QUALITY IN SPORT
eISSN 2450-3118 · Open Access · Peer-reviewed
apcz.umk.pl/QS Nicolaus Copernicus University in Toruń

ROGIŃSKI, Krzysztof, OSSOWSKA, Dominika, ROGIŃSKI, Miłosz, DRĄŻKOWSKI, Kacper, KACZMARKIEWICZ, Mikołaj, BULKOWSKI, Jakub, SERAFIN, Jakub, KUJAWA, Julia, TETŁAK, Zofia and ROGIŃSKA, Karolina. Vitamin D Deficiency, Physical Activity and Musculoskeletal Health: A Narrative Review. Quality in Sport. 2026;74:75404. https://doi.org/10.12775/QS.2026.74.75404

ARTICLE TIMELINE
Received: 17.08.2026. Accepted: 12.09.2026. Published: 21.09.2026.

The journal has been awarded 20 points in the parametric evaluation by the Polish Ministry of Higher Education and Science (Annex to the announcement of 05.01.2024, No. 32553). Unique Journal Identifier: 201398. Scientific disciplines assigned: Economics and Finance (Field of Social Sciences); Management and Quality Sciences (Field of Social Sciences).
Punkty Ministerialne z 2019 – aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych).

Vitamin D Deficiency, Physical Activity and Musculoskeletal Health: A Narrative Review

Krzysztof Rogiński, ORCID https://orcid.org/0009-0003-9820-2443
krzysztof.roginski140@gmail.com,
Collegium Medicum im Ludwika Rydygiera w Bydgoszczy Uniwersytetu Mikołaja Kopernika w Toruniu, 85-067 Bydgoszcz, Poland

Dominika Ossowska https://orcid.org/0009-0001-7196-1277
dominikado123@gmail.com
Hospital named after Dr. Jadwiga Obodzińska – Król, 82-200 Malbork, Poland

Miłosz Rogiński, ORCID https://orcid.org/0009-0007-1863-1416
rogin078@gmail.com
Medical University of Gdańsk, 80-210 Gdańsk, Poland

Kacper Drążkowski ORCID https://orcid.org/0009-0004-8651-8333
kacper.drazkowski@gmail.com
Uniwersytet Technologiczno-Humanistyczny im. Kazimierza Pułaskiego w Radomiu: 26-600 Radom, Mazovia, Poland

Mikołaj Kaczmarkiewicz, ORCID https://orcid.org/0009-0000-3098-9217
kaczmarkiewiczmikolaj@gmail.com
Medical University of Gdańsk, 80-210 Gdańsk, Poland

Jakub Bulkowski, ORCID https://orcid.org/0009-0000-2019-2650
jakubbulkowski2001@gmail.com
Collegium Medicum im Ludwika Rydygiera w Bydgoszczy Uniwersytetu Mikołaja Kopernika w Toruniu, 85-067 Bydgoszcz, Poland

Jakub Serafin, ORCID https://orcid.org/0009-0001-7626-100X
kubaser4@gmail.com
Uniwersytet Technologiczno-Humanistyczny im. Kazimierza Pułaskiego w Radomiu: 26-600 Radom, Mazovia, Poland

Julia Kujawa, ORCID https://orcid.org/0009-0003-2502-8552
jxkujawa@gmail.com
Szpital św. Wincentego a Paulo, Wójta Radtkiego 1, 81-348, Gdynia, Poland

Zofia Tetłak, ORCID https://orcid.org/0009-0003-9981-7490
zofia.tetlak@gmail.com
Uniwersytet Technologiczno-Humanistyczny im. Kazimierza Pułaskiego w Radomiu: 26-600 Radom, Mazovia, Poland

Karolina Rogińska, ORCID https://orcid.org/0009-0009-6497-3980
kroginska09@gmail.com
Poznań University of Medical Sciences, 61-701 Poznań, Poland

Corresponding Author
Krzysztof Rogiński, E-mail krzysztof.roginski140@gmail.com

Abstract

Background: Vitamin D is a steroid hormone precursor involved in calcium-phosphate homeostasis, skeletal mineralization and several biological processes relevant to muscle tissue. In sport and physically active populations, vitamin D status is discussed in relation to training location, season, sunlight exposure, muscle strength, recovery, stress fractures and injury prevention. However, the current evidence is heterogeneous, and the effect of supplementation on performance is not uniform across populations.

Aim: The aim of this narrative review was to synthesize open-access PubMed-indexed evidence from 2017-2026 concerning vitamin D deficiency, physical activity and musculoskeletal health, with particular attention to athletes, exercise performance, muscle function, bone health and supplementation strategies.

Materials and Methods: A narrative literature review was prepared using articles published from 2017 to 2026 and indexed in PubMed or available through PubMed Central. The included literature comprised narrative reviews, systematic reviews, meta-analyses, randomized controlled trials, observational studies, and mechanistic studies relevant to vitamin D metabolism, deficiency, physical activity, muscle function, athletic performance and musculoskeletal injury.

Results: The analyzed literature consistently shows that vitamin D deficiency is common worldwide and may be particularly relevant in groups with limited sun exposure, indoor training, winter season training, obesity, older age, or increased skeletal loading. Mechanistic and clinical studies support a biological role of vitamin D in muscle function, regeneration and bone metabolism. In athletes, low 25-hydroxyvitamin D concentration is frequently reported and may be associated with impaired musculoskeletal health, but supplementation does not consistently improve performance when baseline status is adequate. Meta-analyses indicate that outdoor physical activity is more strongly associated with increased 25-hydroxyvitamin D concentration than indoor exercise, suggesting that sunlight exposure is a key modifier.

Conclusions: Vitamin D deficiency should be considered a modifiable factor relevant to musculoskeletal health in physically active individuals and athletes. The strongest practical rationale for screening and supplementation applies to deficient individuals, athletes training indoors or during low-sunlight seasons, older adults, and people at risk of bone or muscle impairment. Current evidence supports individualized prevention rather than indiscriminate high-dose supplementation for all athletes.

Keywords: vitamin D deficiency; 25-hydroxyvitamin D; physical activity; musculoskeletal health; athletes; supplementation; stress fractures.

1. Introduction

Vitamin D deficiency remains one of the most widely discussed nutritional and endocrine problems in contemporary public health and sports medicine. It is clinically important because vitamin D participates in calcium and phosphate regulation, skeletal mineralization and neuromuscular function. At the same time, it is conceptually difficult because the interpretation of serum 25-hydroxyvitamin D [25(OH)D] is affected by season, latitude, skin pigmentation, adiposity, dietary intake, sunlight exposure, supplementation and analytical variation. A global update described vitamin D deficiency as a continuing worldwide problem, while also emphasizing that prevalence estimates depend strongly on the cut-off used to define deficiency or insufficiency [1]. Contemporary reviews of vitamin D sources, metabolism and deficiency show that the same nutrient can be discussed as a dietary factor, a sunlight-dependent prohormone and a clinical biomarker [2].

The musculoskeletal focus of this review is justified by two overlapping lines of evidence. First, vitamin D has a well-established relationship with bone mineral metabolism, and deficiency is relevant to osteomalacia, reduced bone health and stress fracture risk. Reviews in sport have therefore considered vitamin D as a potentially modifiable factor in stress fracture prevention and therapeutic management [30,37]. Second, experimental and clinical literature has increasingly examined vitamin D in relation to skeletal muscle, including muscle strength, satellite cell function, mitochondrial activity, recovery after exercise-induced muscle damage and age-related sarcopenia [9-12,19-21].

A simple interpretation that higher vitamin D always improves athletic performance would not be supported by the literature. Several athlete-focused reviews and meta-analyses show that supplementation reliably increases serum 25(OH)D in deficient or insufficient individuals, but the translation into strength, power, endurance, recovery or injury reduction is inconsistent [31-35]. This inconsistency is not a contradiction in the evidence; it reflects differences in baseline status, intervention dose, duration, training environment, sport type, outcome measure and season. For that reason, a narrative synthesis is useful because it can integrate mechanistic plausibility, clinical observations and randomized intervention trials without reducing the question to a single pooled estimate.

The aim of this narrative review was to PubMed and PubMed Central literature published from 2017 to 2026 on vitamin D deficiency, physical activity and musculoskeletal health. Particular attention was given to athletes, soccer players, older adults, schoolchildren, postmenopausal women, exercise interventions, muscle function, bone health, stress fractures and supplementation strategies. The practical goal was to identify where the evidence is strong enough for reasonable sports medicine recommendations and where caution is necessary.

2. Research materials and methods

2.1. Participants

This was a narrative review; therefore, no original participants were recruited and no direct clinical intervention was performed. The populations represented in the included literature were diverse and included healthy adults, overweight or obese adults, older adults, schoolchildren, postmenopausal women, professional athletes, collegiate athletes, elite athletes, soccer players, rowers and other trained sport participants [13,18-23,24-43].

The included evidence also contained experimental and mechanistic literature on skeletal muscle repair and regeneration, including animal and cell-model studies. These studies were used only to support biological plausibility and were not treated as direct evidence of performance improvement in athletes [10-12].

The athlete populations were especially relevant because they represent individuals exposed to high training loads, repetitive mechanical stress and sport-specific injury risk. However, the review also included non-athlete populations because the relationship between vitamin D, muscle function and physical activity cannot be understood only from elite sport. Older adults and children provide useful evidence on strength, functional performance and long-term supplementation, while postmenopausal women and overweight adults provide evidence on combined interventions with exercise and vitamin D [18-23].

2.2. Procedure / Test protocol / Measure / Instruments

The literature was organized around the following domains: vitamin D metabolism and deficiency, epidemiology and risk factors, physical activity and sunlight exposure, skeletal muscle function and regeneration, bone health and stress fractures, athlete monitoring, performance outcomes, and supplementation safety.

Across the included studies, vitamin D status was most commonly evaluated by serum 25(OH)D concentration. This biomarker was discussed in relation to season, sun exposure, supplementation, training location and clinical thresholds. The review did not impose one universal cut-off for deficiency because several papers highlight that definitions vary between guidelines and scientific communities [1-4,8].

Outcome measures in the analyzed studies included serum 25(OH)D concentration, muscle strength, muscle power, grip strength, explosive leg power, cardiorespiratory fitness, aerobic capacity, sprint speed, VO2max, physical function tests, body composition, bone resorption markers, stress fracture occurrence, musculoskeletal injury indicators and biochemical markers of recovery or hormonal status [16-23,32-43].

2.3. Data collection and analysis / Statistical analysis

The review was based on publications identified as relevant to the topic of vitamin D deficiency, physical activity and musculoskeletal health. The final set included narrative reviews, systematic reviews, meta-analyses, randomized controlled trials, observational studies and mechanistic studies. Evidence was extracted qualitatively and synthesized thematically rather than by performing a new meta-analysis.

The synthesis prioritized biological plausibility, consistency across study designs, applicability to sport and clinical relevance. Because the included studies varied substantially in populations, supplementation protocols, baseline vitamin D status and performance outcomes, statistical pooling was not performed in this manuscript. Conclusions were formulated conservatively, especially when evidence came from observational associations or small intervention trials.

2.3.1. Statistical Software

No new statistical analysis was performed for this narrative review. The reviewed studies used a range of statistical methods appropriate to their designs, including meta-analytic pooling, between-group comparisons, regression analyses and descriptive statistics. Because no primary dataset was created, no statistical software was required for the present manuscript.

2.3.2. AI

In preparing this work, the author(s) used ChatGPT for the purpose of organization of the text, language editing and consistency of formatting with the target review structure. After using this tool/service, the author(s) have reviewed and edited the content as needed and accept full responsibility for the substantive content of the publication.

2.3.3. Statistical Methods

The manuscript used descriptive and thematic synthesis. No p-values, confidence intervals or pooled effect sizes were calculated by the author. Numerical findings reported from individual studies or meta-analyses were interpreted according to the original publications, with attention to baseline vitamin D status, intervention setting and study limitations.

3. Research results

3.1. Vitamin D metabolism, sources and definitions of deficiency

Vitamin D is obtained from cutaneous synthesis under ultraviolet B exposure and from dietary or supplemental sources. It is hydroxylated in the liver to 25(OH)D and then converted primarily in the kidney to the active hormonal form, 1,25-dihydroxyvitamin D. The circulating 25(OH)D concentration is the most commonly used clinical marker of vitamin D status because it reflects both endogenous synthesis and exogenous intake [2].

The clinical interpretation of vitamin D status is not completely uniform. Reviews of deficiency emphasize that different organizations use different thresholds for deficiency, insufficiency and sufficiency [1,8]. This matters for sport because an athlete classified as insufficient under one threshold may be classified as adequate under another. It also affects prevalence estimates, intervention eligibility and the interpretation of performance studies.

Polish recommendations updated in 2023 provide a useful regional reference for Central and Eastern Europe, where winter sunlight exposure is limited and seasonal decreases in 25(OH)D are expected [3]. A parallel review on supplementing vitamin D in different patient groups stresses that prevention and treatment should account for age, body weight, baseline status, comorbidities and risk category rather than using the same dose for every individual [4].

Safety is also part of definition and dosing. Vitamin D toxicity is uncommon but clinically important, especially when very high doses are used without monitoring. The clinical perspective on toxicity describes hypercalcemia-related manifestations and emphasizes that excessive, unsupervised supplementation can be harmful [5]. Therefore, the sports medicine question is not whether vitamin D is important, but how to maintain adequate status without unnecessary testing, exaggerated claims or unsafe dosing.

3.2. Epidemiology and determinants of deficiency

The global literature shows that low vitamin D status is common across many regions and demographic groups [1]. Major determinants include limited sunlight exposure, winter season, high latitude, darker skin pigmentation, aging, adiposity, low dietary intake, covering clothing and chronic disease. Athletes share several of these determinants with the general population, but sport adds specific circumstances: indoor facilities, early-morning or evening training, travel across latitudes, competition schedules and use of sunscreen or clothing that reduces ultraviolet exposure [24-29].

The fact that athletes are physically active does not automatically protect them from deficiency. Reviews focused on athletes describe vitamin D insufficiency among competitors in different sports and emphasize that risk depends strongly on training environment and season [24-28]. Indoor athletes and athletes training during winter are especially likely to have inadequate 25(OH)D concentration, while outdoor athletes may still be at risk if sun exposure is insufficient or if dietary intake is low.

The concept of personalized vitamin D prevention is increasingly emphasized. Precision-nutrition approaches argue that baseline status, genetic factors, body composition, sun behavior and lifestyle should influence supplementation plans rather than relying on one universal strategy [7]. This approach is compatible with sports medicine, where athletes differ in body mass, training periodization, travel, skin exposure, competition calendar and injury history.

3.3. Biological links with muscle function and repair

Vitamin D has a plausible biological relationship with skeletal muscle. Recent reviews on muscle health discuss associations between vitamin D and muscle strength, mitochondrial function, neuromuscular performance and metabolic regulation [9]. These mechanisms do not prove that supplementation improves performance in every person, but they explain why deficiency may be relevant when muscle function is already compromised.

Experimental literature on skeletal muscle repair and regeneration suggests that vitamin D signaling may participate in repair after injury or exercise-related muscle damage. The systematic review by Agoncillo and colleagues summarized animal and human evidence and concluded that vitamin D may influence muscle repair pathways, although the translation from models to clinical sport remains incomplete [10]. A separate review on recovery after muscular damage following exercise emphasized the possible role of vitamin D in inflammation, oxidative stress and repair processes after intense exercise [11].

Satellite cells are central to skeletal muscle regeneration. The systematic review on vitamin D and satellite cells found that vitamin D-related signaling may influence satellite cell activity in vivo, but the available literature is heterogeneous and many studies are preclinical [12]. In practical terms, these studies support a biological rationale for maintaining sufficiency, but they do not justify assuming that high-dose supplementation will accelerate recovery in athletes who already have adequate status.

The distinction between correcting deficiency and enhancing performance is essential. Deficiency may impair normal muscle physiology, while supplementation beyond sufficiency may not create additional benefits. This distinction explains why observational studies often show associations between low vitamin D and worse muscle outcomes, whereas randomized trials in mixed or sufficient populations can show weak or inconsistent effects [19-21,32-35].

3.4. Physical activity, outdoor exposure and vitamin D status

Physical activity and vitamin D are strongly connected in public discussion, but the relationship is partly confounded by outdoor time. The 2024 systematic review and meta-analysis by Khan and colleagues found that physical activity interventions increased serum 25(OH)D overall, but the effect was concentrated in outdoor interventions; indoor activity did not show the same independent effect [13]. This finding is important because it suggests that sunlight exposure rather than muscular work itself is the main driver of increased vitamin D status in many exercise studies.

The 2026 meta-analysis comparing location of physical activity reached a similar conclusion. Outdoor physical activity was more effective for improving vitamin D status, whereas indoor exercise showed negligible effect compared with controls [14]. For sports medicine, this means that coaches and clinicians should not assume that training volume alone protects vitamin D status. The relevant variable is often where and when training occurs.

The interaction between vitamin D and physical activity may also be bidirectional. The review on vitamin D and physical activity as co-modifiers of muscle health and metabolism argues that exercise and vitamin D may interact through muscle metabolism, insulin sensitivity, inflammation and mitochondrial pathways [15]. This does not mean that the two interventions are interchangeable. Instead, it supports an integrated lifestyle model in which adequate vitamin D status may help preserve musculoskeletal function while exercise improves metabolic and functional outcomes.

Meta-analyses examining vitamin D supplementation combined with exercise in adults suggest that combined interventions may affect metabolic outcomes and 25(OH)D concentration, especially in overweight or obese individuals [16,17]. A pilot randomized trial in overweight or obese older adults with vitamin D deficiency found that supplementation and exercise did not improve all physical and metabolic outcomes, illustrating again that effects depend on study design, sample size, baseline status and outcome selection [18].

3.5. Evidence in older adults, schoolchildren and postmenopausal women

Older adults are highly relevant because vitamin D deficiency, sarcopenia, falls and reduced physical performance frequently coexist. In a randomized controlled trial, vitamin D supplementation was studied in relation to muscle power, strength and physical performance in older adults [19]. Observational evidence from community-dwelling older adults showed that deficiency was associated with impaired muscle strength and physical performance [20]. These findings are clinically important because reduced strength and power are directly linked to independence, mobility and fall risk.

However, the evidence for supplementation in sarcopenia is not uniformly strong. A 2024 systematic review and meta-analysis on vitamin D supplementation and sarcopenia parameters in older people summarized trials with heterogeneous populations and outcomes [21]. The overall message is cautious: supplementation may be most rational in deficient individuals, but it should not replace resistance training, adequate protein intake and comprehensive geriatric care.

Evidence from children and adolescents also contributes to the topic. In Mongolian schoolchildren, long-term weekly oral vitamin D supplementation was assessed for secondary outcomes including muscle strength and exercise capacity [22]. Such studies are valuable because they test whether improving vitamin D status translates into objective physical outcomes during growth. Nevertheless, the findings have to be interpreted in context, including baseline deficiency prevalence, school environment, growth stage and outcome sensitivity.

In postmenopausal women with overweight or obesity, vitamin D3 supplementation combined with aerobic water-based training was reported to enhance some physical fitness indices [23]. This population differs from athletes, but it illustrates a clinically relevant principle: vitamin D supplementation may be more meaningful when combined with structured exercise and when participants have risk factors for impaired musculoskeletal function.

3.6. Vitamin D in athletes: prevalence, monitoring and practical relevance

Athlete-focused reviews consistently identify vitamin D as a relevant but not isolated factor in performance and injury prevention. The review by de la Puente Yague and colleagues described current concepts and trends in vitamin D and athletic performance, including the potential influence on muscle function, bone health and immune processes [24]. The narrative review by Ksiazek and colleagues focused more directly on skeletal muscle function and athletic performance, concluding that vitamin D status may matter particularly when deficiency is present [25].

Owens, Allison and Close emphasized that vitamin D poses new challenges for athletes because sport-specific routines can create unexpected deficiency risk despite high fitness [26]. Yoon and colleagues similarly focused on physical performance and musculoskeletal injuries, presenting vitamin D as a field-relevant factor for athletes but not as a guaranteed ergogenic aid [27].

The review by Ip and colleagues is especially practical because it integrates laboratory, clinical and field perspectives. It highlights the need to connect measured 25(OH)D concentration with symptoms, injury risk, training environment and clinical decision-making rather than treating the laboratory value in isolation [28]. This approach is useful in team sports, where screening, supplementation and follow-up may need to be implemented at squad level.

An editorial and review literature on vitamin D and sport performance also argues for attention to sufficiency, but the evidence should be interpreted carefully [29]. If an athlete is deficient, correction is biologically and clinically reasonable. If an athlete is already sufficient, the expectation of additional performance gains is weaker and should not be exaggerated.

3.7. Athletic performance, strength and power

Performance outcomes are the most attractive but also the most uncertain part of the vitamin D literature. Systematic reviews in elite athletes suggest that supplementation can increase serum 25(OH)D and may benefit selected performance domains, yet the magnitude and consistency of effects vary [31]. This is expected because performance is multifactorial and depends on training, genetics, recovery, nutrition, sleep, psychological state and technical skill.

Meta-analyses focused on strength and power in athletes provide a more precise interpretation. Han and colleagues examined vitamin D3 supplementation in randomized controlled trials and analyzed serum 25(OH)D and strength outcomes in athletes [32]. Sist and colleagues assessed maximal strength and power and found that evidence remains heterogeneous [33]. Zhang and colleagues analyzed upper and lower limb strength and muscle power and similarly highlighted variability between trials [34]. These meta-analyses are useful because they prevent overreliance on individual positive studies.

The review by Wicinski and colleagues on physical efficiency and exercise performance also supports a cautious interpretation: vitamin D may be relevant to exercise capacity, but it is not a simple performance supplement for all athletes [35]. The most defensible conclusion is that deficiency correction is part of musculoskeletal health management, while performance enhancement in already sufficient athletes remains uncertain.

The practical consequence is that vitamin D should be framed as a health-supportive intervention rather than a primary ergogenic strategy. Coaches and clinicians may reasonably monitor athletes at risk, correct deficiency and consider seasonally appropriate supplementation, but they should avoid presenting vitamin D as a substitute for evidence-based training, load management, sleep, energy availability and recovery planning.

3.8. Bone health, stress fractures and musculoskeletal injuries

The skeletal role of vitamin D is better established than many proposed extraskeletal effects. Vitamin D supports calcium and phosphate homeostasis, and deficiency can impair bone mineralization. In sport, this is particularly relevant to stress fractures, where repetitive loading, low energy availability, menstrual dysfunction, low bone mineral density and insufficient vitamin D may interact [30].

The narrative review on vitamin D and stress fractures in sport summarized preventive and therapeutic measures and supports attention to vitamin D status in athletes at risk of bone stress injury [30]. This does not mean vitamin D is the only cause of stress fracture. It should be integrated into a broader risk assessment that includes training load progression, biomechanics, nutrition, sex-specific factors and previous injury.

Observational evidence in collegiate athletes also supports clinical attention. Millward and colleagues reported an association between serum vitamin D levels and stress fractures in collegiate athletes [37]. Such observational studies cannot prove causality, but they are relevant in sports medicine because stress fractures are consequential, recurrent and potentially preventable.

Vitamin D practice patterns in National Collegiate Athletic Association Division I athletic programs show that screening and supplementation are already used in sports settings, but approaches vary [36]. Variation in practice can reflect uncertainty in the evidence, differences in athlete risk profiles and institutional policies. It also indicates the need for practical protocols that distinguish deficiency correction from unnecessary supplementation.

3.9. High-dose supplementation and sport-specific intervention studies

High-dose supplementation has been studied in elite athletes, but interpretation requires caution. Owens and colleagues assessed high-dose vitamin D supplementation in elite athletes and showed that supplementation can correct status, yet performance changes should not be assumed without context [38]. High-dose strategies may be useful for rapid correction under supervision, but they should not become routine without monitoring because toxicity and inappropriate dosing are real clinical concerns [5].

Sport-specific trials provide useful but narrow evidence. Mielgo-Ayuso and colleagues studied vitamin D supplementation in elite male traditional rowers and evaluated hematological values and muscle recovery [39]. This type of study is valuable because it examines a real training population, but the results may not generalize to all athletes because rowing has specific energy demands, training environments and seasonal patterns.

Soccer has a particularly rich body of evidence in the included bibliography. Michalczyk and colleagues evaluated sunlight and oral vitamin D3 supplementation in elite soccer players, including serum 25(OH)D concentration and exercise performance [40]. Jastrzebska and colleagues examined whether vitamin D supplementation could improve aerobic capacity in well-trained youth soccer players [41]. Another one-year study in young soccer players considered seasonal 25(OH)D changes, bone resorption markers, performance and the effect of lockdown conditions [42]. Brzezinski and colleagues reported correlations between the positive effect of vitamin D supplementation and physical performance in young male soccer players [43].

Taken together, soccer studies illustrate three practical points. First, seasonal fluctuation is important and can be large in young athletes [42]. Second, sunlight exposure and supplementation can both influence serum 25(OH)D concentration [40]. Third, performance outcomes are not uniform and should be interpreted as potentially dependent on baseline deficiency, age, training load and intervention duration [41,43].

3.10. Supplementation strategies and safety

Supplementation is most clearly justified when deficiency is present or when risk is high. Polish guidelines and broader supplementation reviews emphasize prevention and treatment according to age, risk group, body weight and clinical context [3,4]. For athletes, the same logic should be applied: indoor athletes, winter-season athletes, athletes with previous stress fracture, athletes with low sun exposure and athletes with symptoms or risk factors may require targeted assessment.

The evidence does not support indiscriminate high-dose supplementation for all physically active people. Personalized supplementation frameworks argue that supplementation plans should account for baseline status, lifestyle, sunlight exposure and individual risk [7]. This is consistent with current controversies in vitamin D research, where routine testing and universal supplementation are debated for low-risk healthy populations [8].

Safety must remain visible in sports practice. Vitamin D toxicity is usually associated with excessive intake rather than sun exposure, and it can produce hypercalcemia and related symptoms [5]. Because athletes may use multiple supplements simultaneously, education is necessary to prevent accidental high intake from overlapping products.

In practical terms, supplementation can be considered as a three-step process. First, identify risk: season, latitude, indoor training, prior stress fracture, dietary restriction, obesity, low sun exposure or clinical symptoms. Second, measure serum 25(OH)D when clinically justified or according to team protocol. Third, correct deficiency using evidence-based doses and recheck when appropriate. This approach avoids both neglect of deficiency and uncritical supplement use.

3.11. Synthesis of evidence quality and research gaps

The included literature provides strong evidence that vitamin D is biologically relevant to bone health and plausible evidence that deficiency may impair muscle function. It also provides consistent evidence that serum 25(OH)D can be raised by supplementation and outdoor sunlight exposure. However, the evidence is less consistent for direct improvements in athletic performance, especially among already sufficient athletes [31-35].

Several gaps remain. Many intervention trials have small samples, short durations, mixed baseline vitamin D status and heterogeneous outcomes. Some studies measure serum changes without sufficiently powered performance outcomes. Other studies examine performance outcomes but do not control fully for training load, sunlight exposure, diet, energy availability or seasonal timing. These limitations explain why meta-analyses can detect biochemical effects more consistently than sport performance effects [32-35].

Another gap concerns injury prevention. The association between low vitamin D and stress fractures is clinically plausible and supported by observational evidence [30,37], but prospective trials proving that supplementation reduces injury incidence in athletes are more difficult to conduct. Such trials require large samples, careful control of training load and long follow-up. Until then, vitamin D should be considered one component of bone stress injury prevention, not a standalone solution.

Finally, future research should distinguish health restoration from performance enhancement. Trials should stratify athletes by baseline 25(OH)D concentration, include sufficient follow-up, account for season and outdoor exposure, and use sport-specific performance endpoints. This would help identify which athletes benefit most and prevent overgeneralization from deficient clinical populations to already sufficient elite performers.

Finally, future studies should include safety and adherence. Supplementation trials often focus on whether 25(OH)D increases, but real-world sport requires knowledge about adherence, total supplement burden, side effects, cost, athlete beliefs and monitoring frequency. This is especially important for high-dose protocols, which may be efficient for correction but require clinical oversight [5,38].

Research should also avoid overbroad performance outcomes. Maximal strength, repeated sprint ability, endurance capacity, jump power, recovery markers and injury incidence are not interchangeable. A supplement may affect one outcome and not another. Athlete studies should therefore choose endpoints that match the sport and the proposed mechanism. For example, a soccer study might include sprint, jump, aerobic capacity and injury surveillance, whereas a rowing study may focus on endurance, recovery and hematological markers [39-43].

Another research priority is standardizing exposure assessment. Studies should report not only supplementation dose and baseline 25(OH)D, but also training location, sunlight exposure, latitude, season, skin coverage, sunscreen use and diet. Without these variables, it is difficult to know whether changes in vitamin D status are caused by tablets, sun exposure, training camps or lifestyle changes [13,14,40,42].

Future research for a sports-oriented journal should aim to separate three questions that are often mixed together. The first question is whether vitamin D deficiency is common in a defined athlete group. The second is whether deficiency is associated with injury or lower performance. The third is whether supplementation improves clinically or sport-relevant outcomes. Each question requires a different study design. Prevalence studies need representative samples and seasonal sampling. Association studies need adjustment for training load, sex, body composition and sun exposure. Intervention studies need baseline deficiency stratification and sport-specific endpoints [24-28,31-37].

3.14. Implications for future Quality in Sport research

The fifth step is outcome interpretation. If an athlete reports improved performance after supplementation, this should be interpreted cautiously because performance changes can result from training adaptation, recovery, psychological expectations, season progression, injury resolution or other nutritional changes. The most defensible outcome of supplementation is correction of deficiency. Performance improvements may occur in some deficient athletes, but they should be treated as possible secondary outcomes rather than guaranteed effects [32-35,38].

The fourth step is follow-up. Measuring 25(OH)D after intervention may be useful in high-risk athletes or after high-dose correction. It can confirm response, detect non-adherence and prevent excessive levels. In team settings, follow-up also helps evaluate whether the protocol is practical. For example, if many athletes remain low after winter supplementation, the program may need to address adherence, dose, timing, or hidden risk factors such as low energy availability or malabsorption [3-5,36].

The third step is intervention. For deficiency, supplementation should follow established guidance and account for body mass, baseline concentration and clinical risk [3,4]. For athletes with borderline status and low-risk profiles, moderate supplementation or lifestyle modification may be sufficient. For athletes with recurrent stress injuries or severe deficiency, supervised correction and follow-up are more appropriate. Importantly, supplementation should be integrated with adequate energy availability, calcium intake, protein intake, progressive loading and recovery, because vitamin D alone cannot correct a poor training or nutrition environment [30,37].

The second step is laboratory assessment when the risk profile justifies it. Serum 25(OH)D remains the central marker, but it should be interpreted with knowledge of timing. A winter measurement and a late-summer measurement may represent different biological contexts. If an athlete is assessed after a sunny training camp, the result may not represent the competitive season. If assessment occurs during lockdown, indoor rehabilitation or injury-related absence from outdoor training, status may decline compared with normal conditions [40,42].

Based on the reviewed literature, a practical pathway can be proposed for active populations. The first step is contextual screening, not immediate supplementation. Contextual screening includes season, latitude, type of sport, indoor versus outdoor training, clothing habits, travel, dietary restriction, supplement use, previous deficiency, previous stress fracture and symptoms such as unexplained muscle weakness or bone pain. This step can identify athletes who need further assessment without converting vitamin D management into routine testing for everyone [8,13,14,28].

3.13. A proposed management pathway for vitamin D in active populations

From the perspective of athlete education, the key message should be balanced. Athletes should understand that deficiency may reduce the biological capacity for optimal musculoskeletal adaptation, yet supraphysiological supplementation is not an evidence-based shortcut to better results. Such communication may reduce both neglect and overuse. It also aligns with the pattern seen in meta-analyses: biochemical correction is common, whereas consistent performance improvement is not guaranteed [31-35].

The role of the coach is different from the role of the physician or dietitian. Coaches can identify training-environment risks and encourage referral, but they should not prescribe high-dose vitamin D. Sports physicians and dietitians can evaluate blood results, comorbidities, total supplement intake and contraindications. This division of responsibilities is important because vitamin D is often perceived as harmless, even though toxicity can occur with inappropriate dosing [5].

For low-risk athletes, education may be sufficient. This includes information on dietary sources, safe sunlight exposure and avoiding unmonitored high-dose supplementation. For moderate-risk athletes, seasonal supplementation or targeted testing may be considered according to local guidelines. For high-risk athletes, serum 25(OH)D testing and supervised correction are more defensible because the clinical consequences of untreated deficiency may be greater [3-5,28,30].

A reasonable sports-medicine protocol would begin with risk classification. Low-risk athletes include those with regular outdoor exposure during high-ultraviolet months, varied diet, no history of bone stress injury and no clinical risk factors. Moderate-risk athletes include those training indoors, during winter, at high latitude or with limited dietary intake. High-risk athletes include those with stress fractures, recurrent musculoskeletal injury, low energy availability, eating disorders, malabsorption, obesity, dark skin pigmentation in low-sunlight climates, or previous documented deficiency [3,4,26,30,37].

Outdoor athletes require a more nuanced assessment. Soccer, running and rowing may involve outdoor training, but outdoor status is not enough to guarantee sufficiency. Training may occur early in the morning or late in the evening, athletes may use covering clothing, and the effective ultraviolet B dose may be low during winter or at high latitudes. This explains why soccer studies still report seasonal changes and supplementation effects despite outdoor training exposure [40-43].

The reviewed evidence can be translated into several practical sports settings. In indoor sports such as basketball, volleyball, gymnastics, combat sports and swimming, high training volume does not automatically increase ultraviolet exposure. These athletes may spend most training hours inside and may travel between indoor venues during winter. For them, vitamin D risk assessment should focus less on total training hours and more on daylight exposure, season and dietary intake [24,26,28,36].

3.12. Practical interpretation for sports settings

The fourth recommendation is to avoid overclaiming performance effects. The current evidence supports vitamin D sufficiency as a health target, but systematic reviews and meta-analyses do not justify presenting supplementation as a universal performance enhancer [31-35]. A scientifically responsible message is that correction of deficiency may remove a barrier to normal adaptation, while extra supplementation in sufficient athletes has uncertain benefit.

The third recommendation is to integrate vitamin D with broader musculoskeletal care. Stress fracture prevention also requires progressive training load, adequate energy and calcium availability, menstrual health assessment when relevant, recovery management, footwear and biomechanical evaluation [30,37]. Muscle performance requires structured training, sleep, protein and energy availability in addition to micronutrient sufficiency [9-12,15].

The second recommendation is to correct deficiency but avoid indiscriminate high-dose use. Supervised supplementation can be effective for raising 25(OH)D, including in athletes, but toxicity literature and supplementation controversies support caution [5,8,38]. Dose selection should follow clinical guidelines and should consider total intake from all supplements.

The first practical recommendation is to prioritize risk-based assessment. Testing or supplementation is most defensible in athletes and active individuals with limited sun exposure, indoor training, winter training, high latitude residence, prior stress fracture, recurrent musculoskeletal injury, obesity, dietary restriction, malabsorption or previous documented deficiency [3,4,26,28,30,37].

3.17. Summary of practical recommendations emerging from the review

A Quality in Sport perspective is therefore useful because it connects health, movement and performance. The journal's broad sport-and-health context allows vitamin D to be discussed not only as a biochemical marker but also as an element of participation in physical activity, injury prevention and long-term musculoskeletal quality of life. Such framing avoids the narrow question of whether vitamin D is an ergogenic aid and instead asks how adequate status contributes to safe, sustainable physical activity.

For older adults, the central outcome is not competition performance but independence, fall prevention, walking ability and capacity to perform daily activities. For children, the question is healthy growth and functional development. For postmenopausal women and overweight adults, combined exercise and supplementation may support musculoskeletal and metabolic goals, but the effect depends on adherence and baseline deficiency. These groups reinforce the same principle observed in athletes: vitamin D is most meaningful as part of an integrated intervention, not as an isolated solution [18,21-23].

Although the sport-specific literature is central to this manuscript, the topic also has broader public health relevance. Physical inactivity, aging, obesity and limited outdoor exposure are common in the general population. Vitamin D deficiency may therefore interact with reduced muscle strength and poor physical function outside elite sport. Studies in older adults, schoolchildren, postmenopausal women and overweight populations show that the vitamin D-exercise relationship is clinically relevant across the lifespan [16-23].

3.16. Public health relevance beyond elite sport

Another practical issue is that vitamin D status can become a surrogate marker of healthy behavior. Athletes with higher 25(OH)D may also have more outdoor training, better diet quality, lower adiposity or more structured recovery. Observational associations between vitamin D and performance or injury can therefore be confounded. This is why randomized trials and meta-analyses are essential, and why their mixed results should temper strong causal claims [13,19,20,32-35,37].

Laboratory thresholds should also be interpreted as clinical decision tools rather than absolute performance thresholds. The literature on deficiency controversies shows that cut-offs vary, and the evidence supporting one universal optimal level for athletic performance is not definitive [1,8]. In practice, the goal should be to prevent clinically meaningful deficiency and maintain a range compatible with bone and muscle health. Claims that athletes require very high concentrations for peak performance remain insufficiently proven.

The timing of blood sampling can strongly affect interpretation. An athlete tested after summer holidays, an outdoor training camp or a period of intense sun exposure may appear sufficient, whereas the same athlete may become insufficient during winter competition. Conversely, testing during injury rehabilitation, illness or lockdown-like conditions may identify a temporary decline that reflects reduced outdoor exposure. Longitudinal soccer studies demonstrate that seasonal and environmental changes can materially alter 25(OH)D concentrations across a training year [40,42].

Interpreting serum 25(OH)D in sport requires caution because the measurement is a marker of exposure and stores rather than a direct performance variable. A low value may indicate inadequate sunlight exposure or intake, but it may also coexist with other factors that more directly influence performance, such as low energy availability, insufficient carbohydrate intake, sleep restriction, illness, high training load or psychological stress. Therefore, a low 25(OH)D concentration should prompt a wider clinical and nutritional assessment rather than an isolated prescription [2,3,8,28].

4. Discussion

The present narrative review indicates that vitamin D deficiency is relevant to physical activity and musculoskeletal health, but the nature of this relevance is often misunderstood. The strongest evidence supports correction of deficiency for health-related reasons: bone mineralization, muscle function, physical performance in vulnerable groups and prevention of deficiency-associated impairment. The weaker and more variable evidence concerns the idea that supplementation improves sport performance in all athletes.

This distinction is central for practical sports medicine. Athletes and coaches may seek supplements that directly improve results. Vitamin D does not fit that model well. Instead, it is best understood as a permissive factor: adequate status supports normal physiology, whereas deficiency may remove the conditions needed for optimal adaptation. In a deficient athlete, correction may improve health and possibly performance-related variables. In a sufficient athlete, extra supplementation is less likely to produce measurable benefit and may only increase cost or risk.

The relationship between physical activity and vitamin D status also requires careful interpretation. People who are more physically active often spend more time outdoors, and outdoor time increases ultraviolet exposure. The meta-analytic evidence suggests that outdoor physical activity is more effective than indoor activity for improving 25(OH)D concentration [13,14]. Therefore, clinicians should avoid telling athletes that exercise itself increases vitamin D status. The more accurate statement is that outdoor training can improve vitamin D status when it meaningfully increases sun exposure, while indoor training generally cannot.

Muscle evidence is promising but incomplete. Recent reviews describe vitamin D in relation to muscle metabolism, mitochondrial function, satellite cells and repair processes [9-12,15]. These mechanisms are relevant for sport because training adaptation depends on muscle remodeling. Yet mechanistic plausibility is not the same as clinical proof. The available human studies suggest that the effect of supplementation on muscle strength and performance depends on baseline deficiency, age, intervention dose, duration and outcome measure [19-23,32-35].

The athlete literature is consistent in recommending attention to risk groups rather than universal high-dose intervention. Indoor athletes, winter-season athletes, athletes at northern latitudes, athletes with prior stress fracture and athletes with limited sun exposure are reasonable candidates for assessment [24-28,30,36,37]. Soccer studies show that seasonal changes can occur across a competitive year and that both sun exposure and supplementation may modify 25(OH)D concentration [40-43]. However, even in soccer players, performance responses are not uniform.

Safety and controversy should not be treated as minor issues. Vitamin D is widely available, inexpensive and familiar, which can create the impression that more is always better. Clinical literature on toxicity shows that excessive intake can be harmful [5]. Reviews on supplementation and deficiency controversies emphasize that definitions and recommendations differ and that routine testing or supplementation in low-risk healthy adults remains debated [4,8]. In sport, where supplement culture is strong, this caution is especially important.

From a practical perspective, the most balanced recommendation is individualized management. Athletes should receive education about dietary sources, safe sun exposure, seasonal risk and the importance of medical supervision when using high-dose supplements. Team protocols may include targeted screening before winter, during indoor seasons or after bone stress injury. Supplementation should aim to correct deficiency and maintain sufficiency, not to push levels above evidence-based targets for hypothetical performance gains.

A final point concerns communication of uncertainty. The literature contains positive, neutral and heterogeneous results, especially for performance outcomes. This should not be seen as a weakness of the topic but as a realistic feature of sports nutrition research. Biological plausibility, observational association and randomized intervention data answer different questions. A responsible review should therefore avoid strong claims that all athletes benefit from supplementation while still recognizing that deficiency is clinically relevant and correctable.

The review also supports cooperation between professionals. Physicians can evaluate laboratory results and contraindications, dietitians can assess intake and supplementation plans, physiotherapists can evaluate musculoskeletal loading and recovery, and coaches can modify training exposure and load progression. Vitamin D management becomes most useful when it is embedded within this interdisciplinary model. Isolated supplementation without attention to training load, recovery and total nutrition is unlikely to solve complex sport-related musculoskeletal problems.

In clinical practice, vitamin D assessment should be linked with the athlete's whole context. A young soccer player with winter training, low sun exposure and recurrent bone pain represents a different situation from an outdoor athlete with no symptoms and documented sufficiency. Similarly, an older adult beginning exercise after a period of inactivity may require broader nutritional and functional assessment than a trained athlete. The same biomarker can therefore lead to different decisions depending on musculoskeletal risk, age, training history and clinical presentation.

The findings also have implications for how vitamin D should be presented in academic sport education. It should be taught as a component of musculoskeletal risk management, not as a simple supplement for faster sprinting, stronger jumping or better endurance. This distinction is important because athletes often receive nutrition information from non-medical sources, advertisements or peer experiences. A careful academic message can help prevent two opposite errors: ignoring deficiency in high-risk athletes and overusing supplements in athletes who do not need them.

5. Conclusion

Vitamin D deficiency is a relevant and modifiable factor in musculoskeletal health, including in physically active individuals and athletes. The evidence is strongest for the importance of adequate vitamin D status in bone health and biologically plausible for muscle function and recovery. Low 25(OH)D concentration is common in many populations and can affect athletes, particularly those with limited sunlight exposure, indoor training, winter-season schedules or previous bone stress injury.

Physical activity should not be viewed as an independent guarantee of vitamin D sufficiency. The available meta-analytic evidence indicates that outdoor activity is more effective than indoor activity for increasing 25(OH)D, most likely through sunlight exposure. Therefore, training environment and season are important determinants of vitamin D status.

Supplementation is best justified for deficient individuals or clearly defined risk groups. It should be individualized, evidence-based and monitored when higher doses are used. Current evidence does not support indiscriminate high-dose supplementation as a universal performance-enhancing strategy for all athletes. For sport practice, the most reasonable approach is to identify deficiency risk, correct confirmed deficiency, support safe outdoor exposure and integrate vitamin D management into broader nutrition, training-load and injury-prevention programs.

Supplementary Materials

Not applicable.

Author Contributions

Conceptualization: Zosia Tetłak, Dominika Ossowska, Jakub Bulkowski
Methogology: Jakub Bulkowski, Mikołaj Kaczmarkiewicz, Jakub Serafin, Kacper Drążkowski,
Writing-rough preparation: Krzysztof Rogiński, Julia Kujawa, Miłosz Rogiński, Karolina Rogińska, Dominika Ossowska
Writing-review and editing: Miłosz Rogiński, Karolina Rogińska, Mikołaj Kaczmarkiewicz
Project administration: Jakub Serafin, Kacper Drążkowski, Krzysztof Rogiński, Zosia Tetłak, Julia Kujawa

Funding

This research received no external funding.

Institutional Review Board Statement

Not applicable. This manuscript is a narrative review and did not involve original human or animal participants.

Informed Consent Statement

Not applicable.

Data Availability Statement

No new datasets were generated or analyzed. All cited publications are available through PubMed, PubMed Central or the journal websites listed in the references.

Acknowledgments

Not applicable.

Conflicts of Interest

The author declares no conflict of interest.

Disclosure

No new original clinical data were created in this study. The manuscript is based on qualitative synthesis of data reported in the cited publications; therefore, separate data sharing is not applicable.

References

[1] Amrein K, Scherkl M, Hoffmann M, Neuwersch-Sommeregger S, Köstenberger M, Berisha AT, Martucci G, Pilz S, Malle O. Vitamin D deficiency 2.0: an update on the current status worldwide. Eur J Clin Nutr. 2020;74(11):1498-1513. doi: 10.1038/s41430-020-0558-y. PubMed: https://pubmed.ncbi.nlm.nih.gov/31959942/

PMCID: PMC7091696.

[2] Dominguez LJ, Farruggia M, Veronese N, Barbagallo M. Vitamin D Sources, Metabolism, and Deficiency: Available Compounds and Guidelines for Its Treatment. Metabolites. 2021;11(4):255. doi: 10.3390/metabo11040255.

PubMed: https://pubmed.ncbi.nlm.nih.gov/33924215/

PMCID: PMC8074587.

[3] Płudowski P, Kos-Kudła B, Walczak M, et al. Guidelines for Preventing and Treating Vitamin D Deficiency: A 2023 Update in Poland. Nutrients. 2023;15(3):695. doi: 10.3390/nu15030695.

PubMed: https://pubmed.ncbi.nlm.nih.gov/36771403/

PMCID: PMC9920487.

[4] Płudowski P. Supplementing Vitamin D in Different Patient Groups to Reduce Deficiency. Nutrients. 2023;15(17):3725. doi: 10.3390/nu15173725.

PubMed: https://pubmed.ncbi.nlm.nih.gov/37686757/

PMCID: PMC10489803.

[5] Marcinowska-Suchowierska E, Kupisz-Urbańska M, Łukaszkiewicz J, Płudowski P, Jones G. Vitamin D Toxicity-A Clinical Perspective. Front Endocrinol (Lausanne). 2018;9:550. doi: 10.3389/fendo.2018.00550.

PubMed: https://pubmed.ncbi.nlm.nih.gov/30294301/

PMCID: PMC6158375.

[6] Bouillon R, Marcocci C, Carmeliet G, Bikle D, White JH, Dawson-Hughes B, et al. Skeletal and Extraskeletal Actions of Vitamin D: Current Evidence and Outstanding Questions. Endocr Rev. 2019;40(4):1109-1151. doi: 10.1210/er.2018-00126.

PubMed: https://pubmed.ncbi.nlm.nih.gov/30321335/

PMCID: PMC6626501.

[7] Mavar M, Sorić T, Bagarić E, Sarić A, Matek Sarić M. The Power of Vitamin D: Is the Future in Precision Nutrition through Personalized Supplementation Plans? Nutrients. 2024;16(8):1176. doi: 10.3390/nu16081176. PubMed: https://pubmed.ncbi.nlm.nih.gov/38674867/

PMCID: PMC11054101.

[8] Sosa-Henríquez M, et al. Rethinking Vitamin D Deficiency: Controversies and Practical Guidance for Clinical Management. Nutrients. 2025;17(22):3573. doi: 10.3390/nu17223573. PubMed: https://pubmed.ncbi.nlm.nih.gov/41305623/

PMCID: PMC12655817.

[9] Kuwabara A, Matsumoto M, Hatamoto Y, Fujita S. Vitamin D and muscle health: insights from recent studies. Curr Opin Clin Nutr Metab Care. 2024;27(6):499-506. doi: 10.1097/MCO.0000000000001071.

PubMed: https://pubmed.ncbi.nlm.nih.gov/39302338/

PMCID: PMC11486990.

[10] Agoncillo M, Yu J, Gunton JE. The Role of Vitamin D in Skeletal Muscle Repair and Regeneration in Animal Models and Humans: A Systematic Review. Nutrients. 2023;15(20):4377. doi: 10.3390/nu15204377.

PubMed: https://pubmed.ncbi.nlm.nih.gov/37892452/

PMCID: PMC10609905.

[11] Caballero-García A, Córdova A, Vicente-Salar N, Pérez-Valdecantos D. Vitamin D, Its Role in Recovery after Muscular Damage Following Exercise. Nutrients. 2021;13(7):2336. doi: 10.3390/nu13072336.

PubMed: https://pubmed.ncbi.nlm.nih.gov/34371846/

PMCID: PMC8308579.

[12] Alfaqih MS, Tarawan VM, Sylviana N, Goenawan H, Lesmana R, Susianti S. Effects of Vitamin D on Satellite Cells: A Systematic Review of In Vivo Studies. Nutrients. 2022;14(21):4558. doi: 10.3390/nu14214558.

PubMed: https://pubmed.ncbi.nlm.nih.gov/36364820/

PMCID: PMC9657163.

[13] Khan SR, Claeson M, Khan A, Neale RE. The effect of physical activity on vitamin D: A systematic review and meta-analysis of intervention studies in humans. Public Health Pract (Oxf). 2024;7:100495. doi: 10.1016/j.puhip.2024.100495.

PubMed: https://pubmed.ncbi.nlm.nih.gov/38601179/

PMCID: PMC11004199.

[14] Vajdi M, Golpour-Hamedani S, Hemami RM, Hassanizadeh S, Darzi M, Askari G. The location of physical activity determines its efficacy on Vitamin D status: Evidence from a meta-analysis. J Res Med Sci. 2026;31:7. doi: 10.4103/jrms.jrms_378_24.

PubMed: https://pubmed.ncbi.nlm.nih.gov/41852786/

PMCID: PMC12994869.

[15] Jawed I, et al. Vitamin D and physical activity as co-modifiers of muscle health and metabolism. 2025.

PubMed: https://pubmed.ncbi.nlm.nih.gov/40787552/

PMCID: PMC12333755.

[16] Feng Y, Zhou W, Niu Y. Effects of vitamin D supplementation combined with exercise on glucolipid metabolism in adults: A meta-analysis. iScience. 2025;28(9):113243. doi: 10.1016/j.isci.2025.113243.

PubMed: https://pubmed.ncbi.nlm.nih.gov/40894889/

PMCID: PMC12392328.

[17] Peng T, Zhang Z, Liang W, Zhang J. Can Vitamin D supplementation enhance the effectiveness of exercise-induced weight loss in overweight or obese adults? Evidence from integrated transcriptomic and meta-analysis. Front Nutr. 2025;12:1664960. doi: 10.3389/fnut.2025.1664960.

PubMed: https://pubmed.ncbi.nlm.nih.gov/41098796/

PMCID: PMC12519668.

[18] Mesinovic J, et al. Vitamin D supplementation and exercise for improving physical function, body composition and metabolic health in overweight or obese older adults with vitamin D deficiency: a pilot randomized, double-blind, placebo-controlled trial. Eur J Nutr. 2023. doi: 10.1007/s00394-022-03038-z.

PubMed: https://pubmed.ncbi.nlm.nih.gov/36333495/

PMCID: PMC9638202.

[19] Houston DK, et al. Vitamin D Supplementation and Muscle Power, Strength and Physical Performance in Older Adults: A Randomized Controlled Trial. Am J Clin Nutr. 2023;117(6):1086-1095.

PubMed: https://pubmed.ncbi.nlm.nih.gov/37084814/

PMCID: PMC10447505.

[20] Aspell N, Laird E, Healy M, Shannon T, Lawlor B, O'Sullivan M. Vitamin D Deficiency Is Associated With Impaired Muscle Strength And Physical Performance In Community-Dwelling Older Adults: Findings From The English Longitudinal Study Of Ageing. Clin Interv Aging. 2019;14:1751-1761. doi: 10.2147/CIA.S222143.

PubMed: https://pubmed.ncbi.nlm.nih.gov/31686797/

PMCID: PMC6800555.

[21] Widajanti N, et al. The Effect of Vitamin D Supplementation to Parameter of Sarcopenia in Elderly People: a Systematic Review and Meta-Analysis. Can Geriatr J. 2024;27(1):63-75. doi: 10.5770/cgj.27.694.

PubMed: https://pubmed.ncbi.nlm.nih.gov/38433884/

PMCID: PMC10896205.

[22] Ganmaa D, et al. Influence of vitamin D supplementation on muscle strength and exercise capacity in Mongolian schoolchildren: secondary outcomes from a randomised controlled trial. BMJ Open Sport Exerc Med. 2024.

PubMed: https://pubmed.ncbi.nlm.nih.gov/39345833/

PMCID: PMC11429264.

[23] Zaravar F, et al. Vitamin D3 supplementation enhances the effect of aerobic water-based training on physical fitness indices in obese and overweight menopausal women: A randomized controlled trial. Women's Health (Lond). 2025.

PubMed: https://pubmed.ncbi.nlm.nih.gov/40735907/

PMCID: PMC12317169.

[24] de la Puente Yagüe M, Collado Yurrita L, Ciudad Cabañas MJ, Cuadrado Cenzual MA. Role of Vitamin D in Athletes and Their Performance: Current Concepts and New Trends. Nutrients. 2020;12(2):579. doi: 10.3390/nu12020579.

https://pubmed.ncbi.nlm.nih.gov/32102188/

PMCID: PMC7071499.

[25] Książek A, Zagrodna A, Słowińska-Lisowska M. Vitamin D, Skeletal Muscle Function and Athletic Performance in Athletes-A Narrative Review. Nutrients. 2019;11(8):1800. doi: 10.3390/nu11081800.

PubMed: https://pubmed.ncbi.nlm.nih.gov/31382666/

PMCID: PMC6722905.

[26] Owens DJ, Allison R, Close GL. Vitamin D and the Athlete: Current Perspectives and New Challenges. Sports Med. 2018;48(Suppl 1):3-16. doi: 10.1007/s40279-017-0841-9. PubMed: https://pubmed.ncbi.nlm.nih.gov/29368183/

PMCID: PMC5790847.

[27] Yoon S, Kwon O, Kim J. Vitamin D in athletes: focus on physical performance and musculoskeletal injuries. Phys Act Nutr. 2021;25(2):20-25.

PubMed: https://pubmed.ncbi.nlm.nih.gov/34315203/

PMCID: PMC8342187.

[28] Ip TST, Fu SC, Ong MTY, Yung PSH. Vitamin D deficiency in athletes: Laboratory, clinical and field integration. Asia Pac J Sports Med Arthrosc Rehabil Technol. 2022;29:22-29. doi: 10.1016/j.asmart.2022.06.001.

PubMed: https://pubmed.ncbi.nlm.nih.gov/35847194/

PMCID: PMC9256943.

[29] Knechtle B, Nikolaidis PT. Vitamin D and Sport Performance. Nutrients. 2020;12(3):841. doi: 10.3390/nu12030841.

PubMed: https://pubmed.ncbi.nlm.nih.gov/32245151/

PMCID: PMC7146184.

[30] Knechtle B, Jastrzębski Z, Hill L, Nikolaidis PT. Vitamin D and Stress Fractures in Sport: Preventive and Therapeutic Measures-A Narrative Review. Medicina (Kaunas). 2021;57(3):223. doi: 10.3390/medicina57030223.

PubMed: https://pubmed.ncbi.nlm.nih.gov/33804459/

PMCID: PMC7999420.

[31] Wyatt PB, et al. Effects of Vitamin D Supplementation in Elite Athletes: A Systematic Review. Orthop J Sports Med. 2024.

PubMed: https://pubmed.ncbi.nlm.nih.gov/38188620/

PMCID: PMC10768611.

[32] Han Q, Li X, Tan Q, Shao J, Yi M. Effects of vitamin D3 supplementation on serum 25(OH)D concentration and strength in athletes: a systematic review and meta-analysis of randomized controlled trials. J Int Soc Sports Nutr. 2019;16:55. doi: 10.1186/s12970-019-0323-6.

PubMed: https://pubmed.ncbi.nlm.nih.gov/31771586/.

[33] Sist M, Zou L, Galloway SDR, Rodriguez-Sanchez N. Effects of vitamin D supplementation on maximal strength and power in athletes: a systematic review and meta-analysis of randomized controlled trials. Front Nutr. 2023;10:1163313. doi: 10.3389/fnut.2023.1163313.

PubMed: https://pubmed.ncbi.nlm.nih.gov/37841405/

PMCID: PMC10570740.

[34] Zhang L, Quan M, Cao ZB. Effect of vitamin D supplementation on upper and lower limb muscle strength and muscle power in athletes: A meta-analysis. PLoS One. 2019;14(4):e0215826. doi: 10.1371/journal.pone.0215826.

PubMed: https://pubmed.ncbi.nlm.nih.gov/31039170/

PMCID: PMC6490896.

[35] Wiciński M, Adamkiewicz D, Adamkiewicz M, Śniegocki M, Podhorecka M, Szychta P, Malinowski B. Impact of Vitamin D on Physical Efficiency and Exercise Performance-A Review. Nutrients. 2019;11(11):2826. doi: 10.3390/nu11112826.

PubMed: https://pubmed.ncbi.nlm.nih.gov/31752277/

PMCID: PMC6893541.

[36] Rockwell M, Hulver M, Eugene E. Vitamin D Practice Patterns in National Collegiate Athletic Association Division I Collegiate Athletics Programs. J Athl Train. 2020;55(1):65-70. doi: 10.4085/1062-6050-21-19.

PubMed: https://pubmed.ncbi.nlm.nih.gov/31729892/

PMCID: PMC6961638.

[37] Millward D, et al. Association of Serum Vitamin D Levels and Stress Fractures in Collegiate Athletes. Orthop J Sports Med. 2020;8(12):2325967120966967. doi: 10.1177/2325967120966967.

PubMed: https://pubmed.ncbi.nlm.nih.gov/33816638/

PMCID: PMC8008136.

[38] Owens DJ, Tang JCY, Bradley WJ, Sparks SA, Fraser WD, Morton JP, Close GL. Efficacy of High-Dose Vitamin D Supplements for Elite Athletes. Med Sci Sports Exerc. 2017;49(2):349-356. doi: 10.1249/MSS.0000000000001105.

PubMed: https://pubmed.ncbi.nlm.nih.gov/27741217/.

[39] Mielgo-Ayuso J, Calleja-González J, Urdampilleta A, León-Guereño P, Córdova A, Caballero-García A, Fernandez-Lázaro D. Effects of Vitamin D Supplementation on

Haematological Values and Muscle Recovery in Elite Male Traditional Rowers. Nutrients. 2018;10(12):1968. doi: 10.3390/nu10121968.

PubMed: https://pubmed.ncbi.nlm.nih.gov/30545134/.

[40] Michalczyk MM, Gołaś A, Maszczyk A, et al. Influence of Sunlight and Oral D3 Supplementation on Serum 25(OH)D Concentration and Exercise Performance in Elite Soccer Players. Nutrients. 2020;12(5):1311. doi: 10.3390/nu12051311.

PubMed: https://pubmed.ncbi.nlm.nih.gov/32375348/

PMCID: PMC7284423.

[41] Jastrzębska M, Kaczmarczyk M, Jastrzębski Z. Can Supplementation of Vitamin D Improve Aerobic Capacity in Well Trained Youth Soccer Players? J Hum Kinet. 2018;61:63-72. doi: 10.2478/hukin-2018-0033.

PubMed: https://pmc.ncbi.nlm.nih.gov/articles/PMC5873337/

PMCID: PMC5873337.

[42] Jastrzębska J, Skalska M, Radzimiński Ł, et al. Changes of 25(OH)D Concentration, Bone Resorption Markers and Physical Performance as an Effect of Sun Exposure, Supplementation of Vitamin D and Lockdown among Young Soccer Players during a One-Year Training Season. Nutrients. 2022;14(3):521. doi: 10.3390/nu14030521.

PubMed: https://pubmed.ncbi.nlm.nih.gov/35276883/

PMCID: PMC8838295.

[43] Brzeziański M, Migdalska-Sęk M, Czechowska A, Radzimiński Ł, Jastrzębski Z, Brzeziańska-Lasota E, Sewerynek E. Correlation between the Positive Effect of Vitamin D Supplementation and Physical Performance in Young Male Soccer Players. Int J Environ Res Public Health. 2022;19(9):5138. doi: 10.3390/ijerph19095138.

PubMed: https://pubmed.ncbi.nlm.nih.gov/35564532/

PMCID: PMC9101676.