020. The following search terms were used: "vitamin D and athlete and performance," "vitamin D and athlete and injury prevention," "vitamin D immune function athletes," and "athlete risk of vitamin D deficiency".

Terms Used to Guide Search Strategy

Population: Athletes

Intervention/Exposure: Participants following any form of vitamin D supplementation. Also, any participant following vitamin D supplementation with other intervention such as: exercise program, calcium supplement, and/or surgery.

Comparison: Participants following any intervention with no vitamin D supplementation if they were included as controls in a retained supplementation study.

Outcome Measures: Measures related to improvement of athletic performance and/or reduction of injury risk with vitamin D supplementation, or restoration of normal levels of vitamin D in dosage studies.

Study Design: Any observational or experimental study design reporting new results for a study sample (i.e., we excluded case studies and meta-analyses).

Inclusion and Exclusion Criteria:

Inclusion Criteria:

To be included in this review, articles were required to meet the following criteria:

- Investigate vitamin D supplementation and athletic performance, OR
- Investigate vitamin D supplementation and injury prevention, OR
- Investigate vitamin D supplementation dosage and athlete vitamin D status AND
- Written in the English language AND
- Published within the year 2015-2020.

Exclusion Criteria:

The following criteria were used to exclude articles from the review:

- Studies that did not focus on vitamin D supplementation with regard to athletes, such as those that focused on elderly and post-menopausal women.
- Studies that focused on vitamin D supplementation with regard to outcomes other than those directly related to athletic performance or injury risk, such as those focusing on depression and cancer patients.
- Case study, meta-analysis, systematic review. However, the references in any found meta-analyses and systematic reviews were checked for additional novel studies that fit the inclusion criteria but were not found by our search terms.

RESULTS

Results of Database Search and Screening Procedures

The search returned an initial group of 325 articles, which decreased to 320 when duplicates were removed. Each article was reviewed while applying the inclusion and exclusion criteria, which resulted in a final group of 21 qualifying articles retained for the systematic review. Table 1 shows hits and retained articles by search term. Figure 1 presents the study's PRISMA flow diagram. The findings of the retained studies are reviewed below in terms of effects on athletic performance, as well as effects on injury risk and general health.

Search Term	Hits	Retained
"Vitamin D and athlete performance"	211	11
"Vitamin D and athlete injury prevention"	16	1
"Vitamin D immune function athletes"	12	1
"Athlete risk of vitamin D deficiency"	86	8

Table 1. Search Criteria

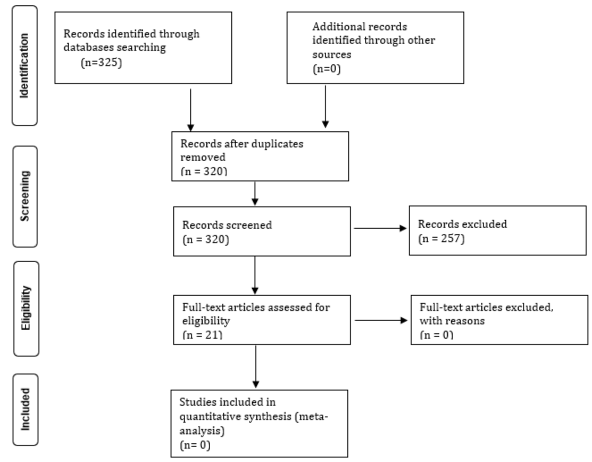

Figure 1: PRISMA 2009 FLOW DIAGRAM

Effects of Vitamin D Supplementation on Athletic Performance

Alimoradi et al. (2019) conducted a randomized controlled clinical where 77 athletes (ages 18-23 y/o) were divided into a VD supplement group that received 50,000 IU Vitamin D3 (VD3) for 8-weeks and a placebo group. The VD group exhibited a significant increase in circulating 25(OH)D concentration (17.3 ± 16.9 ng/mL, P < 0.001), and the placebo group exhibited a significant decrease (−3.1 ± 8.4 ng/mL, P = 0.040). The VD group exhibited a significant improvement in the strength leg press test (P=0.034) and the sprint test (P=0.030). Weekly 50,000 IU VD supplementation caused a 17 ng/mL increase in calcifediol in blood circulation, which resulted in improved strength and speed of the subjects.[24]

Baikoglu et al. (2020) recruited 36 wrestlers (ages 14-16 y/o) and divided them into an experimental group (VD3 supplements plus the exercise program) and placebo (exercise program). Wrestlers from the experimental group with VD levels below 20 ng/mL were placed on a 300,000 IU VD3 replacement supplement in order to increase levels to the accepted limit. The experimental group's VD levels increased from 13.85 ng/mL to 26.28 ng/mL post treatment and aerobic endurance significantly increased (p<0.5) after the replacement. VD supplementation with an eight-week training program resulted in obtaining adequate levels of VD and improvement in aerobic capacity.[44]

Bezrati et al. (2020) conducted a randomized control trial on male amateur soccer players to assess whether VD supplementation affects measures of physical performance in athletes. The soccer players had equivalent baseline VD concentrations and were randomly assigned to a single dose of 200,000 IU of VD (n = 19) or placebo (n = 17) for 12-weeks. The VD group demonstrated increased serum 25 (OH)D levels and improved performance in triple hop jump ($F = 24.2$, $p < 0.001$, $\eta_p^2 = 0.513$), 10-m ($F = 4.46$, $p = 0.046$, $\eta_p^2 = 0.162$) and 30-m ($F = 6.56$, $p = 0.017$, $\eta_p^2 = 0.222$) sprints, and shuttle run ($F = 13.4$, $p = 0.001$, $\eta_p^2 = 0.369$). A single dose of 200,000 IU improved jumping ability, agility, and running speed after 3-months of the single dose.[45]

Jastrzębska et al. (2018) recruited 36 soccer players that were allocated to an experimental group that were supplemented with 5,000 IU VD (n=20) for 8-weeks and a placebo group (n=16). Both groups were assigned to a High-Intensity Interval Training (HIIT). Initial plasma concentration of 25(OH)D of all athletes were inadequate (below 50 nmol/l). The VD supplement group had a significant increase in VD concentration (119%) (initial 48.5 ± 8.6 mmol/l, post intervention 106.3 ± 26.6 mmol/l, mean change 57.8 ± 21.7 mmol/l, p < 0.0001) and the placebo had a decrease of VD concentration (8.4%) (initial 47.5 ± 16.2 mmol/l, post intervention (43.5 ± 16.7 mmol/l, mean change of - 4.0 ± 12.7 mmol/l, p = 0.228). The VD supplemented group demonstrated improvements in VO2 max results by 20% and there was a 13% improvement in the placebo group. Both groups demonstrated similar results in the velocity test. Overall, VD supplementation resulted in moderate and positive effects on soccer players subject to high-intensity training.[46]

Książek et al., (2018) investigated the relationship between 25(OH)D levels and hand grip strength, lower limb isokinetic strength and muscle power in 25 elite judoist athletes. Electrochemiluminescence (ECLIA) revealed that 80% of athletes were VDD and mean PTH and calcium levels were 28.9±9.8 pg/ml and 2.4±0.40 mmol/l. Serum PTH has an inverse relationship with 25(OH)D levels (r = -0.69, p≤0.009). There was a positive correlation between 25(OH)D levels and left-hand grip strength, power of vertical jump, and total work for both the right (r = 0.42, p≤ 0.05) and left (r = 0.44, p≤ 0.05) lower extremity extension (60°/s). Muscle recovery from the stress of intense exercise was accelerated when VD supplements were taken.[47]

Michalczyk et al. (2020) analyzed the influence of de novo synthesis of VD and 6-weeks of VD supplementation on serum 25(OH)D levels, testosterone levels, cortisol levels as well as speed, power and VO_{2max} in 28 professional soccer players. The study was set up to have three stages. Stage 1 occurred during January for 10 days and involved all the athlete's obtaining VD via sun exposure. Stage 2 involved randomly assigning the athletes to a placebo group or intervention group, which was assigned 6,000 IU VD supplements for 6-weeks. Stage 3 involved assessing athletic performance. The athletes had the following baseline VD concentrations: 12 subjects (≤20 ng/mL), 14 subjects (20-30 ng/mL) and 2 subjects (>30 ng/mL). After the 6-week VD supplementation stage, the athletes presented with the following VD concentrations: 2 subjects (<20 ng/mL), 12 subjects (20 and 30 ng/mL) and 14 subjects (30-50 ng/mL). Stage 2 demonstrated significant changes in 25(OH)D concentration, cortisol concentration, testosterone concentration, and the 5 m sprint test. There was a positive correlation between VD, cortisol, and testosterone concentrations.[23]

Ramezani et al. (2020) performed a randomized, double-blind, placebo-controlled trial to investigate the effects of VD supplementation on anerobic and aerobic performance. Forty-six active males were assigned to the VD supplement group (2,000 IU/ day of VD3 for 12-weeks) and the placebo group. The Wingate test, VO_2max, and serum levels of 25-OH-D, and Parathyroid hormone (PTH) were assessed. The VD supplement group had a higher serum level of 25(OH)D ($p = 0.004$), VO_2max ($p = 0.016$), and average power ($p = 0.044$) compared to the placebo. Also, the VD supplement group exhibited lower levels of PTH ($p = 0.004$) and fatigue index ($p < 0.001$). There was an improvement in aerobic capacity, anaerobic performance, and an increase in vitamin D status for the VD supplement group.[48]

Wyon et al., (2016) conducted a randomized placebo controlled double-blind study to determine the effects of giving a single dose of vitamin D3 (150,000 IU) to adult white male indoor judoka athletes on muscle function. There were 22 participants who were allocated to the placebo group or the intervention group (150,000 IU VD3 supplement). The intervention group exhibited an increase in serum 25(OH)D (34%, $P \leq 0.001$) and muscle strength (13%, P = 0.01). A single dose of the VD supplement (150,000 IU) increased serum levels and improved muscle function for athletes with insufficient serum levels. These results highlight the importance of monitoring an indoor athlete's VD serum levels. The study recruited white athletes and did not test on athletes with darker skin tones.[49]

Wyon et al., (2018) conducted a double-blind study on adolescent dancers in order to determine if taking 120,000 IU of vitamin D over a 4-month period results in improved muscle function and reduced injury incidence. The cohort included 67 dancers (Female: n = 29 and Male: n = 38) ages 17-19 years old that were randomly allocated to the placebo group and the intervention group (120,000 IU VD supplement/week). The VD status of the dancers were as follows: 6% VDD, 81% VD insufficient, and 13% VD sufficient. Post intervention VD status were as follows: 53% VD insufficient and 47% VD sufficient. Traumatic injury occurrence for the intervention and control groups (10.9% vs 31.8%; $P < .02$) was associated and there was no increase in muscle power. The intervention group exhibited a significant increase in serum 25(OH)D levels (57%; P< .001) and isometric strength (7.8%; P = .022) that had a negative association with traumatic injury occurrence.[50]

Dubnov-Raz et al. (2015) recruited 53 adolescent swimmers who were VD insufficient. Athletes were randomized into the experimental group (2,000 IU VD3/day for 12 weeks) and the placebo. The experimental group exhibited significantly higher VD concentrations compared to the placebo group (29.6 ± 6.5ng/ml vs. 20.3 ± 4.2ng/ml, $p < .001$) and only 48% of the experimental group became VD sufficient with a mean increase of 9.3 ng/mL above the placebo. There was no improvement of physical performance.[51]

Fairbairn et al. (2018) conducted a prospective double-blind, randomized placebo-controlled intervention trial. The trial consisted of 57 professional rugby players that were randomly assigned to the placebo group or the experimental group, which received 50,000 IU of cholecalciferol (equivalent to 3,570 IU/day) for 11-weeks. The experimental group exhibited a significant increase in serum 25(OH)D concentration (32 nmol/L increase) compared to placebo between 11-12 weeks (95% CI, 26–38; $p < 0.001$) with a 32 nmol/L increase. VD supplemented athletes demonstrated a 5.5 kg increase in performance on the weighted reverse-grip chin up compared to the placebo group (95%

CI, 2.0–8.9; p = 0.002). Overall, VD supplementation was not found to have significant improvement on athletic performance.[52]

Scholten et al. (2020) conducted a double-blind randomized control trial that involved allocating specific VD dosing for 42 participants ages 18-42 years old with regards to their body weight and initial vitamin D status. Participants who exhibited insufficient/deficient 25(OH)D levels (<75 nmol/L) were given an individualized VD dose to achieve 25(OH)D levels of 120 nmol/L within 8-weeks of supplementation. Twenty-seven participants from the VD group had an increase in 25(OH)D concentration from 61 nmol/L to 123 nmol/L (P<0.001) and twelve participants in the placebo group had a decrease in 25(OH)D concentration from 98 nmol/L to 83 nmol/L (P=0.02). Vitamin D repletion was not found to improve anaerobic performance.[53]

Effects of Vitamin D Supplementation on Athlete Health and Injury Risk

Flueck et al. (2016) conducted a retrospective analysis in order to observe the occurrence of VDD between winter and summer months over a year. It was found that 73.2% of all samples exhibited VD insufficiency/deficiency. Athletes had higher VD levels during the summer compared to winter months and 80.9% of indoor athletes demonstrated VD insufficiency/deficiency compared to 70.1% of outdoor athletes (P=0.042). Athletes who presented with a spinal cord injury reached optimal VD levels when given a dose of 6,000 IU of VD3 daily in a 12-week timeframe.[54]

Owens et. al, (2017) recruited 46 athletes that received 35,000 IU or 70,000 IU of VD3 per week for 12-weeks. The response to VD supplementation was monitored by taking blood samples for 18-weeks. Both doses lead to increased levels of VD at week 6 and increased levels of VD continued after supplementation was withdrawn at week 18. Overall, lower doses of VD3 supplementation are suggested due to the increased risk of Vitamin D toxicity when taking high doses. Lower doses of Vitamin D3 ingested frequently, and gradual withdrawal is safer for athletes.[55]

Sekel et al. (2020) conducted a quasi-experimental study in order to determine an optimal dose of vitamin D for a diverse population of collegiate basketball players. A daily dosage of 10,000 IU of vitamin D3 led to increases in 25(OH)D concentration by +35.1 nmol/L. A dosage of 5,000 IU daily leads to a mean decrease of -9.34 nmol/L. The 10,000 IU supplementation was not able to achieve sufficient status among all participants, but it protected against seasonal declines in 25(OH)D concentration. Limited sun exposure, altitude of residency and seasonal variations may inhibit subcutaneous synthesis of vitamin D. Basketball players who have a darker skin pigmentation and train solely indoors are at risk in having reduced dermal production of vitamin D, which predisposes them to VDD. Studies on a larger and more diverse population group should be conducted.[5]

Cassidy et al. (2016) analyzed the relationship between 25(OH)D and bone turnover in swimmers and divers in a 6-month period. It was found that 48% of the vitamin D group experienced low bone turnover at the end of the study. Athletes who were supplemented with 4000 IU of VD3 experienced less bone turnover and maintained more stable 25(OH)D concentrations. There was an inverse correlation between BMI and 25(OH)D change in athletes supplemented with 4000 IU of VD3. BMI was an important indicator in predicting the 6-month change of 25(OH) D change in athletes. It is suggested that an athlete with a normal BMI should be supplemented with VD3 in order to achieve sufficient VD status. Athletes with high bone turnover are more at risk for decreasing 25(OH)D concentrations.[56]

Male and female Dutch athletes were involved in a randomized, double blind, dose-response study and were randomly assigned to take 400 IU, 1,000 IU or 2,200 IU a day for one year with serum total 25(OH)D concentrations assessed every 3-months. Athletes with 25(OH)D concentrations greater than 75 nmol at baseline received no supplements and it was found that athletes with deficient or insufficient 25(OH)D concentration could achieve sufficient concentration for three months by taking 2,200 IU per day.[57]

Mieglo-Ayuso et al., (2018) evaluated the effects of 8-weeks of 3,000 IU VD supplementation per day on hematological, iron metabolism, and the analytical values of testosterone and cortisol on elite male traditional rowers. Another aim was to examine if serum 25(OH)D is a predictor of testosterone and cortisol levels. Thirty-six elite male rowers (27 ± 6 years) were allocated to the experimental group (3,000 IU VD3/day) and the placebo. A regression multivariate analysis revealed that cortisol and testosterone levels were associated with 25(OH)D levels ($p < 0.05$). VD supplementation with 3,000 IU/day during 8-weeks is shown to be sufficient in improving VD levels and prevent decreases in hematological levels of hemoglobin and hematocrit. Testosterone and cortisol responses revealed that VD concentrations are not sufficient to enhance muscle recovery.[58]

Parsaie et al. (2019) conducted a randomized control trial on 22 soccer players who were randomly allocated to a placebo group (n=11) or intervention group (n=11), which received 50,000 IU VD/ week for 8-weeks. Athletes participated in a simulated soccer match post 8-weeks and the intervention group demonstrated an increase in serum 25-hydroxyvitamin D levels (10.68 ng/mL, $P <$ 0.0001). There were no differences in circulating markers of muscle damage and CRP ($P > 0.05$) but there were increased levels of IL-6 ($P = 0.034$). VD supplementation with 50,000 IU/week for 8-weeks resulted in increasing serum 25-hydroxyvitamin D levels in deficient and insufficient athletes with up to a 53.93 ng/mL increase. VD supplementation may have a role in accelerating an athlete's recovery and adaptation to exercise.[59]

Jung et al. (2018b) conducted a randomized control trial in order to analyze the effects of VD3 supplementation on salivary immune function and URTI symptoms during winter training in VD insufficient male taekwondo athletes. Twenty-five athletes (ages 19-22 y/o) with VD insufficiency were allocated to the placebo and the experimental group (n=13), which received 5,000 IU of VD/day for the entire 4-week training period. The experimental group exhibited a 255.6% increase in serum 25(OH)D concentration and serum 25(OH)D concentration was found to have a negative association with total URTI symptoms ($r = -0.435$, $p = 0.015$). A daily dose of 5,000 IU of VD3 increased serum 25(OH)D level to a sufficient level and resulted in reduced URTI symptoms.[38]

Scott et al. (2019) conducted a randomized, double-blind placebo-controlled study in order to examine the effects of VD supplementation on salivary immune responses during Marine Corps basic training. Recruited subjects (75 males and 74 females) received either 1000 IU vitamin D3 + 2000 mg calcium or placebo for 12 weeks. Saliva samples were collected pre-training, during (weeks 4 and 8), and post-training (week 12) in order to determine salivary SIgA and cathelicidin (indices of mucosal immunity) and α-amylase (indicator of stress). Recruits entering training in the summer presented with 37% higher serum 25(OH)D levels compared to winter recruits. Baseline 25(OH)D levels and SIgA secretion rates (-SR) have a positive association with SIgA-SR being higher in the treatment group. VD may have a role in changes of SIgA-SR, cathelicidin-SR and in immune responses.[60]

CONCLUSION

The purpose of this review is to investigate the effects of VD supplementation in athletes and to clarify levels of need, appropriate dosages, and effectiveness of supplementation programs. The results included 21 articles, where 3 of the articles negated the effects of VD supplementation on athletic performance and injury prevention.

The following protocol is suggested in order to maintain adequate VD levels. An athlete should have blood work done to determine their VD levels. Athletes who do not exhibit any risk factors for VDD should start with 600 IU per day. They should strive to maintain 25 (OH) D levels above 75 nmol / L > 30 μg/L. If VD levels above 75 nmol/L > 30 μg/L cannot be maintained with 600 IU per day, then the VD supplementation dosage can be increased. VD levels should be monitored on a weekly basis in order to determine the most effective dose that enables adequate and stable VD levels.

It is pertinent that specific risk factors are considered when determining the appropriate dosage of VD supplementation for athletes. The risk factors are as follows: darker skin tone, indoor environment, higher latitude, winter season, and apparel that covers majority of the skin. For athletes who exhibit VDD, they should be given 50,000 IU/week for 8-months in order to reach 25(OH) D levels above 75 nmol/L >30 μg/L. Once adequate VD levels are reached then the protocol for determining the most effective dose to maintain adequate and steady VD levels can be used. Lower doses of Vitamin D3 ingested frequently, and gradual withdrawal is safer for athletes. This will ensure that athletes are at their optimal health and can train at maximum capacity.

VD via sun exposure does not provide adequate VD for athletes due to increased metabolic activity from high intensity training. Athletes with darker skin pigmentation who train solely indoors result in reduced dermal production of VD. This predisposes them to VDD, which increases their risk of having fractures. A dose of 600 IU-10,000 IU VD3 supplementation every day is effective in reducing bone turnover and helping athletes maintain stable 25(OH)D concentrations. Furthermore, a dose of 600 IU-10,000 IU per day is deemed to be safe and will not result in VD toxicity. Each athlete is unique, and it is vital that one's VD levels are monitored in order to ensure that the dose assigned to them will not result in VDD or VD toxicity.

Results from studies that met the inclusion criteria emphasized on improvement in anaerobic activity and strength tests for athletes. VD supplementation was found to accelerate muscle recovery from the stress of intense exercise. In essence, results of the systematic review indicate the efficacy of VD supplementation on improving athletic performance and injury prevention.

Further studies need to recruit a more diverse group of athletes in order to investigate optimal VD dosing for athletes from various athletic backgrounds, skin pigmentations, and geographic regions. More data will enable more accurate VD dosing protocols when it comes to each unique athlete. It is necessary that specific protocols with specific criteria are determined. This can be a valuable resource for Athletic Trainers to reference in order to tailor a unique treatment for each athlete and ensure that they have sufficient VD levels. Very few athletic programs utilize VD testing and VD supplementation.

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