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Vitamin D in the Life of the Athlete: A Narrative Review of Biology, Status, Performance, Injury and Practical Management

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Abstract

Introduction

Vitamin D is essential for bone health and supports muscle and immune function. Deficiency is common among athletes due to indoor training, high latitudes, winter, clothing and darker skin. The main concern is how vitamin D status and supplementation affect performance, recovery and risk of illness or injury.

Aim

This review summarizes evidence on:

• mechanisms linked to muscle and immune function,

• prevalence and causes of deficiency,

• impact on strength, endurance and recovery,

• role in bone health, fractures and soft tissue injuries,

• associations with respiratory infections,
• strategies for screening and supplementation.

Material and Methods

A narrative review was conducted using PubMed and Google Scholar. Priority was given to randomized controlled trials, systematic reviews, meta-analyses and clinical guidelines.

Results

Vitamin D receptor activity regulates calcium handling, mitochondrial function and tissue repair. Deficiency affects 40–70% of athletes in winter, particularly those engaged in indoor and high-latitude sports. Supplementation effectively raises serum 25(OH)D levels. Effects on performance are modest but more pronounced when deficiency is corrected. Calcium combined with vitamin D reduces stress fracture risk in military cohorts. Observational studies indicate that low vitamin D increases the risk of bone stress injuries. Evidence for protection against respiratory infections is inconclusive.

Conclusions

Adequate vitamin D supports bone integrity and recovery. Ergogenic effects are modest and mainly relevant in deficiency. Guidelines recommend individualized vitamin D_3 supplementation, usually 1,000–2,000 IU/day, and screening for high-risk athletes. High-dose bolus regimens are not recommended. Maintaining sufficiency reduces bone injury risk and supports overall health, though performance benefits in sufficient athletes remain uncertain.

Keywords: vitamin D, athletes, supplementation, performance, stress fracture, respiratory infection, bone health, muscle

1. Introduction

Vitamin D is a secosteroid hormone whose active form [1,25$(OH)_2$D] act via the vitamin D receptor (**VDR**) to regulate calcium-phosphate homeostasis and influence tissues relevant to sport, particularly skeletal muscle and immune cells. In elite and sub-elite athletes, vitamin D status fluctuates with season, latitude, training environment (indoor vs. outdoor), skin pigmentation and clothing, with suboptimal levels frequently observed during winter or periods of heavy indoor training. Therefore, athlete support teams must balance the prevention and correction of deficiency for health and performance outcomes – such as reducing the risk of bone stress injuries – while acknowledging that evidence for direct ergogenic benefits remains mixed. This review integrates mechanistic, epidemiological, interventional and guideline-based evidence to provide a practical, evidence-informed framework for athlete care.

2. Research materials and methods

2.1. Participants

This review focused on human studies involving athletes and, where appropriate, military recruits as analogs for bone stress injury risk. Eligible participants were adults engaged in structured physical training. Studies conducted in pediatric populations or specific clinical cohorts (e.g., patients with rickets) were excluded, unless they provided mechanistic insights directly relevant to sports performance.

2.2. Procedure

A comprehensive literature search was conducted in PubMed and Google Scholar, covering the years 2012–2025. Eligible study designs included randomized controlled trials (RCTs), systematic reviews and meta-analyses, consensus statements, guidelines and observational studies related to vitamin D and sports performance. Mechanistic reviews on vitamin D's role in muscle biology and immune function were also considered to provide biological context. Outcomes of interest included performance measures (strength, power, endurance), injury prevention (stress fracture incidence), and risk of respiratory illness.

2.3. Data Collection and Analysis

The selection process prioritized studies linking vitamin D status or supplementation with performance and health outcomes in athletes. Given heterogeneity in populations, methodologies and endpoints, a narrative synthesis was applied rather than a quantitative meta-analysis. Studies were grouped thematically according to their relevance to performance, injury prevention or immune function.

2.3.1. Statistical Software

As this was a narrative review, no original statistical analyses were performed. Reported statistical results were extracted directly from the included studies, which primarily employed software such as SPSS or equivalent statistical packages.

2.3.2. Statistical Methods

No new statistical procedures were conducted within this review. Instead, the statistical approaches of the included studies (e.g., ANOVA, regression analyses, effect size calculations) were summarized where relevant for interpreting the findings.

3. Research results

3.1. Mechanistic Background: Why Vitamin D Matters to Athletes

VDR is expressed in adult human skeletal muscle at low basal levels and is upregulated in response to injury or regeneration. Ligand activation modifies transcripts that regulate calcium handling, mitochondrial function and myogenesis. Non-genomic signaling influences ion channels and intracellular cascades relevant to excitation–contraction coupling. Animal and in vitro studies, along with human biopsy evidence, collectively support a biologically plausible pathway through which vitamin D deficiency could impair type II fiber function and delay recovery [1-5].

3.2. Vitamin D Status in Athletes: Prevalence, Determinants and Seasonality

Based on the 2022 systematic review and meta-analysis conducted in elite athletes, a significant prevalence of vitamin D insufficiency (defined as ≤ 50 nmol/L or 20 ng/mL) was observed. The study consistently identified indoor training environments and winter months as factors associated with lower serum **25-hydroxyvitamin D** (25(OH)D) concentrations. These findings underscore the impact of environmental conditions and seasonal variations on vitamin D status in high-performance athletes [6].

A 2023 systematic review and meta-analysis examining differences between indoor and outdoor athletes revealed that indoor training and higher latitudes were significant predictors of lower serum 25(OH)D levels. Specifically, one model estimated a reduction of approximately 4.4 ng/mL in 25(OH)D concentrations in indoor athletes after multivariable adjustment. These findings highlight the role of environmental factors in modulating vitamin D status in athletic populations [7].

Prospective data collected from Premier League footballers at 53°N latitude demonstrated a significant decline in serum 25(OH)D levels from approximately 104 ± 21 nmol/L in summer to 51 ± 19 nmol/L in winter. By December, 65% of the athletes were classified as vitamin D insufficient [8]. Similar patterns have been observed in elite collegiate and professional athletes across various sports, with a notably higher prevalence of vitamin D deficiency in indoor and wheelchair para-athletes, as well as during winter training cycles [9-12].

Implication: Without proactive strategies, many athletes – particularly those who train indoors, reside at high-latitude, or have darker skin pigmentation – may exhibit vitamin D insufficiency during late winter, which could have negative consequences for bone health and availability.

3.3. Vitamin D Forms, Dosing and Pharmacology

Comparison of Vitamin D_2 and D_3

Meta-analytic evidence demonstrates that **cholecalciferol** (vitamin D_3) is more effective than **ergocalciferol** (vitamin D_2) in elevating serum 25(OH)D levels, a finding consistently confirmed in subsequent analyses [13, 14].

Vitamin D_3 Supplementation in Athletes

Systematic reviews of **randomized controlled trials** (RCTs) in athletes confirm that vitamin D_3 supplementation effectively increases serum 25(OH)D levels, with typical net gains ranging from 10 to 20 ng/mL. Winter supplementation regimens of ≥2,000 IU/day over periods of 4–12 weeks are particularly effective in transitioning athletes from insufficient to sufficient vitamin D status. However, the effects of supplementation on muscle strength are heterogeneous. Notably, improvements in quadriceps strength are the most consistently observed, while combined strength and power outcomes in meta-analyses often fail to reach statistical significance [15, 16].

3.4. Performance Outcomes

Strength and Power

Controlled prospective studies in elite ballet dancers, administering 2,000 IU/day of vitamin D_3 for 4 months, demonstrated approximately a 19% increase in isometric strength and a ~7% improvement in vertical jump performance, alongside a reduction in injury incidence compared to the control group [17]. Comparable benefits have been observed in adolescent dancers in randomized controlled trias [18]. In soccer, certain trials reported improvements in sprint performance and jump height in vitamin D-deficient athletes. For instance, a single loading dose of vitamin D resulted in enhanced vertical jump, agility, and 10–30 meter sprints over a 3-month period in vitamin D-deficient youth. However, other randomized controlled trials conducted in well-trained athletes have yielded no significant effects [19-21].

Syntheses of randomized controlled trials in athletes consistently conclude that:

- Vitamin D supplementation effectively increases serum 25(OH)D levels,

- Benefits on strength and power are modest, with the most pronounced effects observed when correcting deficiency,
- Null results are frequently reported when baseline vitamin D status is already adequate [15, 16, 22].

Endurance and Aerobic Capacity

A recent systematic review of elite athletes reported possible improvements in aerobic endurance and anaerobic power, but the heterogeneity of findings and small sample sizes in the included studies limit inference [23]. Trials examining the combined effects of vitamin D_3 supplementation and sprint interval training have yielded mixed outcomes on endurance-related measures. Observational studies in professional soccer have reported associations between higher 25(OH)D levels and improved performance indices, though causality remains unclear [24, 25]. Overall, correcting deficiency is advisable, however expecting consistent VO_2max gains in replete athletes is unrealistic.

The key conclusion regarding performance is that vitamin D deficiency should be addressed to support overall health and eliminate a potential limiting factor; however, the ergogenic effects of supplementation should not be overstated in athletes with already adequate vitamin D status.

3. 5. Bone Health, Stress Fracture and Soft-Tissue Injury

Vitamin D plays a crucial role in maintaining calcium-phosphate homeostasis and supporting bone remodeling. In a landmark randomized, placebo-controlled trial of **5,201** female Navy recruits, **800 IU D_3 plus 2,000 mg calcium daily** for 8 weeks reduced stress fracture incidence by **20%** (intention-to-treat) and **21%** (per-protocol) [24]. Subsequent military studies and observational data in athletes corroborate seasonal insufficiency and associations with bone stress injury phenotypes [26-29].

Athletes experiencing low energy availability or menstrual dysfunction, as seen in the female athlete triad or **relative energy deficiency in sport** (RED-S), often present with compromised bone health. Expert consensus recommends ensuring adequate calcium intake (typically ~1,500 mg/day for athletes at risk) and vitamin D supplementation (commonly 1,500–2,000 IU/day, particularly when sun exposure is insufficient). These interventions should be implemented alongside comprehensive strategies for nutritional optimization and the recovery of menstrual function [30-33].

3.6. Immunity and Acute Respiratory Infections (ARIs)

Earlier meta-analytic evidence suggested small protective effects of daily or weekly vitamin D supplementation against ARIs, particularly with modest daily dosing (400–1,000 IU) and in vitamin D-deficient groups [34]. However, an updated **2024** *Lancet Diabetes & Endocrinology* meta-analysis, incorporating recent large trials (>60,000 participants), found **no statistically significant reduction** in ARI incidence overall [35-37]. Athlete-specific RCTs are sparse, and extrapolation from general populations should be approached with caution.

Practical conclusion: Ensure adequate vitamin D levels to support overall health. However, it is important not to rely on vitamin D supplementation as a primary or robust strategy for infection prevention.

3.7. Contemporary Guidance and Safety

Guidelines (2024 Endocrine Society)

The 2024 Endocrine Society guidelines recommend a shift in focus away from routine 25(OH)D testing and high-dose supplementation in healthy adults under the age of 75 without specific indications. For the majority of individuals, a daily intake of 600–800 IU, as advised by the National Academies, is deemed sufficient, with adjustments based on age. Higher dosages may be warranted for specific populations, such as children, pregnant individuals, those over 75 years of age, individuals with prediabetes, or those at high risk for vitamin D deficiency [38-40].

Upper Intake Levels and Toxicity

National and international bodies set a **Tolerable Upper Intake Level (UL) of 4,000 IU/day (100 µg)** for adolescents and adults. Toxicity is rare but classically presents with hypercalcemia when 25(OH)D exceeds ~150 ng/mL. A 2023 safety meta-analysis found that supplementation with **3,200–4,000 IU/day** increased relative risk of hypercalcemia (~4/1,000) and slightly increased falls or hospitalizations in some trials. Case reports describe severe hypervitaminosis with **≥50,000 IU/day** [41-44].

3.8. Practical Algorithm for Athlete Care

1. **Who to screen and when?**

   • Targeted screening for vitamin D deficiency should be conducted at **end of winter** (or at the end of the indoor season) for athletes in high-latitude regions, those participating in indoor sports, darker-skinned athletes, individuals engaged in sports involving covered clothing and those with a history of bone stress injuries or features of RED-S [6, 7, 30-33].

2. **Interpreting 25(OH)D**

   • It is important to acknowledge the variability in assay methods and the absence of universally accepted "optimal" vitamin D levels for athletic performance. Many sports programs adopt a pragmatic target of **≥30 ng/mL** (≥75 nmol/L) to reduce the risk of bone stress, while also adhering to the 2024 Endocrine Society guidelines, which caution against routine testing and supplementation in healthy populations without specific indications [30, 38-40].

3. **Correcting deficiency and maintenance**

   • In cases where serum 25(OH)D levels are below 20 ng/mL (50 nmol/L) or in the presence of clinical risk factors, cholecalciferol (D_3) should be considered the preferred therapeutic option. Typical supplementation regimens involve daily doses of 1,000–2,000 IU (or equivalent weekly dosage), adjusted according to baseline vitamin D status, body size, sun exposure and seasonal variation. These regimens are generally continued for 8–12 weeks, followed by reassessment of vitamin D levels. Routine use of large bolus doses is not recommended [13-16, 38-41].

4. **Bone-stress risk or RED-S**

   • It is essential to maintain a total calcium intake of approximately 1,500 mg/day in individuals at risk of bone injuries or those experiencing low energy availability. This intake should be complemented by vitamin D supplementation as necessary, while simultaneously addressing the underlying energy deficiency [30-33].

5. **Performance expectations**

   • Modest improvements in strength and power can be anticipated primarily in athletes with vitamin D deficiency. However, consistent gains in endurance performance should not be expected in individuals with sufficient vitamin D levels [15-23].

6. **Safety**

   • Habitual vitamin D intake should be maintained at or below 4,000 IU/day unless under medical supervision. In cases of higher dosing or conditions of increased risk, calcium status should be regularly monitored [41-44].

3.9. Limitations of the Evidence Base

Most athlete RCTs are small, short in duration, performed in winter and rarely stratified by baseline 25(OH)D or race/ethnicity. Outcome heterogeneity (e.g., strength tests, jump protocols, time-to-exhaustion, illness diaries) limits the ability to pool results. New guidelines de-emphasize categorical sufficiency thresholds for otherwise healthy adults, while many sports programs still apply practical targets for bone-stress prevention. These differences should be reconciled locally through shared decision-making.

4. Discussion

Mechanistic evidence supports the role of the vitamin D receptor in skeletal muscle, regulating calcium homeostasis, mitochondrial function and tissue regeneration. Observational studies indicate a high prevalence of deficiency among athletes, particularly during winter, in indoor disciplines and at higher latitudes. Supplementation with vitamin D_3 (1,000–2,000 IU/day) reliably increases serum 25(OH)D concentrations. The greatest benefits for strength and power are observed in deficient athletes, whereas ergogenic effects in individuals with sufficient vitamin D levels are minimal. Findings regarding endurance performance remain inconsistent.

Evidence is stronger with respect to bone health. Vitamin D supplementation, particularly when combined with adequate calcium intake, reduces the risk of stress fractures. Proposed immune benefits are less consistent, with large meta-analyses failing to confirm a protective effect against respiratory infections.

Practical recommendations include targeted screening in high-risk groups, correction of deficiency with moderate doses of vitamin D_3 and concurrent calcium intake when bone injury risk is elevated. Current data do not support expectations of meaningful ergogenic improvements in vitamin D-replete athletes.

5. Conclusions

This review highlights the multifaceted role of vitamin D in sports. Deficiency remains common in athletic populations and is associated with impaired performance, increased injury risk and higher incidence of stress fractures. Supplementation effectively improves serum 25(OH)D levels and provides the greatest benefits in athletes with low baseline status.

Improvements in muscle strength and power are most evident in deficient individuals, whereas evidence for endurance enhancement is inconsistent. Positive effects on bone health, particularly in reducing stress fractures, are better established. Evidence for immune benefits is less consistent, with current analyses not confirming reliable protection against respiratory infections.

Vitamin D should therefore be regarded as essential for maintaining musculoskeletal health and reducing injury risk. Supplementation is most justified in cases of deficiency, whereas routine use in vitamin D-replete athletes offers limited performance benefits.

Disclosure

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