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The Effect of Abnormal Vitamin D Levels in Athletes.

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REVIEW ARTICLE

The Effect of Abnormal Vitamin D Levels in Athletes

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ABSTRACT

Vitamin D is a lipophilic prohormone integral to musculoskeletal, autoimmune, oncologic, cardiovascular, and mental health. Of particular importance to the orthopedic surgeon is the role of vitamin D in the regulation of bone mass, muscle strength, and physical performance. Although vitamin D-related skeletal pathologies are rare in industrialized nations, emerging research in the field has shown that most American adults have inadequate levels of vitamin D. Even among athletes, there is a high prevalence of vitamin D deficiency, which may place competitors at risk of stress fractures, illness, and delayed muscle recovery. Adequately identifying vitamin D-deficient individuals in need of supplementation is important to help optimize performance and prevent future injury. The goal of this review is to describe the epidemiology of vitamin D deficiency and its effects on athletic performance and musculoskeletal health. Future double-blinded studies of vitamin D supplementation in athletes are needed. We recommend treating athletes who have insufficient or deficient vitamin D levels.

INTRODUCTION

Vitamin D deficiency is common, even among athletes. The goal of this review is to describe the epidemiology of vitamin D deficiency and its effects on athletic performance and musculoskeletal health.

EPIDEMIOLOGY

Vitamin D deficiency is a common finding among Americans: 36% to 57% of adults are deficient.[1] Causes include low ultraviolet (UV) exposure, lack of fortified nutrition, skin pigmentation, and malabsorption disorders.[1] Public health initiatives, including food fortification and education among pediatric and adolescent populations, have significantly decreased the prevalence of such developmental problems as rickets and growth retardation.[1-3] However, symptoms of vitamin D deficiency in adults such as osteoporosis, osteomalacia, myalgias, and immune deficiencies are often ignored. Patients with vitamin D deficiency presenting as musculoskeletal pain are often misdiagnosed with fibromyalgia, chronic fatigue syndrome, and myositis, among others.[4]

Vitamin D *deficiency* is defined as having a level below 20 ng/mL, and vitamin D *insufficiency* is defined as a vitamin D level under 30 ng/mL. Worldwide, 1 billion people are estimated to fall into these categories.[1] Both vitamin D insufficiency and deficiency are increasing in prevalence.[3]

Professional athletes are similarly affected. In professional basketball, 32% of athletes are found to be deficient and 47% are found to be insufficient with respect to vitamin D levels.[5] Among players in the National Football League, 26% were found to have deficient vitamin D levels, and 42% to 80% of the athletes had levels defined as insufficient.[6,7] Only 36% of Liverpool's professional soccer academy players were found to be either deficient or insufficient.[8] Among professional hockey players, Mehran et al[9] found vitamin D deficiencies in 0% and insufficiency in only 13%. The authors attributed these low numbers to race, given that 96.2% of the hockey players were white. Deficiencies or insufficiencies have been found in most dancers, taekwondo fighters, jockeys, elite wheelchair athletes, handball players, track and field athletes, weightlifters, swimmers, and volleyball players.[10-15]

Multiple studies have shown that athletes with darker skin are at higher risk of vitamin D abnormalities developing.[6,16,17] One study, for example, demonstrated that black race (odds ratio [OR] = 19.1; $p < 0.0001$) and dark skin tones (OR = 15.2; $p < 0.0001$) were the greatest predictors of abnormal vitamin D levels.[16] One study demonstrated that athletes with high concentrations of melanin in their skin need up to 10 times longer UVB exposure times to generate the same vitamin D stores as fair-skinned athletes do.[18]

PATHOPHYSIOLOGY

Vitamin D controls the body's phosphate and calcium stores. The major source of vitamin D is from sunlight, but other sources include fish, mushrooms, eggs, fortified foods, and supplements. With the help of solar UVB radiation, 7-dehydrocholesterol is converted to previtamin D_3. Previtamin D goes into the circulation and is hydrolyzed by the liver to create 25-hydroxyvitamin D (25[OH]D), the major form that clinicians use to measure vitamin D status. The kidneys then create the biologically active form of 1,25-dihydroxyvitamin D (1,25[OH]2D).

The biological feedback loop is a complex interplay between bone, intestines, and the parathyroid glands. Vitamin D receptors are found throughout the body and affect the skeletal muscle, bones, immune system, gastrointestinal tract, kidneys, parathyroid glands, cardiovascular system, and some cancers.[19,20] More than 1000 genes expressed are often dictated by vitamin D, including those of angiogenesis, cellular proliferation, differentiation, and apoptosis.[4,21,22] Vitamin D receptors, when activated, promote cell protein synthesis and have associations with muscle mass and function.[22-24] Levels of less than 30 ng/mL decrease

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gastrointestinal calcium absorption and increase parathyroid hormone activity, resulting in the dissolution of bone matrix by osteoclasts to maintain serum calcium levels within physiologic range.[25-27] Deficiencies prevent the maximum deposition of calcium in the skeleton.[28]

ROLE IN MUSCLE FUNCTION

Vitamin D deficiency leads to structural pathology of muscle tissue. Muscle specimens of vitamin D-deficient individuals exhibit enlarged interfibrillar spaces and infiltration of fat, fibrosis, and glycogen.[29] A South Korean study showed that higher serum vitamin D was associated with less fatty degeneration in rotator cuff muscles and had a positive correlation to muscle torque.[30] Type 2 muscle fibers, also known as fast twitch fibers, have a direct association with vitamin D. Biopsies of 12 vitamin D-deficient patients, before and after vitamin D treatment, found atrophy of type 2 muscle fibers before treatment and significant improvement after treatment.[31] Additionally, Heath and Elovic[32] found that 93% of patients presenting to a community clinic with nonspecific musculoskeletal pain were found to have vitamin D deficiency. Furthermore, Ahmed et al[33] reversed myositis-myalgia in statin-treated patients who had vitamin D deficiency using vitamin D supplementation. Athletes in the National Football League Combine with a history of lower extremity muscle strain and core muscle injury had a higher prevalence of inadequate vitamin D.[34]

ROLE IN INFLAMMATION

Vitamin D can reduce inflammation by its inhibitory effect on proinflammatory cytokines such as Interleukin-6, which converts monocytes to macrophages, which in turn produce more inflammatory cytokines. Interleukin-6 can be increased very early in a single workout[35] and has been hypothesized to be related to the occurrence of muscle damage in a workout.[36] Vitamin D has also been shown to reduce the production of other proinflammatory cytokines such as interferon-α, Interleukin-2, and tumor necrosis factor-6.[37-40]

HISTORICAL IRRADIATION IN ATHLETES

UV irradiation of athletes to improve performance has been an area of intrigue far before its relationship with vitamin D was established. Studies dating to the 1930s and 1940s have noted improvement in running speed and bike ergometer readings among study participants.[41-43] More recent work has shown that UV radiation improved forearm strength, work performance on bike ergometers, and strength and speed of college women.[44-47]

In 1952, Ronge[48] was the first to hypothesize that the production of vitamin D explained the success of UV radiation in physical performance. He supplemented nonirradiated German schoolchildren with a single dose of vitamin D and greatly improved their cardiovascular performance, equivalent to a group of radiation-treated children. The UVB range was the most effective wavelength in consistently reducing resting pulse, lowering the basal metabolic rate, and increasing work performance on a bike ergometer.[49]

IMPACT ON ATHLETIC PERFORMANCE

Vitamin D supplementation has been shown in multiple studies to affect muscle performance, kinetics, and efficiency.[50,51] Close et al[8] demonstrated that professional soccer players increased their vertical jump and 10-m sprints ($p = 0.008$) when taking vitamin D supplements. Additionally, ballet dancers who supplemented with vitamin D showed they had a 7% higher vertical jump ($p < 0.01$) and an 18% increase in isometric strength ($p < 0.01$).[52] A British study using novel jump mechanography found a positive relationship between serum vitamin D levels and jump height, velocity, and power ($p = 0.005$, 0.002, and 0.003, respectively) in postmenarchal adolescent girls.[51] In a randomized, double-blind trial, judo athletes supplemented with vitamin D_3 demonstrated a 13% increase in muscle strength compared with a placebo group ($p = 0.01$).[53]

LOSS OF ATHLETIC PARTICIPATION

Athletes with subtherapeutic vitamin D levels may be at higher risk of missing practices and games as a result of stress fractures, muscle injuries, and upper respiratory tract infections. Serum 25(OH)D levels less than 20 ng/mL have been associated with double the risk of tibial and fibular stress fractures in female naval cadets than those with serum levels greater than 40 ng/mL (OR = 0.51, 95% confidence interval = 0.34-0.76, $p \leq 0.01$).[54] In a large prospective study of 756 Finnish military recruits with a mean age of 19 years old, a multivariate analysis showed that serum 25(OH)D levels below 30.4 ng/mL significantly correlated with stress fractures (OR = 3.6, $p = 0.002$).[55]

Vitamin D levels have also been shown to affect muscular injury rates. Lower levels of serum vitamin D have been associated with increased amounts of muscle weakness after injury ($p < 0.05$).[56] Ballet dancers who received vitamin D supplementation sustained fewer injuries than did those who did not receive supplementation ($p < 0.01$),[52] and injury incidence was lower in summer, when vitamin D was at higher levels ($p < 0.05$).[57] After decreases in serum 25(OH)D levels, collegiate swimmers have been shown to be at increased risk of connective tissue and muscle injuries.[58]

Acutely after endurance exercises, the immune system is suppressed and the body is vulnerable to infection,[59,60] and vitamin D is vital in expression of antimicrobial cells.[13,61,62] In 1945, UV-irradiated University of Illinois students not only did better on physical examination tests but also had half as many viral respiratory tract infections.[43] Elite athletes have a higher incidence (incidence rate = 4.04, confidence interval = 95%, $p < 0.05$) of upper respiratory tract infections than do recreationally competitive athletes, putting them at higher risk of missing playing time.[63] Additionally, athletes with optimal vitamin D levels (> 48.08 ng/mL [> 120 nmol/L]) present significantly less often for treatment of upper respiratory tract infections, and their severity scores and days experiencing illness are significantly lower than those with vitamin D deficiency (< 12.02 ng/mL [< 30 nmol/L]).[13]

MEDICAL MANAGEMENT

A patient's vitamin D status can be assessed with a blood draw assessing 25(OH)D level. The Endocrine Society[64] defines vitamin D *deficiency* as 25(OH)D level below 20 ng/mL, *insufficiency* as 21ng/mL to 29 ng/mL, and *sufficient* as above 30 ng/mL. Recommended daily intake varies by age. To achieve blood levels of 25(OH)D consistently above 30 ng/mL, children aged 1 to 18 years are recommended to consume at least 1000 IU/d; adults in the 19- to 50-year range may need at least 1500 IU/d to 2000 IU/d to reach the same level.[64] Vitamin D toxicity manifests with hypercalcemia-related symptoms such as nausea, vomiting, fatigue, and weakness[65] and can occur when doses reach greater than 50,000 IU/d, with blood levels above 150 ng/mL. Sunlight alone cannot cause toxicity, as excess vitamin D is broken down by sunlight.[66]

Although doses of 10,000 IU/d for 5 months do not cause toxicity,[67] it is suboptimal to overload the body in this fashion to raise vitamin levels. A dose of 70,000 IU/wk has been shown to be detrimental to increase 25(OH)D blood levels; after stopping the supplementation, serum 24,25(OH)2D persists at high levels, which inhibits the bioactivity of 1,25(OH)2D.[68]

RECOMMENDATIONS

Future research is greatly needed, focusing on double-blinded supplementation and optimal vitamin D levels in athletes. We recommend that vitamin D levels should be checked on an annual basis in all athletes. If their level is deficient or insufficient, athletes should be supplemented with vitamin D to help decrease the risk of injuries while possibly improving performance. In patients who are vitamin D deficient or insufficient, we recommend a treatment dosage of 50,000 IU/wk for 8 weeks. Once the treatment regimen has been completed, the physician may choose to recheck vitamin D levels and then initiate another 8-week round of treatment if levels remain deficient. If the patient's vitamin D level is adequate after 1 round of treatment, we recommend a daily maintenance dose as described by the Endocrine Society.[64] ❖

Disclosure Statement

The author(s) have no conflicts of interest to disclose.

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