The Effects of Vitamin D Deficiency on Physical Fitness and Sport Performance – A Review

Irida Ikonomi Hoxha[1], Silvi Bozo[2], Marsida Krasniqi[1], Dr. Dhurata Bozo[3]

[1]*"Aleksander Moisiu" University, Faculty of Professional Studies, Department of Medical Technical Science, Durrës, Albania*
[2]*Catholic University "Our Lady of Good Counsel, Faculty of Pharmacy, Department of Chemical-Pharmaceutical and Biomolecular Technologies, Tirana, Albania.*
[3]*Sport University of Tirana, Sport Research Institute, Department of Health and Physical Activity, Tirana, Albania*

KEYWORDS
Vitamin D deficiency, Fitness, Sport performance, Vitamin D status, Elite athletes.

ABSTRACT
Introduction: Deficiency or insufficiency of vitamin D affects all individuals, of both sexes and all ages, and consequently brings a series of negative health consequences for them. This deficiency seems to be a very widespread problem in the population in general and also among physically active individuals and particulary in athletes. Currently, the insufficiency of vitamin D is a problem appearing worldwide. While in the population the main source of deficiencies are insufficient exposure to the sun and deficiency in the food diet, in individuals who participate in physical activity and sports it seems that the main factors are high use and depletion of reserves from muscle and adipose tissue. Vitamin D deficiency has an important role not only in bone and muscle health, but also negatively affects physical fitness and sports performance. Therefore, continuing measurement and monitoring of free vitamin D and/or its bioavailable 25(OH)D metabolites is the best way to determine the true vitamin D status for preventive reasons or supplementation in all individuals. Objectives: This review aims to highlight the current situation of the status of vitamin D, especially in subjects participate in physical activity and sports, and its importance and role in the health of athletes and in sports performance. Methods: For this review, we used the database in Scopus and PubMed, searching with key words: vitamin D deficiency - vitamin D status - elite athletes - sports performance. Full articles in English, published from 2016 to 2024, that evidenced the association between vitamin D status and health outcomes and sports performance were included. Results and Conclusions: The results of the study showed that the deficiency of vitamin D in the general population, but also in those who are actively involved in sports and even elite sports, is present at worrying levels. In different groups and populations, the deficiency factors are partly different, but the results show that the lack of food in the diet today constitutes one of the main factors that has almost taken the same weight as insufficient exposure to the sun. For physically active subjects and those involved in various types of sports, deficiencies are present at an unpredictably high rate, putting in serious danger in some cases the lives of the athletes. This comes from a low attention regarding the deficiencies of this vitamin, compared to other elements that are usually taken in the form of supplements in sports. The results show that maintaining an optimal level of vitamin D affects not only the bone and muscle health, the optimal physical fitness of physically active individuals, but also the health and improvement of sports performance (not only physical) of athletes. Therefore, the measurement, monitoring, ensuring a balanced food diet and supplementing with this vitamin, if needed, should accompany the entire course and activity of the subjects of this category in a strict and consistent manner.

1. Introduction

Today it is scientifically proven that adequate levels of vitamin D are essential for bone and muscle health. Recent studies also show that the role of this vitamin is not limited to musculoskeletal health, but is also related to other equally important functions such as the growth processes of muscle development, immune functions, inflammatory modulatory processes, cardiac function, cell regeneration, etc. [1] [2].

Many studies have reported the correlation between vitamin D insufficiency and other diseases such as Covid-19, diabetes mellitus, hypertension, metabolic diseases, autoimmune diseases, cardiovascular diseases and depression. [3] [4] [5] [6] [7].

The term "Vitamin D" refers to a class of fat-soluble steroid substances that have different biological effects but similar chemical properties. It comes in two forms: ergocalciferol D_2 and cholecalciferol D_3. [8] Synthesis in the skin under the action of ultraviolet radiation, food sources, and dietary supplements are some ways to obtain vitamin D [9].

Despite its endogenous production, contributing factors to vitamin D deficiency in athletes are thought to be low

sun exposure and insufficient dietary sources, geographic location, indoor exercise, use of sunscreens, melanin, pollution air and lifestyle. [10] [11]

However, it seems that exposure to the sun is not among the determining factors for significant differences in deficiency between athletes and non-athletes. Therefore, it is considered that nutrition, higher vulnerability to vitamin D, the way in which the reserves of this vitamin are used and mobilized may be among the contributing factors. [12] Numerous studies on the risk factors in the population of athletes such as runners, dancers, swimmers, gymnasts, basketball players have shown that this population is more at risk of developing vitamin D deficiency than the general population. [11] [13] [14] [15] [16] [12].

The importance of vitamin D is related to the physiological functions it performs in our body thanks to the VDR receptors found in bones and skeletal muscles, evidencing the direct role in muscle function. As a modulator of muscular power and strength, it affects the athlete's ability to perform at their best. Vitamin D deficiency also goes beyond this, low levels are associated with increased risk of fractures, musculoskeletal injuries, weakened immune system and inflammation after intense exercise. [17] It is very important in sportist as they are often subject of trauma [54]. Given that these problems are significantly aggravated especially in individuals who develop regular physical activity and sports, deficiencies in these individuals not only affect physical and sports performance, but also constitute a health problem first until the mobilization of calcium from bone tissue and indirectly from its level in skeletal muscles. [18].

Combining knowledge on the effects of vitamin D insufficiency on the health and performance of athletes, this literature review seeks to provide guidance to sports professionals on how to improve training and its effectiveness while also providing suggestions for supplementation/potential supplementation therapies of its deficiencies.

2. Objectives

This review aims to highlight the current situation of the status of vitamin D, especially in subjects participate in physical activity and sports, and its importance and role in the health of athletes and in sports performance.

3. Methods

This review used the descriptive review method. We searched two important databases Scopus and PubMed using the keywords: vitamin D deficiency, fitness, sports performance, elite athletes, muscle and bone function. The search results included articles published from 2016 to 2024 (original review and English-language articles) that evidenced the association between vitamin D status and health outcomes and sports performance.

Publications without reviews, those that did not have data relevant to our focus or were published in languages other than English were excluded. Data from articles such as objectives, key findings and any statistical data related to the impact of vitamin D deficiency on sports performance were systematically extracted.

Throughout the review process, ethical principles were followed in respect of the confidentiality rights of the study participants. A summary discussion was conducted on the results of the review to synthesize the information and draw connections between the different studies and their effects. We used appropriate citations and references to ensure the transparency and reliability of the sources used in view of the purpose and scope of this literature review.

4. Results

4.1 Vitamin D deficiency status

About one billion people in the world suffer from vitamin D deficiency, making it a global health problem. [19] [20] Serum values considered normal physiological 25(OH)D, as determined by the European Society of Endocrinology are from 40 to 60 ng/mL serum. However, serum values above 30 ng/mL (75 nmol/L) are classified as vitamin D sufficiency or sufficiency, values 20–29 ng/mL (52.5–72.5 nmol/L) vitamin D insufficiency or insufficiency, and less than 20 ng/mL (50 nmol/L) are considered deficiency or deficiency. The dividing threshold between sufficiency and insufficiency is the value of 30 ng/mL. When serum levels exceed 100 ng/mL, values for risk of Vitamin D toxicity are considered. [21] Most treatment protocols have concluded that serum 25(OH)D values less than 10 or 12 ng/mL (25–30 nmol/L) are values that should be avoided in all cases. ages. Recommended levels of vitamin D in athletes should be greater than 40 ng/mL for musculoskeletal health and optimal physical performance. [22]

4.2 Vitamin D in bone and muscle health

Vitamin D is essential for bone formation and development as it significantly improves calcium absorption from the intestines and affects the mineral metabolism of the bone system. [23] According to study [7] proved that there is a relationship between vitamin D deficiency and bone mineral density, BMD. Female athletes, compared to women in the general population, have a higher risk of developing osteoporosis as a result of physical stress during intense training. Long-distance athletes, cyclists, swimmers, gymnasts and dancers, are at risk of having low bone mineral density (BMD), which increases their chance of developing osteoporosis. The lack of menstruation, when combined with physical activity, causes female athletes to have low bone density and therefore more fragile bones and risk for spontaneous fractures. Female gender, hypoprotein and hypocalcemic diets are risk factors for decreased bone density. [24] [25]

Other studies have shown that maintaining an optimal level of vitamin D is important for bone health and preventing bone damage in the athlete population. [26]

Physical activity is important for increasing bone strength and stability. [27] Bone, although rigid, is not solid, on the contrary, it undergoes continuous remodeling as a result of the action of osteoblasts, which are responsible for bone formation, and osteoclasts, which are responsible for bone resorption. Previous studies have shown that the type of physical activity affects the increase in bone strength caused by exercise. This is especially true in high-load strength training, high-impact training, and plyometric training (jumping exercises). [27] Lack of vitamin D and calcium can seriously affect bone health, leading to osteomalacia, osteoporosis, multiple fractures and delays in bone development, especially in physically active individuals and athletes. [28]

Vitamin D is essential for strength and power because it regulates the physiological function of skeletal muscles. The high number of its receptors is related to this function. By inducing the activation of genes involved in muscle growth and differentiation, particularly in fast-twitch type II fibers, and by increasing the interaction between myosin and actin in the sarcomere, vitamin D affects muscle performance through both genomic and non-genomic pathways. This results in stronger muscle contraction. [28]
Muscle strength and mass increase when muscle protein synthesis is stimulated by vitamin D. Athletes' ability to train is affected by hypertrophy of type II muscle fibers. Sprinting and other short high-power activities are associated with the activity of type II fibers because of their faster and stronger contractile force compared to type I fibers. [29] Vitamin D receptors (VDRs) have an important role in muscle repair/rehabilitation after an injury. Muscle fibers allow damaged muscles to synthesize $1,25(OH)_2D$, the active form, by locally activating 1α-hydroxylase. High strength and fast muscle contraction are determined primarily by type II muscle fibers and neuromuscular control. [22]

A study [30] using isokinetic dynamometry muscle assessment, showed that athletes with less than 12 ng/mL of serum vitamin D insufficiency had improved muscle function after receiving vitamin D at a dose of 4,000 IU per week.

Another study [31] showed that vitamin D supplementation significantly affected muscle strength of the lower limbs compared to the upper limbs, especially for athletes training indoors. After taking 5,000 IU vitamin D for 8 weeks, [32] showed a significant improvement in vertical jump and 10 m sprint.

A study in female athletes, [33] showed that female participants in the sport of jumping reported improvement in their isometric strength and vertical throw after consuming vitamin D supplements over a four-month period.

4.3 Vitamin D and sport performance

To perform at their best, athletes must maintain optimal muscle strength and power, which depends on adequate levels of vitamin D. [34]

Several muscle disorders, such as myalgia, asthenia, and falls, are associated with vitamin D insufficiency. In some subjects, changes in muscle strength are associated with polymorphisms in the vitamin D receptor (VDR) gene. [35] [36]
showed that there is a positive correlation between vitamin D levels and sports performance. They studied representatives of the Polish national judo team and noted that this sport requires high hand grip strength, showing a link between vitamin D levels and muscle strength.
Insufficiency of vitamin D causes an increase in PTH - which in turn causes cardiac hypertrophy, influencing the reduction of cardiac contraction, alteration of vascular tone and maturation of the cardiac muscle. Based on

the transport capacity and utilization of oxygen by different tissues, vitamin D appears to affect VO_2 max through the ability to transport and increase oxygen in the blood. Hypertrophy is a factor that affects sports performance because it alters cardiac filling and ejection capacities, which results in muscle hypoxia. [28]

It has been proven that the effects of vitamin D on maximum oxygen utilization (VO_2 max) positively affect endurance and performance in athletes. This mechanism is related to Cytochrome P $_{450}$ enzymes, which activate vitamin D_3 to 1,25-dihydroxy vitamin D_3. Cytochrome P $_{450}$ contains the heme group, which increases the binding affinity of oxygen to hemoglobin. [29]

Vitamin D affects VO_2 max through its effects on erythropoiesis and iron metabolism, modifying oxygen delivery capacity during exercise and thus influencing aerobic exercise performance. [37] The study [38] showed a strong correlation between vitamin D levels in soccer players and their muscle strength as measured by jump squats and 10 and 20 meter running ability and aerobic capacity or VO_2 max. This study suggests that optimal levels of vitamin D have a major benefit in sports performance. Healthy levels of 25(OH)D are associated with a lower incidence of stress fractures in athletes, which may have an indirect impact on performance through injury prevention. Furthermore, because it works actively in the muscles, a lack of vitamin D can affect sports performance. [37] There are also many studies that show the positive effect that vitamin D supplements have on sports performance. According to [39] supplementation improves aerobic sports performance, after taking 5000 IU for eight weeks, VO_2 max increased by 20%. According to another study, when athletes aged 18 to 23 years received a weekly therapy of 50,000 IU, blood levels of vitamin D increased by 17 ng/mL, improving their strength and speed.[40], [41] showed that the running, jumping and agility of soccer players increases after receiving a single dose of 200,000 IU. Soccer players showed improved performance in the 5-meter sprint test, an increase in VO_2 max, and greater testosterone concentrations after 10 days of sun exposure and 6 weeks of vitamin D supplementation. [42]

The following table summarizes the main outcomes of the reviewed studies related to the impact of vitamin D on sports performance in the population of athletes and that have proven an improvement in this situation after the use of vitamin D supplementation as an efficient solution .

Study (Year)	Impact on health and sport performance
L. Owens, 2015	athletes with less than 12 ng/mL of serum vitamin D insufficiency had improved muscle function after receiving vitamin D at a dose of 4,000 IU per week.
L. Q. M. &. C. Z. B. Zhang, 2019	vitamin D supplementation significantly affected muscle strength of the lower limbs compared to the upper limbs, especially for athletes training indoors.
G. Close, J. Leckey, M. Patterson, W. Bradley, D. Owens, W. Fraser and J. Morton, 2013	ignificant improvement in vertical jump and 10 m sprint after taking 5,000 IU vitamin D for 8 weeks.
N. Wyon, 2014	women participating in the sport of jumping reported improvement in their isometric strength and vertical throw after consuming vitamin D supplements over a four-month period.
M. Książek, 2018	representative of the Polish national judo team, noted that the sport requires high hand grip strength, showing a link between vitamin D levels and muscle strength.
N. Koundourakis, 2014	showed a strong correlation between vitamin D levels in soccer players and their muscle strength as measured by jump squats and 10- and 20-meter running ability and aerobic capacity or VO_2 max.
Weiss K, 2022	vitamin D affects VO_2 max through its effects on erythropoiesis and iron metabolism, modifying oxygen delivery capacity during exercise and thus influencing aerobic exercise performance.
Jastrzębska M, 2018	supplementation improves aerobic sports performance, after taking 5000 IU for eight weeks, VO_2 max increased by 20%.
R. Alimoradi, 2019	athletes aged 18 to 23 years received a weekly therapy of 50,000 IU, blood levels of vitamin D increased by 17 ng/mL, improving their strength and speed.
M. Bezrati, 2020	showed that the running, jumping and agility of soccer players increases after receiving a single dose of 200,000 IU.
A. Michalczyk, 2020	soccer players showed improved performance in the 5-meter sprint test, an increase in VO_2 max, and greater testosterone concentrations after 10 days of sun exposure and 6 weeks of vitamin D supplementation.

5. Discussion

By grouping the results of the table and discussing them, we can draw some essential conclusions:

- Risk factors in the population of athletes such as runners, dancers, swimmers, gymnasts, basketball players have shown that this population is more at risk of developing vitamin D deficiency than the general population.

- Effect of Vitamin D on Muscle Strength and Sports Performance: Most studies show an improvement

in muscle function and sports performance after taking vitamin D. This includes muscle strength, vertical jump, sprint speed and aerobic abilities such as VO_2 max.

- Vitamin D Level on Sports Performance: There is a strong correlation between vitamin D levels, muscle strength and overall sports performance. Low levels of vitamin D are associated with poor performance and lack of improvement in some sports tests.
- Benefits of high-dose vitamin D intake: high-dose vitamin D intake, such as 5,000 IU per week or a single dose of 200,000 IU, is associated with greater improvements in athletic performance.
- Influence of environment and sun exposure: sun exposure is a natural and effective way to increase vitamin D levels and sports performance.

In general, the results of the studies in the table show a consistency in the improvement of sports performance after taking vitamin D, especially in athletes with low levels of this vitamin. While high-dose supplementation has the potential to improve athletic performance. Sun exposure is also an important means of increasing vitamin D levels and improving sports performance. Therefore, the doctor or coach must be aware of the effects of this deficiency not only on health but also on sports performance. Based on the above we recommend the serial measurement of $25(OH)D_3$ in athletes who are at risk as well as their treatment.

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