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Vitamin D and its impact on musculoskeletal system and endurance among athletes – a narrative review of literature

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Abstract

Background. Vitamin D is known as a crucial molecule in bone metabolism and optimal bone forming process. Naturally is activated by sun radiation in skin and then hydrolysed in the liver and kidneys. The risk of deficient or insufficient level of the active metabolite is depended on geographic altitude, skin colour and inadequate supplementation. The athlete's population are prone to lower level of this vitamin. Traditionally has been recognized for its role in calcium homeostasis and bone metabolism; however, increasing evidence indicates that it also plays a crucial role in skeletal muscle function. Skeletal muscle is now considered an important target tissue for vitamin D action due to the presence of vitamin D receptors (VDRs) within muscle fibers. Through genomic and non-genomic mechanisms, vitamin D influences muscle development, contractility, regeneration, and overall physical performance. Consequently, adequate vitamin D status is essential not only for maintaining skeletal integrity but also for optimizing muscle function and preventing musculoskeletal disorders.

Aim. To evaluate and summarize the current scientific evidence regarding the role of vitamin D in the musculoskeletal system and endurance performance among athletes. Particular attention is given to the effects of vitamin D on bone health, skeletal muscle function, muscle recovery, injury prevention, and physiological factors influencing endurance capacity

Material and methods. A narrative literature review was conducted using PubMed MEDLINE and Google Scholar databases. Publications from 2014-2026 included were analysed by using with keywords such as: „vitamin D”, „muscles”, „athletes”, „25-hydroxyvitamin D", "Cholecalciferol", "Athletic Injuries", „endurance”.

Results. Supplementation of vitamin D turned out to beneficial for those who started at suboptimal level of this molecule. Moreover, it impacts on muscle recovery, especially lower limb.

Conclusions. Athletes as a group of endangered vitamin d deficiency should be tested for the baseline level of this molecule. Supplementation of vitamin D may be beneficial in context of recovery and enhancing lower limbs strength although the adequate dose was not found.

Key words: vitamin D, anti-inflammatory, musculoskeletal system, athletes, muscle recovery

Introduction

Vitamin D is a unique secosteroid molecule that functions both as a nutrient and as a hormone, playing a fundamental role in calcium and phosphate homeostasis and the maintenance of skeletal health [1,2]. Unlike most vitamins, vitamin D can be synthesized endogenously in the skin following exposure to ultraviolet B (UVB) radiation, which converts 7-dehydrocholesterol into vitamin D_3 (cholecalciferol). [4] The other sources include nutrients such as fish, mushrooms, eggs and supplements. Following synthesis or dietary intake, vitamin D undergoes sequential hydroxylation in the liver and kidneys to produce the biologically active metabolite 1,25-dihydroxyvitamin D_3 (calcitriol), which exerts its effects primarily through the vitamin D receptor (VDR) [3, 5]. What is surprising $1,25(OH)_2D_2$ (rozwinięcie skrótu?)and $1,25(OH)_2D_3$ (rozwinięcie skrótu?)have comparable affinities for the VDR.

The active form of vitamin D regulates gene expression through interaction with the VDR, a ligand-activated nuclear receptor that functions as a transcription factor. Upon activation, the VDR forms heterodimers with retinoid X receptors and binds to vitamin D response elements within target genes, thereby influencing numerous cellular processes including mineral metabolism, cell proliferation, differentiation, apoptosis, and immune regulation [3,4]. Current evidence suggests that vitamin D signalling influences the expression of hundreds of genes throughout the human body, highlighting its widespread physiological significance.

Although vitamin D has historically been associated with bone health and the prevention of diseases such as rickets and osteomalacia, increasing evidence indicates that its biological functions extend beyond the skeletal system. Vitamin D has been implicated in the regulation of innate and adaptive immune responses, cardiovascular function, metabolic homeostasis, and cellular growth control [5,6]. Recent discoveries have also identified alternative metabolic pathways and tissue-specific activation mechanisms that contribute to the diverse actions of vitamin D in different organs and physiological systems [6].

The molecular structure of vitamin D is closely related to its biological activity. As a secosteroid, vitamin D possesses an opened steroid ring structure that provides conformational flexibility and enables specific interactions with the VDR. Studies examining structure–activity relationships have demonstrated that modifications to the vitamin D molecule can significantly alter receptor affinity, metabolic stability, and biological potency, leading to the development of synthetic vitamin D analogues with potential therapeutic applications [4].

Given its multifaceted physiological functions and extensive influence on human health, vitamin D remains a major focus of biomedical research. Understanding its molecular structure, metabolic pathways, and mechanisms of action is essential for elucidating its role in normal physiology and disease and for developing novel therapeutic strategies targeting vitamin D signalling pathways. The advantages definitely will be contribute to improvement of life satisfaction and management of endocrinological disorders such as diabetes and autoimmune impairment [7].

Purpose of work

The aim of this review is to assess the impact of serum vitamin D status on athletic performance and to determine how adequate 25(OH)D concentrations influence muscle strength, endurance, recovery, and injury risk in athletes. Also, the non-muscular effects, which are tightly connected with athletic performance are mentioned in this publication. This area seems to have a hidden potential, which can be explored in the clinical studies. [8,9,10]

Materials and methods

The research was based on articles from PubMed/MEDLINE and Google Scholarship. The detailed keywords used to find the most adequate texts for my topic included: (("Vitamin D"[Mesh] OR "Cholecalciferol"[Mesh] OR "Ergocalciferols"[Mesh] OR "Vitamin D

Deficiency"[Mesh] OR "vitamin d"[tiab] OR "25-hydroxyvitamin D"[tiab] OR "25(OH)D"[tiab] OR "calcidiol"[tiab] OR "calcitriol"[tiab]) AND ("Wounds and Injuries"[Mesh] OR "Fractures, Bone"[Mesh] OR "Soft Tissue Injuries"[Mesh] OR "Athletic Injuries"[Mesh] OR "Sprains and Strains"[Mesh] OR "Tendinopathy"[Mesh] OR "Tendon Injuries"[Mesh] OR "Ligaments/injuries"[Mesh] OR "injur*"[tiab] OR "fracture*"[tiab] OR "sprain*"[tiab] OR "strain*"[tiab] OR "tendin*"[tiab] OR "tendon*"[tiab] OR "ligament*"[tiab]) AND ("Cohort Studies"[Mesh] OR "Case-Control Studies"[Mesh] OR "Cross-Sectional Studies"[Mesh] OR "Randomized Controlled "[pt] OR "cohort"[tiab] OR "prospective"[tiab] OR "retrospective"[tiab] OR "case-control"[tiab] OR "cross-sectional"[tiab] OR "randomized"[tiab] OR "randomised"[tiab] OR "RCT"[tiab]) AND "English"[lang]). Articles were selected according to predefined inclusion requirements, including: English language, the year of publication between 2013-2026, investigations conducted on humans not animals.

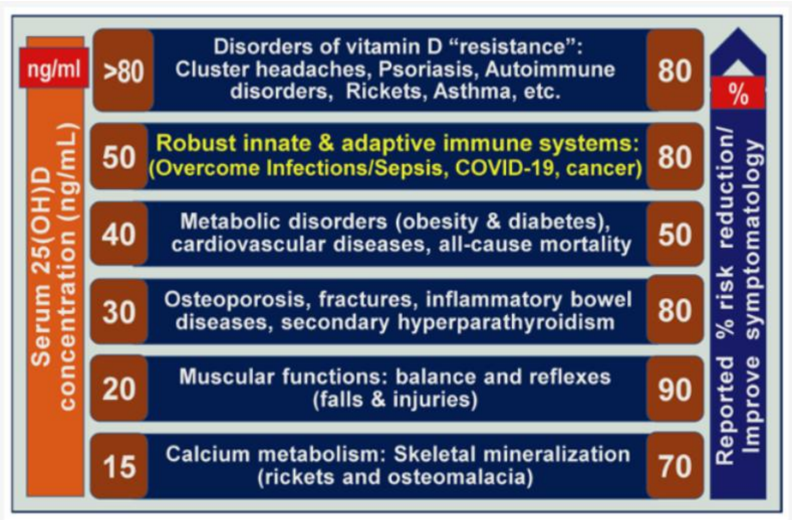
Results

Vitamin D – metabolism

Vitamin D, a fat-soluble vitamin, is involved in the body's phosphate and calcium metabolism. The major source of vitamin D is from sunlight, but other sources include nutrients such as fish, mushrooms, eggs and supplements. Solar UVB radiation helps in converting 7-dehydrocholesterol into previtamin D_3. Previtamin D goes into the circulation and is hydrolysed firstly by the liver to create 25-hydroxyvitamin D (25[OH]D), the major form that clinicians use to measure vitamin D status. Then the kidneys create the biologically active form of 1,25-dihydroxyvitamin D (1,25[OH]2D) also known as calcitriol. [7]

Calcitriol exerts its effects through the vitamin D receptor (VDR), which is expressed in numerous tissues throughout the body and moderates the musculoskeletal system, parathyroid glands immune system, gastrointestinal tract, kidneys, cardiovascular system and come cancers. Vitamin D is involved in gens expression associated in angiogenesis, cellular proliferation, differentiation and apoptosis. [11,12]

The primary function of vitamin D is the regulation of calcium and phosphate homeostasis, thereby supporting bone mineralization, skeletal growth, and maintenance of bone health. Beyond its classical role in the musculoskeletal system, vitamin D influences immune responses, cell proliferation and differentiation, muscle function, and cardiovascular health. Vitamin D deficiency has been associated with impaired bone metabolism, increased susceptibility to infections, autoimmune disorders, and various chronic diseases. Therefore, maintaining adequate vitamin D levels is essential for both skeletal and extraskeletal functions and overall human health. According to the work of Wimalawansa SJ published in 2023 and corrected in 2024, there is a connection between serum concentration of 25(OH)D and reported %risk reduction/improve symptomatology. [12]



Source: **12.** Wimalawansa, S. J. (2023). *Physiological basis for using vitamin D to improve health*. **Biomedicines, 11**(6), 1542. https://doi.org/10.3390/biomedicines11061542 (Erratum: Wimalawansa, S. J. (2024). *Biomedicines, 12*(12), 2807. https://doi.org/10.3390/biomedicines12122807

Figure 1. the scheme showing connection between serum 25(OH)D concentration and reported %risk reduction/improve symptomatology.

Role in inflammation

Vitamin D is increasingly recognized as an important immunomodulatory molecule that influences both innate and adaptive immune responses. Elite athletes frequently experience transient increases in inflammatory markers as a consequence of strenuous exercise and inadequate recovery. Beyond its well-established role in calcium homeostasis and bone metabolism, vitamin D plays a crucial role in regulating inflammatory processes and maintaining immune system balance. The biologically active form of vitamin D, 1,25-dihydroxyvitamin D_3 (calcitriol), exerts its effects through the vitamin D receptor (VDR), which is expressed in numerous immune cells, including macrophages, dendritic cells, T lymphocytes, and B lymphocytes. [7,13]

One of the primary mechanisms through which vitamin D regulates inflammation is the suppression of pro-inflammatory signalling pathways. Calcitriol inhibits the activation of nuclear factor-kappa B (NF-κB), a key transcription factor involved in the expression of inflammatory mediators. As a result, vitamin D reduces the production of pro-inflammatory cytokines such as tumor necrosis factor-alpha (TNF-α), interleukin-1 beta (IL-1β), interleukin-6 (IL-6), and interleukin-17 (IL-17), which are commonly associated with chronic inflammatory conditions [13;14]. Simultaneously, vitamin D promotes the production of anti-inflammatory cytokines, particularly interleukin-10 (IL-10), contributing to the resolution of inflammation and the maintenance of immune homeostasis. [7,14]

Vitamin D also plays a significant role in the regulation of innate immunity. Macrophages and dendritic cells express both the VDR and the enzyme 1α-hydroxylase, enabling local synthesis of calcitriol within immune tissues. This local production enhances antimicrobial defense mechanisms by stimulating the expression of antimicrobial peptides such as cathelicidin and β-defensins, which help eliminate invading pathogens. In addition, vitamin D promotes a more tolerogenic phenotype in dendritic cells by reducing their maturation and antigen-presenting capacity, thereby limiting excessive immune activation and inflammatory responses [13,14].

The effects of vitamin D on adaptive immunity are equally important. Vitamin D suppresses the differentiation and activity of T helper 1 (Th1) and T helper 17 (Th17) cells, both of which are major producers of pro-inflammatory cytokines. At the same time, it promotes the development of regulatory T cells (Tregs), which are essential for maintaining self-tolerance and preventing excessive immune responses. Through these actions, vitamin D helps shift the immune response from a pro-inflammatory state toward a more regulated and anti-inflammatory profile [13]. Furthermore, vitamin D can inhibit B-cell proliferation, plasma-cell differentiation, and antibody production, further contributing to immune regulation.

Growing evidence suggests that vitamin D deficiency is associated with an increased risk of several chronic inflammatory and autoimmune diseases, including rheumatoid arthritis, multiple sclerosis, inflammatory bowel disease, systemic lupus erythematosus, and asthma [14]. Although the precise causal relationships remain under investigation, low vitamin D status has consistently been linked with elevated inflammatory markers and dysregulated immune responses. Experimental and clinical studies indicate that adequate vitamin D levels may help attenuate inflammatory activity and improve immune function, although further research is required to determine optimal supplementation strategies and therapeutic applications.

Vitamin D also contributes to cancer prevention through the induction of apoptosis, a highly regulated process of programmed cell death that eliminates damaged or abnormal cells. Studies have demonstrated that calcitriol influences both intrinsic and extrinsic apoptotic pathways by regulating the expression of pro-apoptotic and anti-apoptotic proteins. Through these mechanisms, vitamin D facilitates the removal of potentially malignant cells before they can accumulate additional genetic alterations and develop into clinically significant tumors [15].

Another important mechanism involves the inhibition of tumor angiogenesis and metastasis. Tumor growth depends on the formation of new blood vessels that provide oxygen and nutrients to rapidly proliferating cancer cells. Vitamin D has been shown to suppress the expression of pro-angiogenic factors and interfere with signalling pathways that promote vascular development. Furthermore, vitamin D reduces the migratory and invasive properties of cancer cells, thereby limiting metastatic dissemination to distant organs. Experimental studies have demonstrated that vitamin D and its analogues can reduce metastatic potential in several cancer models [15].

The anti-inflammatory and immunomodulatory properties of vitamin D may further contribute to cancer prevention. Chronic inflammation is recognized as a hallmark of cancer and creates a microenvironment that promotes tumor initiation and progression. Through inhibition of pro-inflammatory cytokines and modulation of immune-cell activity, vitamin D helps maintain immune homeostasis and may reduce inflammation-associated carcinogenesis. In addition, vitamin D influences antitumor immunity by regulating the activity of macrophages, dendritic cells, T lymphocytes, and other immune cells involved in tumor surveillance [4,15]

Athletes and vitamin D level

The level of vitamin D should be measured before supplementation. There are two main states in which the level of this molecule is suboptimal. The first one described as deficiency, when the level of vitamin d in serum is below 20ng/mL and the second known as insufficiency when the level of vitamin d is below 32ng/mL. According to the [16]

Table 2. Prevalence of Vitamin D deficiency (<20 ng/mL) and insufficiency (<32 ng/mL) in various athletic populations.

Type of Athlete	Indoor/Outdoor	Gender	Vitamin D Status	Reference
Finnish military recruits	Combination	Male	39% deficient	Valimaki *et al.* [8]
UK professional athletes (jockeys, rugby, soccer)	Combination	Male	62% deficient	Close *et al.* [39]
UK athletes (football, rugby)	Combination	Male	57% deficient	Close *et al.* [40]
Middle Eastern sportsman	Combination	Male	32% insufficient 58% deficient	Hamilton *et al.* [33]
Australian gymnasts	Indoor	Female	33% insufficient	Lovell [36]
Israeli athletes & dancers	Indoor	Male & Female	73% insufficient	Constantini *et al.* [35]
USA indoor/outdoor athletes	Combination	Male & Female	12% insufficient	Halliday *et al.* [37]
USA endurance athletes (runners)	Outdoor	Male & Female	42% insufficient 11% deficient	Willis *et al.* [2]
USA outdoor athletes (rugby, football, track, cross country)	Outdoor	Male	25% insufficient	Storlie *et al.* [38]

[16]

Source: **16.** Ogan, D., & Pritchett, K. (2013). *Vitamin D and the athlete: Risks, recommendations, and benefits*. **Nutrients,** **5**(6), 1856–1868. https://doi.org/10.3390/nu5061856

Figure. 2 prevalence of Vitamin D deficiency (<20ng/mL) and insufficiency (<32ng/mL) in various athletic populations.

There was a study focused on finding connection between vitamin D and haematological values and muscle recovery in Elite Male Traditional Roweres. The study investigated the effects of eight weeks of vitamin D_3 supplementation (3000 IU/day) in elite male rowers with insufficient vitamin D status. The authors assessed muscle recovery indirectly through the anabolic-catabolic hormone balance, specifically testosterone and cortisol concentrations. [17]

The results showed that vitamin D supplementation significantly increased serum 25-hydroxyvitamin D [25(OH)D] concentrations. However, supplementation did not produce significant improvements in testosterone or cortisol levels compared with the control group. Consequently, no direct enhancement of muscle recovery or strength-related hormonal markers was observed during the 8-week intervention. Nevertheless, regression analyses demonstrated significant associations between 25(OH)D concentrations and both testosterone and cortisol, suggesting that vitamin D status may influence the hormonal environment involved in recovery and adaptation to training. [16,17]

Vitamin D supplementation had a more pronounced effect on haematological variables. Athletes receiving vitamin D maintained or improved several markers associated with oxygen transport and iron metabolism, whereas these parameters declined in the control group. Specifically, significant group-by-time differences were observed for:

- **Haemoglobin:** Vitamin D supplementation prevented the reduction in haemoglobin levels seen in controls.
- **Haematocrit:** Supplemented athletes maintained or slightly increased haematocrit, while controls experienced a decline.
- **Transferrin:** Vitamin D supplementation significantly improved transferrin concentrations, indicating a potential beneficial effect on iron transport and metabolism.

These findings suggest that adequate vitamin D status may support erythropoiesis and iron metabolism, helping preserve oxygen-carrying capacity during periods of intensive training. Improved maintenance of haemoglobin and haematocrit could be advantageous for endurance performance by supporting oxygen delivery to working muscles. [18]

Bone health and stress fractures

Stress fractures are a common consequence of repetitive loading that exceeds the bone's capacity for repair. They frequently occur in endurance runners, military recruits, dancers, and athletes participating in high-impact sports. Unlike acute traumatic fractures, stress fractures develop gradually through the accumulation of microscopic bone damage. Research suggests that inadequate vitamin D status is an important risk factor for stress fracture development because insufficient mineralization reduces bone strength and delays the repair of microstructural damage. Several studies have reported a higher incidence of stress fractures among athletes with low serum 25-hydroxyvitamin D concentrations compared with those who maintain adequate vitamin D levels. [19]

The relationship between vitamin D and stress fracture risk is further supported by intervention studies demonstrating that optimization of vitamin D status may contribute to improved bone health and injury prevention. Adequate vitamin D availability promotes calcium absorption and supports bone remodelling processes necessary for adapting to mechanical loading. Consequently, athletes with sufficient vitamin D levels may exhibit greater bone mineral density and enhanced resistance to repetitive stress injuries. While supplementation does not eliminate all risk factors associated with stress fractures, it is increasingly recognized as an important component of comprehensive injury prevention strategies, particularly in athletes with documented deficiency or insufficiency [1,20]

Skeletal muscle function

The biological effects of vitamin D on skeletal muscle are mediated primarily by its active metabolite, 1,25-dihydroxyvitamin D_3 (calcitriol). After binding to the vitamin D receptor, calcitriol regulates the transcription of genes involved in muscle cell growth, protein synthesis, and cellular differentiation. These genomic effects contribute to the maintenance of muscle mass and support the development and repair of muscle tissue. In addition, vitamin D exerts rapid non-genomic actions by influencing intracellular calcium transport and signalling pathways that regulate muscle contraction. Because calcium is essential for excitation–contraction coupling, vitamin D deficiency may impair muscle function by disrupting normal calcium homeostasis within muscle cells [21].

One of the most widely reported consequences of vitamin D deficiency is reduced muscle strength. Numerous studies have demonstrated an association between low serum vitamin D concentrations and decreased muscular performance, particularly in the lower extremities. [20,21,22] Deficiency has been linked to muscle weakness, reduced force production, impaired balance, and increased susceptibility to fatigue. These effects are especially relevant in athletes, for whom optimal muscle function is critical for performance and injury prevention. [23,24] Research suggests that vitamin D may be particularly important for maintaining type II (fast-twitch) muscle fibers, which are responsible for generating rapid and powerful contractions required during sprinting, jumping, and explosive athletic movements [1,24]

Vitamin D also plays an important role in muscle regeneration and recovery following exercise-induced damage. Intense physical activity results in microscopic muscle injury that stimulates repair and adaptation processes. Evidence indicates that vitamin D contributes to these mechanisms by regulating satellite cells, which are muscle stem cells responsible for muscle growth and regeneration. Furthermore, vitamin D influences mitochondrial function and cellular energy metabolism, supporting efficient recovery after strenuous exercise. Athletes with inadequate vitamin D status may therefore experience delayed recovery, prolonged muscle soreness, and impaired adaptation to training stimuli [19].

In addition to its direct effects on muscle tissue, vitamin D may indirectly improve muscle performance through its anti-inflammatory properties. Exercise, particularly when intense or prolonged, induces inflammatory responses characterized by the release of cytokines and reactive oxygen species. While these responses are necessary for adaptation, excessive inflammation may contribute to muscle damage.

Furthermore, vitamin D contributes to the maintenance of neuromuscular function by supporting communication between nerves and muscles. Adequate vitamin D levels are associated with improved motor control, coordination, and balance, whereas deficiency may impair neuromuscular efficiency and increase the risk of falls and musculoskeletal injuries. These effects are particularly relevant not only for athletes but also for older adults and clinical populations in whom muscle weakness can significantly affect quality of life and physical independence [21].

Recovery and regeneration

Muscle recovery and regeneration are fundamental physiological processes that enable athletes to adapt to training, restore muscle function, and prevent the accumulation of exercise-induced damage. Intense exercise, particularly resistance and endurance training, causes microscopic disruptions to muscle fibers, resulting in inflammation, oxidative stress, and temporary reductions in muscle function. Recovery involves a complex sequence of events, including the activation of immune cells, removal of damaged tissue, proliferation of satellite cells, protein synthesis, and remodelling of muscle fibers. Efficient regeneration is essential for maintaining athletic performance, reducing fatigue, and minimizing the risk of overuse injuries.

Vitamin D has emerged as an important factor influencing skeletal muscle recovery and regeneration. The discovery of vitamin D receptors (VDRs) in skeletal muscle tissue has provided evidence that vitamin D exerts direct effects on muscle cells. Through its interaction with VDRs, vitamin D regulates gene expression involved in muscle cell proliferation, differentiation, protein synthesis, and calcium homeostasis, all of which are essential for muscle repair and contractile function [2,21,26]. Furthermore, vitamin D appears to support the activity of satellite cells, the muscle stem cells responsible for repairing damaged muscle fibers and facilitating muscle adaptation following exercise [8,25].

Another important mechanism through which vitamin D may enhance recovery is its immunomodulatory and anti-inflammatory action. Strenuous exercise induces the release of pro-inflammatory cytokines, such as interleukin-6 (IL-6) and tumor necrosis factor-alpha (TNF-α), which contribute to muscle soreness and delayed recovery. Adequate vitamin D status has been associated with reduced inflammatory responses and improved regulation of immune function, potentially limiting excessive inflammation and promoting more effective tissue repair [2,26]. In addition, vitamin D may reduce oxidative stress and support mitochondrial function, thereby improving cellular energy production required for recovery processes.

There are associations between low serum 25-hydroxyvitamin D [25(OH)D] concentrations and impaired muscle function, increased muscle weakness, prolonged recovery times, and a greater incidence of musculoskeletal injuries in athletes [1,27]. Athletes with vitamin D deficiency frequently report increased muscle soreness and reduced training capacity, whereas correction of deficiency through supplementation has been linked to improvements in muscle strength, neuromuscular function, and recovery outcomes. Although supplementation does not consistently enhance performance in athletes with already sufficient vitamin D levels, maintaining adequate vitamin D status appears to be particularly important for individuals exposed to high training loads and repeated muscle damage. [9,11,28]

Overall, the current evidence suggests that vitamin D contributes to muscle recovery and regeneration through multiple mechanisms, including the regulation of muscle protein synthesis, satellite cell activity, calcium metabolism, inflammation, and oxidative stress. Consequently, adequate vitamin D status may facilitate more efficient repair of exercise-induced muscle damage, improve recovery between training sessions, and support long-term athletic adaptation.

Supplementation – recommendations for athletes

Vitamin D supplementation is recommended for insufficient or in deficiency level of this molecule. The first part of introducing it should be measurement of its level. This recommendation is functioning not only among athletes but should include also non-athletes. [26,29]

According to Yoon, Kwon, and Kim (2021) [19], maintaining adequate vitamin D status is an important aspect of athlete health and performance management. Athletes are at increased risk of vitamin D insufficiency due to factors such as indoor training, limited sunlight exposure, high latitudes, and seasonal variations, particularly during the winter months. It is recommend regular screening of serum 25-hydroxyvitamin D [25(OH)D] concentrations, especially in athletes with a history of stress fractures, recurrent injuries, muscle weakness, or prolonged recovery periods. While serum levels above 30 [30] or 32 ng/mL are considered sufficient for general musculoskeletal health, concentrations above 40 ng/mL may be more beneficial for athletes to support optimal muscle function, recovery, and injury prevention. When vitamin D deficiency or insufficiency is identified, supplementation with vitamin D3 at doses ranging from 2,000 to 6,000 IU per day is recommended, depending on the severity of the deficiency and individual needs. In addition to supplementation, athletes are encouraged to obtain adequate sunlight exposure and consume dietary sources rich in vitamin D. [30,31]

The Dutch investigation among the group of 128 highly trained athletes conducted in 2016 by research unit tried to find the most suitable dosage, which can be used during the year. Almost 70% of the group showed an insufficient or a deficient level of vitamin D at baseline. They tested the dosage of 400, 1100 and 2200IU per day orally in groups assigned randomly and assessed every 3 months the serum total 25(OH)D concentration. After the year the best results were observed in the group supplemented with 2200 IU/day. [32]

Discussion

The trial conducted by … [10] seems to have innovative approach, but the relatively small sample size and exclusive inclusion of male ultramarathon runners restrict the generalizability of the findings. Furthermore, the intervention consisted of a single high dose of vitamin D administered shortly before the race, which may not reflect typical long-term supplementation practices. The time of observation was also very short, so the studies need to be conducted to find a real power of supplementation.

Also, the work of Kim et al. [23] have some limitations because the main focus of the study was in the isokinetic knee strength measurement. The overall performance, whole-body muscle function or recovery capacity were not take in to the account. The study also relied on a single measurement of vitamin D status and assessed only lower-limb strength without examining broader performance or recovery outcomes. Consequently, further longitudinal and intervention studies are required to determine whether improving vitamin D status directly enhances muscle strength and athletic performance.

In the study conducted by Backx [28] the athletes who were extra exposed on UV radiation were not excluded, but only stricted observed. This group of athletes was small so it reduces statistical power and may limit the detection of subtle differences between supplementation doses.

The limitations is that there were no evidence how oversupplemetation affects the athletic performance. Further studies should focus on finding the ….

Conclusion

Supplementation of vitamin D turned out to beneficial for those who started at suboptimal level of this molecule. Moreover it impacts on muscle recovery , especially lower limb.

The role of vitamin D is unquestionable essential for homeostasis and wellbeing on many fields of human life. Especially its role in optimal functioning muscosceleteal system among athletes and non athletes seems to be essential.

Mostly the effects of this moleculeare grounded in its anti-inflammatory response.The affection of many molecular pathways may be for sure used to find a solution, how to manage chronic diseases, such as autoimmune or endocrine disorders.

In athletes, its primary importance lies in enhancing muscle power, performance, recovery, and injury prevention. In non-athletes, particularly older adults, vitamin D contributes mainly to muscle strength, balance, mobility, and the prevention of falls and fractures. The greatest benefits of vitamin D supplementation are observed in individuals with vitamin D deficiency, whereas supplementation provides little additional benefit when vitamin D levels are already adequate.

The preferential atrophy of type II muscle fibers observed during vitamin D deficiency may partially explain the reductions in muscular strength, power output, and athletic performance frequently reported in individuals with inadequate vitamin D status."

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References

1. Książek, A., Zagrodna, A., & Słowińska-Lisowska, M. (2019). *Vitamin D, skeletal muscle function and athletic performance in athletes: A narrative review*. **Nutrients, 11**(8), 1800. https://doi.org/10.3390/nu11081800

2. von Hurst, P. R., & Beck, K. L. (2014). *Vitamin D and skeletal muscle function in athletes*. **Current Opinion in Clinical Nutrition and Metabolic Care, 17**(6), 539–545. https://doi.org/10.1097/MCO.0000000000000105

3. Bikle, D. D. (2016). *Extraskeletal actions of vitamin D*. **Annals of the New York Academy of Sciences, 1376**(1), 29–52. https://doi.org/10.1111/nyas.13219

4. Carlberg, C., & Muñoz, A. (2022). *An update on vitamin D signaling and cancer*. **Seminars in Cancer Biology, 79**, 217–230. https://doi.org/10.1016/j.semcancer.2020.05.018

5. Pludowski, P., Holick, M. F., Grant, W. B., Konstantynowicz, J., Mascarenhas, M. R., Haq, A., Povoroznyuk, V., Balatska, N., Barbosa, A. P., Karonova, T., Rudenka, E., Misiorowski, W., Zakharova, I., Rudenka, A., Łukaszkiewicz, J., Marcinowska-Suchowierska, E., Łaszcz, N., Abramowicz, P., Bhattoa, H. P., & Wimalawansa, S. J. (2018). *Vitamin D supplementation guidelines*. **Journal of Steroid Biochemistry and Molecular Biology, 175**, 125–135. https://doi.org/10.1016/j.jsbmb.2017.01.021

6. Bouillon, R., Marcocci, C., Carmeliet, G., Bikle, D., White, J. H., Dawson-Hughes, B., Lips, P., Munns, C. F., Lazaretti-Castro, M., Giustina, A., & Bilezikian, J. (2019). *Skeletal and extraskeletal actions of vitamin D: Current evidence and outstanding questions*. **Endocrine Reviews, 40**(4), 1109–1151. https://doi.org/10.1210/er.2018-00126

7. Silva, I. C. J., & Lazaretti-Castro, M. (2022). *Vitamin D metabolism and extraskeletal outcomes: An update*. **Archives of Endocrinology and Metabolism, 66**(5), 748–755. https://doi.org/10.20945/2359-3997000000565

8. Weng, P. W., Nanda, J. D., Chien, Y. H., Lin, C. F., Cheng, S. C., & Yang, M. T. (2026). *Effects of vitamin D_3 supplementation on cardiac, muscle, and immune responses after a marathon race: A single-blind, placebo-controlled trial*. **Journal of the International Society of Sports Nutrition, 23**(1), 2657316. https://doi.org/10.1080/15502783.2026.2657316

9. Mieszkowski, J., Borkowska, A., Stankiewicz, B., Kochanowicz, A., Niespodziński, B., Surmiak, M., Waldziński, T., Rola, R., Petr, M., & Antosiewicz, J. (2021). *Single high-dose vitamin D supplementation as an approach for reducing ultramarathon-induced inflammation: A double-blind randomized controlled trial*. **Nutrients, 13**(4), 1280. https://doi.org/10.3390/nu13041280

10. Bischoff-Ferrari, H. A., Vellas, B., Rizzoli, R., Kressig, R. W., da Silva, J. A. P., Blauth, M., Felson, D. T., McCloskey, E. V., Watzl, B., Hofbauer, L. C., Felsenberg, D., Willett, W. C., Dawson-Hughes, B., Manson, J. E., Siebert, U., Theiler, R., Staehelin, H. B., de Godoi Rezende Costa Molino, C., Chocano-Bedoya, P. O., Abderhalden, L. A., Egli, A., Kanis, J. A., Orav, E. J., & DO-HEALTH Research Group. (2020). *Effect of vitamin D supplementation, omega-3 fatty acid supplementation, or a strength-training exercise program on clinical outcomes in older adults: The DO-HEALTH randomized clinical trial*. **JAMA, 324**(18), 1855–1868. https://doi.org/10.1001/jama.2020.16909

11. Bowles, S. D., Jacques, R., Hill, T. R., Eastell, R., & Walsh, J. S. (2024). *Effects of high-dose bolus cholecalciferol on free vitamin D metabolites, bone turnover markers and physical function*. **Nutrients, 16**(17), 2888. https://doi.org/10.3390/nu16172888

12. Wimalawansa, S. J. (2023). *Physiological basis for using vitamin D to improve health*. **Biomedicines, 11**(6), 1542. https://doi.org/10.3390/biomedicines11061542 (Erratum: Wimalawansa, S. J. (2024). *Biomedicines, 12*(12), 2807. https://doi.org/10.3390/biomedicines12122807

13. Wöbke, T. K., Sorg, B. L., & Steinhilber, D. (2014). *Vitamin D in inflammatory diseases*. **Frontiers in Physiology, 5**, 244. https://doi.org/10.3389/fphys.2014.00244

14. Yin, K., & Agrawal, D. K. (2014). *Vitamin D and inflammatory diseases*. **Journal of Inflammation Research, 7**, 69–87. https://doi.org/10.2147/JIR.S63898

15. Dallavalasa, S., Tulimilli, S. V., Bettada, V. G., Karnik, M., Uthaiah, C. A., Anantharaju, P. G., Nataraj, S. M., Ramashetty, R., Sukocheva, O. A., Tse, E., Salimath, P. V., & Madhunapantula, S. V. (2024). *Vitamin D in cancer prevention and treatment: A review of epidemiological, preclinical, and cellular studies*. **Cancers, 16**(18), 3211. https://doi.org/10.3390/cancers16183211

16. Ogan, D., & Pritchett, K. (2013). *Vitamin D and the athlete: Risks, recommendations, and benefits*. **Nutrients, 5**(6), 1856–1868. https://doi.org/10.3390/nu5061856

17. Mielgo-Ayuso, J., Calleja-González, J., Urdampilleta, A., León-Guereño, P., Córdova, A., Caballero-García, A., & Fernandez-Lázaro, D. (2018). *Effects of vitamin D supplementation on haematological values and muscle recovery in elite male traditional rowers*. **Nutrients, 10**(12), 1968. https://doi.org/10.3390/nu10121968

18. (duplikat pozycji 17 — w APA 7 nie powtarza się tej samej pozycji; usuń z bibliografii)

19. Yoon, S., Kwon, O., & Kim, J. (2021). *Vitamin D in athletes: Focus on physical performance and musculoskeletal injuries*. **Physical Activity and Nutrition, 25**(2), 20–25. https://doi.org/10.20463/pan.2021.0011

20. Książek, A., Zagrodna, A., Słowińska-Lisowska, M., & Lombardi, G. (2022). *Relationship between metabolites of vitamin D, free 25-(OH)D, and physical performance in indoor and outdoor athletes*. **Frontiers in Physiology, 13**, 909086. https://doi.org/10.3389/fphys.2022.909086

21. de la Puente Yagüe, M., Collado Yurrita, L., Ciudad Cabañas, M. J., & Cuadrado Cenzual, M. A. (2020). *Role of vitamin D in athletes and their performance: Current concepts and new trends*. **Nutrients, 12**(2), 579. https://doi.org/10.3390/nu12020579

22Rebolledo, B. J., Bernard, J. A., Werner, B. C., Finlay, A. K., Nwachukwu, B. U., Dare, D. M., Warren, R. F., & Rodeo, S. A. (2018). *The association of vitamin D status in lower extremity muscle strains and core muscle injuries at the National Football League Combine*.

Arthroscopy, 34(4), 1280–1285. https://doi.org/10.1016/j.arthro.2017.10.005 (doi.org in Bing)

23. Kim, D. K., Park, G., Kuo, L. T., & Park, W. H. (2020). *Association of vitamin D status with lower limb muscle strength in professional basketball players: A cross-sectional study*. **Nutrients, 12**(9), 2715. https://doi.org/10.3390/nu12092715

24. Zalneraitis, B. H., Huuki, E., Benavides, L. C., & Benavides, J. M. (2023). *Relation of vitamin D level, BMI, and location of lower extremity stress fractures in military trainees*. **Military Medicine, 188**(7–8), e1970–e1974. https://doi.org/10.1093/milmed/usac258 (doi.org in Bing)

25. Khatri, S., Albright, J. A., Byrne, R. A., Quinn, M., Zhu, A. S., Arcand, P. H., Daniels, A. H., & Owens, B. D. (2025). *Association of vitamin D deficiency with distal biceps injury: A retrospective analysis of 336,320 patients*. **Sports Health, 17**(4), 775–782. https://doi.org/10.1177/19417381241273453 (doi.org in Bing)

26. Wiciński, M., Adamkiewicz, D., Adamkiewicz, M., Śniegocki, M., Podhorecka, M., Szychta, P., & Malinowski, B. (2019). *Impact of vitamin D on physical efficiency and exercise performance: A review*. **Nutrients, 11**(11), 2826. https://doi.org/10.3390/nu11112826

27. Sikora-Klak, J., Narvy, S. J., Yang, J., Makhni, E., Kharrazi, F. D., & Mehran, N. (2018). *The effect of abnormal vitamin D levels in athletes*. **The Permanente Journal, 22**, 17–216. https://doi.org/10.7812/TPP/17-216 (doi.org in Bing)

28. Backx, E. M., Tieland, M., Maase, K., Kies, A. K., Mensink, M., van Loon, L. J., & de Groot, L. C. (2016). *The impact of 1-year vitamin D supplementation on vitamin D status in athletes: A dose–response study*. **European Journal of Clinical Nutrition, 70**(9), 1009–1014. https://doi.org/10.1038/ejcn.2016.133 (doi.org in Bing)

29. Chevalley, T., Brandi, M. L., Cashman, K. D., Cavalier, E., Harvey, N. C., Maggi, S., Cooper, C., Al-Daghri, N., Bock, O., Bruyère, O., Rosa, M. M., Cortet, B., Cruz-Jentoft, A. J., Cherubini, A., Dawson-Hughes, B., Fielding, R., Fuggle, N., Halbout, P., Kanis, J. A., … Rizzoli, R. (2022). *Role of vitamin D supplementation in the management of musculoskeletal diseases: Update from an ESCEO working group*. **Aging Clinical and Experimental Research, 34**(11), 2603–2623. https://doi.org/10.1007/s40520-022-02279-6 (doi.org in Bing)

30. Han, Q., Li, X., Tan, Q., Shao, J., & Yi, M. (2019). *Effects of vitamin D_3 supplementation on serum 25(OH)D concentration and strength in athletes: A systematic review and meta-analysis of randomized controlled trials*. **Journal of the International Society of Sports Nutrition, 16**(1), 55. https://doi.org/10.1186/s12970-019-0323-6 (doi.org in Bing)