NIECZYPORUK, Mateusz, OMIDI, Amin, ŁUPICKA, Aleksandara, KIELAN, Aleksandara, ORZECHOWSKA, Paulina, DZIURDŹ, Aneta, BUDZISZEWSKA, Gabriela, OKUPNIAK, Alicja, ZIEMBA, Monika and MAJEWSKA, Katarzyna. Vitamin D as a Key Modulator of Physical Performance and Injury Prevention: A Narrative Review. Quality in Sport. 2026;49:67801. eISSN 2450-3118.
https://doi.org/10.12775/QS.2026.49.67801
https://apcz.umk.pl/QS/article/view/67801

The journal has been awarded 20 points in the parametric evaluation by the Ministry of Higher Education and Science of Poland. This is according to the Annex to the announcement of the Minister of Higher Education and Science dated 05.01.2024, No. 32553. The journal has a Unique 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 l.p. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych).
The authors declare that there is no conflict of interest regarding the publication of this paper.
Received: 28.12.2025. Revised: 10.01.2026. Accepted: 10.01.2026. Published: 17.01.2026.

Vitamin D as a Key Modulator of Physical Performance and Injury Prevention: A Narrative Review

Mateusz Nieczyporuk (First and Corresponding Author)

First Department of Internal Medicine, Szpital Bielański im. ks. Jerzego Popiełuszki, Cegłowska 80, 01-809 Warsaw, Poland

ORCID: https://orcid.org/0009-0002-0196-0946

E-mail: mateusz.nieczyporuk@wp.pl

Amin Omidi

Medical University of Warsaw Żwirki i Wigury 61, 02-091 Warszawa

omidiamin99@gmail.com

0009-0008-9432-3957

Aleksandra Łupicka

First Department of Internal Medicine, Szpital Bielański im. ks. Jerzego Popiełuszki, Cegłowska 80, 01-809 Warsaw, Poland

lupicka.ola@gmail.com

0009-0004-0371-8656

Aleksandra Kielan

Szpital Matki Bożej Nieustającej Pomocy w Wołominie Gdyńska 1/3, 05-200 Wołomin

aaleksandrakielan@gmail.com

0009-0004-7690-2825

Paulina Orzechowska

Samodzielny Publiczny Zespół Zakładów Opieki Zdrowotnej im. marszałka Józefa Piłsudskiego w Płońsku Henryka Sienkiewicza 7, 09-100 Płońsk

porzechowska1999@gmail.com

0009-0009-4277-6337

Aneta Dziurdź

Samodzielny Publiczny Szpital Kliniczny nr 1 im. prof. Tadeusza Sokołowskiego Pomorskiego Uniwersytetu Medycznego w Szczecinie 71-252 Szczecin, ul. Unii Lubelskiej 1

anetadziurdz2000@gmail.com

0009-0005-1166-1749

Gabriela Budziszewska

Wojewódzki Szpital Specjalistyczny we Włocławku ul. Wieniecka 49, 87-800 Włocławek

budziszewskagabriela@gmail.com

0009-0000-4110-6395

Alicja Okupniak

Powiatowe Centrum Medyczne w Grójcu Sp. z o.o. Ul. Piotra Skargi 10, 05-600 Grójec

alicjaokupniak@gmail.com

0009-0009-1117-398X

Monika Ziemba

Szpital Powiatowy SPZZOZ w Kozienicach Ul. Sikorskiego 10 26-900, Kozienice

Monika.ziemba@onet.com.pl

0009-0008-8060-8097

Katarzyna Majewska

Mazowiecki Szpital Wojewódzki w Siedlcach SP. z o.o.Ul. Poniatowskiego 26, 08-110 Siedlce
kmajewska25@gmail.com
0009-0003-4341-1862

Abstract

The role of vitamin D3 (cholecalciferol) as a key modulator of athletic performance has been the subject of a considerable number of studies for a number of years. Vitamin D3, functioning as a prohormone, exerts its effects on muscle tissue through the action of VDR receptors,

thereby influencing the morphology of type II fibres and calcium metabolism. The present article focuses on the correlation between serum 25(OH)D3 concentration and explosive strength, aerobic threshold, and immune resistance in athletes. The analysis demonstrates that maintaining concentrations between 40 and 70 ng/ml is imperative for optimising regenerative processes and minimising the risk of fatigue fractures. Furthermore, the prevalence of deficiencies within the athlete population, in conjunction with the recommended supplementation protocols, should be duly noted.

Keywords: Vitamin D3, VDR, athlete, regeneration, endurance

1. Introduction

Contemporary professional sports are distinguished by a perpetual pursuit of methodologies aimed at maximising the biological potential of the human body. In this context, the role of vitamin D3 extends beyond the conventional paradigm of calcium-phosphate homeostasis[1]. The discovery of vitamin D receptors (VDR) in satellite cells and skeletal muscle myocytes has provided novel insights into its function in energy generation and hypertrophy[2].

Deficiency of vitamin D3 among athletes represents a significant global health concern.[3]. This phenomenon is not exclusive to indoor athletes; it is also observed in athletes training outdoors in latitudes above 35 degrees north[4]. The objective of this study is to provide a comprehensive discussion of the mechanisms through which vitamin D3 impacts final athletic performance[5].

2. Methodology

In order to ensure the reliability and high quality of this study, the data collection process was based on a strategy of systematic searching of bibliographic resources. A comprehensive analysis was conducted on publications that have been indexed in international databases. The following bibliographic databases were consulted: PubMed/MEDLINE, Scopus, Google Scholar and Cochrane Library. The time frame of the search was constrained to 2007–2025, thus enabling the incorporation of pioneering work on the VDR receptor and the most recent reports in the domain of sports immunometabolism.

2.1. Search strategy and Keywords

The search was implemented using Boolean operators, with the following terms employed (MeSH):

- *„Vitamin D AND Athletic Performance”*,
- *„Cholecalciferol AND Skeletal Muscle”*,
- *„Vitamin D Receptor (VDR) AND Muscle Power”*,
- *„25(OH)D AND VO2max”*,
- *„Vitamin D AND Stress Fractures in Athletes”*.

2.2. Inclusion Criteria

The following publications were selected for detailed analysis, having met the specified requirements:

1. **Randomised, double-blind studies (RCTs)** in which the intervention involved vitamin D3 supplementation in competitive athletes or people with high physical activity.
2. **Meta-analyses and systematic reviews** evaluating the effects of vitamin D status on strength and speed parameters, and aerobic capacity.
3. **Observational and prospective studies** correlating serum 25(OH)D concentrations with the risk of osteoarthritis, injury, or upper respiratory tract infection (URTI).
4. **Molecular biology studies** elucidating the mechanisms of calcitriol's effects on myocytes and mitochondria.

2.3. Exclusion Criteria

In order to preserve the homogeneity of the results, publications were rejected from the analysis:

1. The aforementioned criteria were applicable exclusively to specific demographic groups, namely elderly populations (i.e. those exhibiting sarcopenia), paediatric populations, and individuals afflicted with chronic diseases (e.g. renal failure, diabetes).
2. The findings were derived from in vitro studies or animal models, which lack direct relevance to exercise physiology in humans.
3. The publications in question were disseminated in languages other than Polish and English.
4. The reports were of a concise nature, encompassing either conference reports or case reports, which lacked a robust statistical foundation.

2.4. Selection

The preliminary identification procedure yielded 112 distinct records. Following a thorough analysis of the abstracts, and the subsequent removal of duplicates, a total of 45 publications were deemed to be suitable for full-text analysis. Following a thorough evaluation of the methodological quality and relevance to the final conclusions, 30 publications were utilised in this study to provide a factual foundation for the theses presented (Fig. 1).

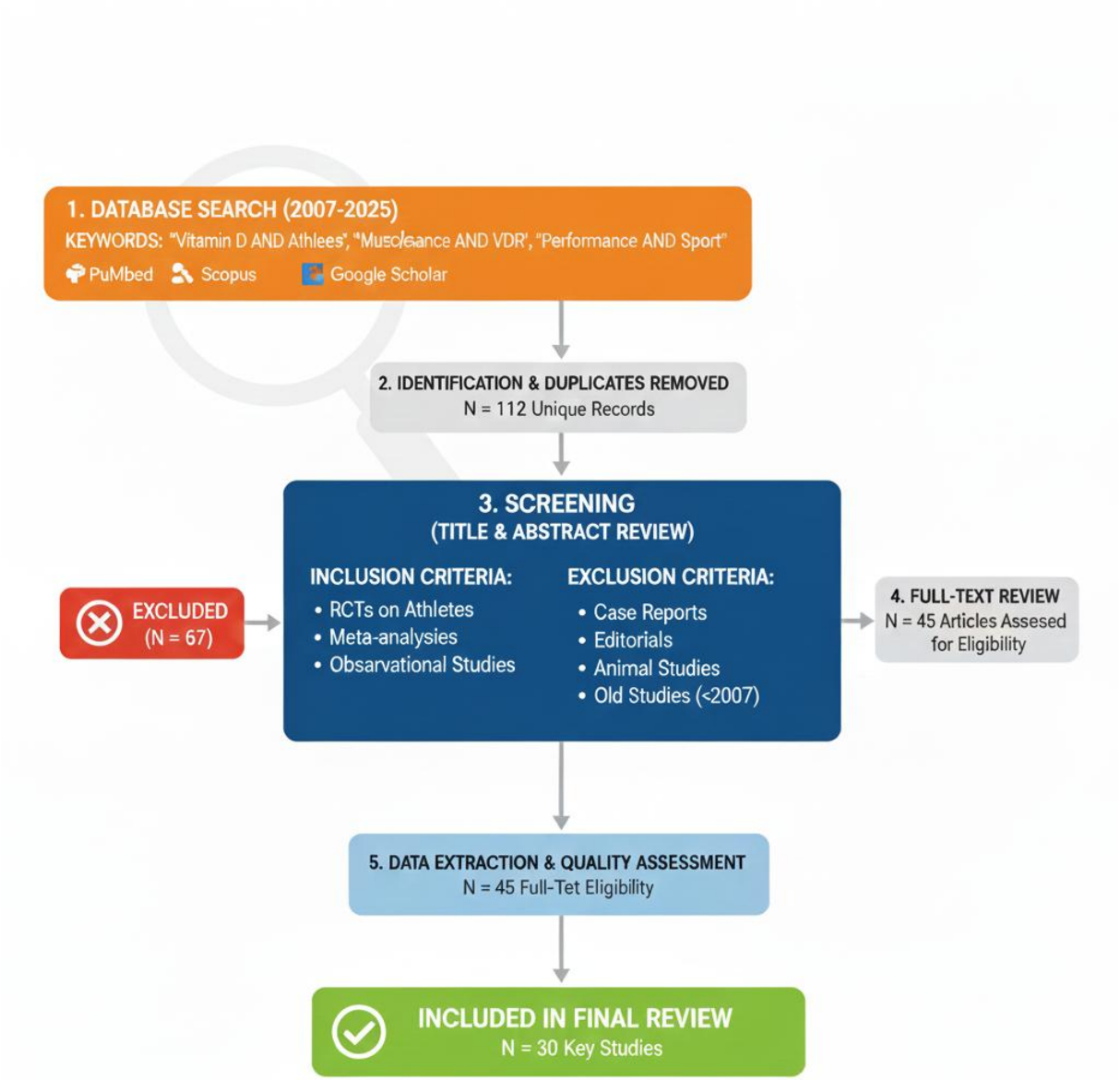

Fig 1. The selection process of publications used in the article. From among the unique 112 records, after preliminary data analysis, excluding duplicates, 45 publications were obtained, further data quality analysis reduced this number to 30 publications, which were finally included in the publication.

3. Molecular mechanisms: the VDR and muscle tissue — a detailed analysis

The interaction of vitamin D3 on skeletal muscle tissue is a highly complex process that extends beyond the simple support of mineral metabolism. A pivotal component of this interaction is the vitamin D receptor (VDR), which is present in nearly all tissues of the body. However, its density in myocytes (muscle cells) directly determines an athlete's adaptive potential [2]. The mechanism can be subdivided into two primary pathways: the genomic pathway, which affects muscle structure and mass, and the non-genomic pathway, which modulates its adventitious function [6].

3.1. Genomic pathway and the biosynthesis of contractile proteins:

In the genomic pathway, the active metabolite of vitamin D3, 1,25(OH)D3 (calcitriol), has been observed to penetrate the lipid bilayer of the cell membrane and bind to the VDR receptor located in the cell nucleus[6]. Following the formation of a complex with the retinoid X receptor (RXR), it engages with DNA sequences designated as vitamin D response elements (VDREs). This process initiates the transcription of genes encoding key structural proteins, such as actin and myosin, and regulatory proteins (troponin and tropomyosin)[7].

It is particularly pertinent to athletes who specialise in strength and speed that the effect of vitamin D on satellite cell proliferation and differentiation should be given due consideration[8]. These cells act as precursors of new muscle fibres and are essential in the process of hypertrophy and repair of micro-injuries incurred during eccentric phases of exercise. Optimal concentrations of vitamin D have been demonstrated to promote the differentiation of satellite cells into mature type II (fast twitch) muscle fibres [7]. These fibres are distinguished by elevated myosin ATP-ase activity, enabling them to generate substantial force over a brief interval – a pivotal factor in events such as sprinting, jumping and Olympic doubles.

3.2. Non-genomic regulation of contraction kinetics and calcium transport

The non-genomic action of vitamin D3 occurs much more rapidly (within seconds or minutes) and is based on interaction with receptors located in cell membranes (Membrane-Associated, Rapid Response Steroid receptors, 1,25D3-MARRS)[9]. Vitamin D modulates the opening of voltage-dependent calcium channels, leading to a rapid influx of Ca ions into the sarcoplasm.

Calcium acts as the 'switch' for muscle contraction. An increase in its concentration exposes binding sites on actin, enabling myosin cross-bridges to generate displacement and contraction. Additionally, vitamin D stimulates the activity of the sarcoplasmic reticulum calcium pump (SERCA), accelerating calcium reuptake after contraction[9]. Faster ion uptake results in more efficient fibre relaxation, directly affecting the frequency of generated contractions and preventing premature neuromuscular fatigue.

3.3. The impact of phosphagenics on energy metabolism

Recent studies have indicated that vitamin D may also influence the kinetics of phosphocreatine (PCr) resynthesis[10]. Research utilising magnetic resonance spectroscopy has demonstrated that patients with elevated vitamin D levels exhibit faster recovery of ATP stores following intense anaerobic exercise[11]. For the athlete, this signifies the capacity to sustain elevated levels of intensity during subsequent training series or in the culminating phases of interval match exercise. The study found that by optimising mitochondrial function, vitamin D3 reduced electron leakage and the formation of reactive oxygen species (ROS), thereby protecting myocytes from oxidative stress and accelerating post-workout recovery[12].

4. VO2 max, aerobic capacity, and metabolic efficiency of mitochondria

Aerobic capacity, defined as maximum oxygen uptake (VO2max), is the foundation of success in endurance sports such as road cycling, long-distance running, triathlon and swimming. For many years, it was hypothesised that this parameter was contingent on cardiovascular fitness, the stroke volume of the heart and the density of capillaries in the muscles. However, contemporary scientific research has identified vitamin D3 as a significant modulator of cardiorespiratory fitness, functioning at both the central (cardiac) and peripheral (muscular) levels[3].

4.1. Improvement of blood transport function and erythropoiesis

The primary impact of vitamin D on aerobic capacity is its involvement in red blood cell formation, also known as erythropoiesis. It has been demonstrated through a range of studies that VDR receptors are present in bone marrow precursor cells[13]. Optimal concentrations of cholecalciferol have been demonstrated to potentiate the effects of erythropoietin (EPO), a hormone that stimulates erythrocyte production. It has been established that increased red blood cell mass and higher hemoglobin concentrations result in greater blood capacity to transport oxygen from the lungs to the muscles used during physical activity[14].

Moreover, the impact of vitamin D3 on blood vessel elasticity is attributed to its capacity to stimulate nitric oxide (NO) production. Improved vasodilatation (vasodilation) allows for enhanced blood flow and reduced peripheral resistance, thereby alleviating stress on the heart muscle during exertion close to the lactate threshold [9].

4.2. Mitochondrial efficiency and ATP resynthesis

In the mitochondria, the process of oxidative phosphorylation is responsible for the production of energy in the form of ATP, which is essential for the sustained function of muscles. Vitamin D3 plays a critical role in maintaining the integrity of mitochondrial membranes and optimising the respiratory chain[11].

Research utilising magnetic resonance spectroscopy (31P-MRS) has demonstrated that individuals experiencing vitamin D3 deficiency exhibit considerably prolonged phosphocreatine recovery times following physical exertion[10]. The restoration of 25(OH)D levels to normal (above 30-40 ng/ml) through supplementation results in a reduction of this time by nearly 20%. For the athlete, this signifies that their mitochondria become more efficient, resulting in the capacity to produce energy at a faster rate with the same oxygen consumption levels[15]. Improved aerobic kinetics at the cellular level has been demonstrated to allow the anaerobic threshold to be shifted, thereby enabling the athlete to maintain a higher running pace or higher generated power (W) without increasing acidification.

4.3. Effects on myocardial morphology

It has been demonstrated that vitamin D3 exerts a protective and adaptive effect on cardiomyocytes, otherwise known as heart cells. It is an established fact that athletes who participate in endurance events develop physiological hypertrophy of the left ventricle, a

condition that is colloquially referred to as the "athlete's heart". The presence of vitamin D deficiency has been demonstrated to be a contributing factor to abnormal cardiac remodeling (remodeling) and subsequent tissue fibrosis. These alterations have been observed to result in impaired diastolic function[9]. Optimal levels of 25(OH)D have been demonstrated to promote normal contractility of cardiac myocytes, resulting in higher stroke volume. It has been demonstrated that the capacity of the heart to eject blood during a single contraction directly correlates with the frequency at which it must contract under a given load. This, in turn, has been shown to enhance exercise economy and elevate the individual's maximum VO2 level[15].

4.4. Reduction of post-exercise oxidative stress

Prolonged aerobic exercise has been demonstrated to be associated with the generation of significant quantities of free radicals, which have been observed to cause damage to proteins and lipids in muscle cells. Vitamin D3 has been demonstrated to act as an indirect antioxidant by increasing the expression of genes responsible for the production of defence enzymes, such as superoxide dismutase (SOD) and glutathione peroxidase[12]. This process has been shown to reduce mitochondrial damage and facilitate a more rapid return to homeostasis following a strenuous beginning, a phenomenon that is critical to the development of long-term endurance capacity[16].

5. Injury prevention, osteoarticular health and immunomodulation

The issue of injury prevention is as important in professional sports as the form-building process itself. An injury, particularly one resulting from excessive exertion, has the potential to eliminate an athlete from a critical phase of preparation, thereby invalidating months of training. Vitamin D3 has been identified as a multifaceted regulator in this domain, impacting not only mineral density of the bone, but also the integrity of soft tissues and the efficiency of the immune system, which forms the basis of regeneration[17].

5.1. Structural integrity of the skeleton and stress fractures

The most classic and pivotal function of vitamin D3 is the regulation of calcium-phosphate homeostasis. Within a competitive sporting context, where bones are subjected to repetitive mechanical loading (for instance, in the cases of marathon runners or dancers), the process of micro-damage to the bone matrix is an ongoing phenomenon. It is a process of the body's natural healing mechanisms that these microtears are then repaired through the process of bone remodelling[18] (Fig. 2).

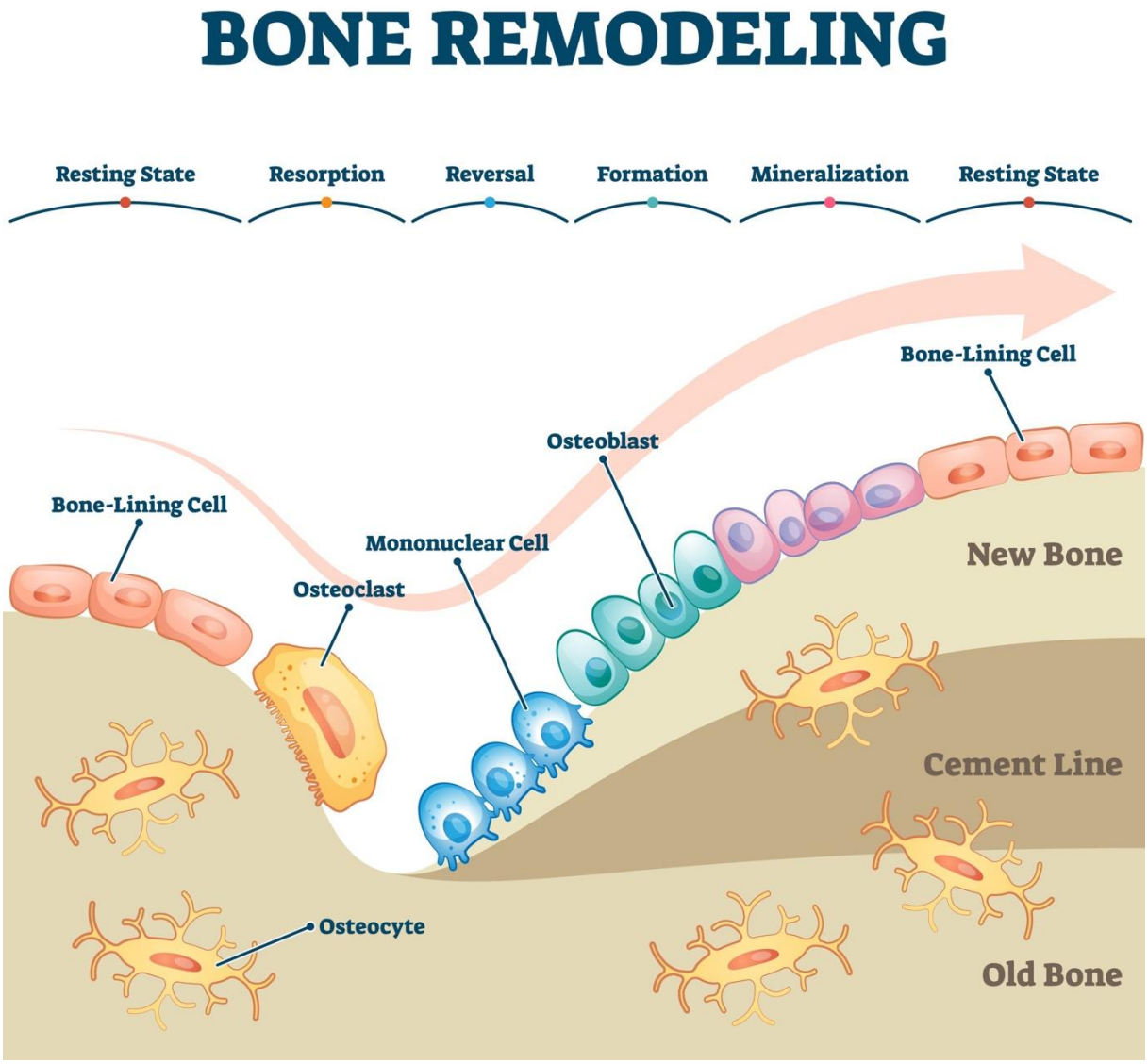

Fig. 2. The diagram illustrates the continuous cycle of bone tissue renewal. The process begins with resorption, where osteoclasts break down the old bone matrix. This is followed by the reversal phase and the subsequent formation of new bone by osteoblasts, which synthesize the organic matrix. The final stage is mineralization, where the new bone (osteoid) is hardened by calcium and phosphate deposits. Vitamin D3 is a critical regulator of this cycle, ensuring efficient calcium absorption and stimulating osteoblasts to produce osteocalcin, which is essential for maintaining high bone mineral density (BMD) and preventing stress fractures in athletes.

In the context of vitamin D3 deficiency, the process of calcium absorption in the gut is impaired, consequently prompting the body to activate parathormone (PTH). High concentrations of parathyroid hormone (PTH) have been shown to stimulate osteoclasts, the cells responsible for the formation of bone, to release calcium from the bones into the bloodstream. This process is vital for maintaining homeostasis within the body. This process is associated with a decrease in bone mineral density (BMD) and the formation of foci of osteopenia. Consequently, mechanical forces acting upon the tibia, metatarsal bones or femoral neck result in fatigue fractures that necessitate weeks of revalidation[19]. The supplementation of vitamin D3 has been demonstrated to stimulate osteoblasts in the production of osteocalcin, thereby ensuring adequate "stiffness" and mechanical resistance of the skeletal system[1].

5.2. Collagen synthesis and stability of the ligamentous apparatus

Recent advancements in the field of molecular biology have provided novel insights into the presence of VDR receptors in fibroblasts, the cells responsible for collagen production in tendons and ligaments[20]. Ligaments, such as the anterior cruciate ligament (ACL) in the knee, are critical stabilisers in sports that require sudden changes in direction (e.g. soccer and basketball).

Optimal levels of calcitriol have been demonstrated to facilitate the cross-linking of collagen fibres, thereby enhancing the tensile strength of tendons[21]. Furthermore, the impact of vitamin D on the strength of the muscles responsible for stabilising the joint (proprioception) has been demonstrated to enhance the musculoskeletal apparatus's responsiveness to uneven terrain or contact with an opponent, thereby significantly reducing the risk of torsional injury[22]. Consequently, athletes with elevated levels of 25(OH)D exhibit not only stronger bones, but also more flexible and rupture-resistant soft tissues [3].

5.3. Immune response vs. maintaining training continuity

The immune system has been demonstrated to play a direct role in the process of muscle recovery subsequent to training. Macrophages and lymphocytes infiltrate damaged fibres to "clean up" cellular debris and initiate repair processes. It is evident that vitamin D3 plays a pivotal role in regulating this response[13].

The functionality of the system is operable in a dual manner.:

1. Protection against infections: By stimulating the production of antimicrobial peptides such as cathelicidin and defensin-beta, vitamin D drastically reduces the risk of upper respiratory tract infection (URTI). During periods of heavy training, when post-workout immunosuppression occurs, vitamin D acts as a barrier to protect the athlete from falling out of the training cycle due to a cold [13].
2. Reduction of chronic inflammation: Vitamin D3 inhibits excessive production of pro-inflammatory cytokines (IL-1, IL-6, TNF-alpha), which with chronic overtraining can lead to pain syndromes and muscle tissue degradation[12]. As a result, anabolic processes prevail over catabolic ones, allowing faster adaptation to increasing training loads[23].

5.4. Effect on regeneration of the nervous system

A final element of the prevention strategy is the effect on neuromuscular conduction. Vitamin D3 has been demonstrated to promote the synthesis of neurotrophic factors (NGF), thereby enhancing brain-muscle communication. It is an established fact that central nervous system (CNS) fatigue is a frequent cause of technical errors at the culmination of competitive events, which in turn result in injuries. The enhancement of neuroprotection afforded by vitamin D enables athletes to sustain motor precision despite substantial physical exhaustion[9, 24].

6. Discussion and Conclusions

A thorough analysis of the extant evidence indicates that vitamin D3 is a pivotal, albeit frequently disregarded, component of biological support in competitive sports. Notwithstanding the compelling evidence that has been presented on the subject of its effects on muscle strength[25] and aerobic capacity [21], the definition of "optimal concentration" remains a subject of debate within the sporting community. The majority of authors concur that 25(OH)D

levels in excess of 30 ng/ml are adequate for general health. However, levels of up to 40-70 ng/ml are proposed for the purpose of enhancing athletic performance [26]. The question of whether to supplement in "blind" fashion remains the subject of considerable controversy. A body of research on elite athletes suggests that the blind ingestion of high doses, without the concomitant monitoring of serum levels, may result in suboptimal outcomes, particularly in cases where the athlete's initial status was within the normal range[27]. Furthermore, the role of cofactors should be emphasised in the ensuing discussion. In the event of magnesium deficiency, supplementation with cholecalciferol alone may prove ineffective, as magnesium is required to activate the enzymes responsible for converting vitamin D into its active form[28]. A further salient point pertains to the variation in response to supplementation, contingent on season and latitude. Athletes engaged in training in temperate climates exhibit a substantial decline in immune function during the winter months, which is directly associated with a decrease in vitamin D concentrations resulting from reduced UVB exposure. Recent meta-analyses posit that the personalisation of dosage, overseen by periodic blood tests, constitutes the sole efficacious modality for enhancing athletic performance in a safe manner.

Final conclusions:

1. It has been demonstrated that the maintenance of 25(OH)D levels in excess of 40 ng/ml has a beneficial effect on the optimisation of type II (fast twitch) fibres, whilst concomitantly reducing metabolic recovery time following periods of physical exertion[29].
2. Vitamin D3 has a synergistic effect with resistance training, enhancing anabolic processes by directly acting on receptors in the cell nucleus of myocytes.[30]
3. In injury prevention, optimal vitamin D3 status is essential for maintaining the continuity of the training process, reducing the risk of stress fractures and upper respiratory tract infections.

Conceptualization, Mateusz Nieczyporuk, and Aleksandra Łupicka; methodology, Mateusz Nieczyporuk; software, Katarzyna Majewska; check, Mateusz Nieczyporuk, Amin Omidi and Aleksandra Kielan; formal analysis, Paulina Orzechowska; investigation, Aneta Dziurdz; resources, Gabriela Budziszewska; data curation, Alicja Okupniak; writing - rough preparation, Monika Ziemba; writing - review and editing, Katarze Majewska; visualization, Mateusz Nieczyporuk; supervision, Mateusz Nieczyporuk; project administration, Mateusz Nieczyporuk;

All authors have read and agreed with the published version of the manuscript.

Funding statement:The study did not receive special funding.

Institutional Review Board Statement:Not applicable.Informed

Consent Statement:Not applicable.

Data Availability Statement:Not applicable.

Conflict of Interest Statement:The authors declare no conflict of interest.

References:

[1] M. F. Holick, "Vitamin D deficiency," *New England Journal of Medicine,* vol. 357, no. 3, pp. 266-281, 2007.

[2] L. Ceglia and S. S. Harris, "Vitamin D and its role in skeletal muscle," *Calcified Tissue International,* vol. 92, no. 2, pp. 151-162, 2013.

[3] M. E. Angeline, S. O. Gee, M. Shindle, R. F. Warren, and S. A. Rodeo, "Vitamin D and the Athlete's Health and Performance," *American Journal of Sports Medicine,* vol. 41, no. 2, pp. 461-469, 2013.

[4] F. Farrokhyar, R. Tabasinejad, and D. Dao, "Prevalence of vitamin D inadequacy in athletes: A systematic-review and meta-analysis," *Sports Medicine,* vol. 45, no. 3, pp. 365-378, 2015.

[5] J. J. Cannell, B. W. Hollis, and M. B. Sorenson, "Athletic Performance and Vitamin D," *Medicine & Science in Sports & Exercise,* vol. 41, no. 5, pp. 1102-1110, 2009.

[6] L. Zhang and J. Cheng, "Vitamin D receptor and its role in skeletal muscle: A review of current knowledge," *Frontiers in Physiology,* vol. 10, p. 1178, 2019.

[7] R. M. Pojednic and L. Ceglia, "The Emerging Role of Vitamin D in Skeletal Muscle: A Proposed Mechanism of Action," *Exercise and Sport Sciences Reviews,* vol. 42, no. 2, pp. 76-81, 2014.

[8] A. B. Baanen and B. van der Meijden, "The role of vitamin D in skeletal muscle repair and regeneration," *Nutrients,* vol. 12, no. 11, p. 3485, 2020.

[9] B. Hamilton, "Vitamin D and Human Skeletal Muscle," *Scandinavian Journal of Medicine & Science in Sports,* vol. 21, no. 3, pp. 337-346, 2011.

[10] D. T. Dahlquist, B. P. Dieter, and M. S. Koehle, "Plausible ergogenic effects of vitamin D on athletic performance and recovery," *Journal of the International Society of Sports Nutrition,* vol. 12, no. 1, p. 33, 2015.

[11] A. T. Carswell, S. J. Oliver, and L. M. Wentz, "Influence of Vitamin D Supplementation on Muscle Function and Performance in Athletes," *International Journal of Sport Nutrition and Exercise Metabolism,* vol. 28, no. 5, pp. 454-463, 2018.

[12] M. Zielińska-Przyjemska and J. Kujawski, "Vitamin D3, oxidative stress, and muscle recovery in high-performance athletes," *Antioxidants,* vol. 12, no. 2, p. 341, 2023.

[13] C. S. He, M. Handzlik, and W. D. Fraser, "Influence of vitamin D status on respiratory infection and immune function in athletes," *Exercise Immunology Review,* vol. 19, pp. 86-101, 2013.

[14] D. E. Larson-Meyer and K. S. Willis, "Vitamin D and Athletes: Assessing Status and Ensuring Adequacy," *Current Sports Medicine Reports,* vol. 9, no. 4, pp. 220-226, 2010.

[15] M. Lakkireddy, S. G. Gadiga, and I. R. Malathi, "Impact of vitamin D on muscle performance and VO2 max in endurance athletes," *International Journal of Research in Medical Sciences,* vol. 8, no. 6, p. 2110, 2020.

[16] A. Sinha, K. G. Hollingsworth, S. Ball, and T. Cheetham, "Improving the vitamin D status of vitamin D deficient adults is associated with improved

mitochondrial oxidative function in skeletal muscle," *J Clin Endocrinol Metab,* vol. 98, no. 3, pp. E509-13, Mar 2013, doi: 10.1210/jc.2012-3592.

[17] F. D. Shuler, M. K. Wingate, G. H. Moore, and C. Giangarra, "Vitamin D for the Athlete: Why, How Much, and When?," *Orthopedic Reviews,* vol. 4, no. 2, p. e16, 2012.

[18] J. J. Todd, L. K. Pourshahidi, and E. M. McSorley, "Vitamin D: An overview of its role in skeletal muscle function and athletic performance," *Journal of Bone and Mineral Research,* vol. 30, no. 12, pp. 2150-2160, 2015.

[19] Z. Kasprzak and L. Pilaczyńska-Szcześniak, "Vitamin D and Physical Performance in Athletes: A Review of Current Evidence," *Polish Journal of Sport and Tourism,* vol. 28, no. 1, pp. 15-22, 2021.

[20] J. Valtueña, D. Dominguez, and L. Til, "High prevalence of vitamin D insufficiency among elite Spanish athletes," *British Journal of Nutrition,* vol. 110, no. 11, pp. 2055-2062, 2013.

[21] M. A. Wyon, Y. Koutedakis, and R. Wolman, "The influence of winter vitamin D supplementation on muscle function and injury occurrence in elite ballet dancers," *Journal of Science and Medicine in Sport,* vol. 17, no. 1, pp. 8-12, 2014.

[22] J. J. Knapik, S. S. Hoedebecke, and G. G. Rogers, "Vitamin D Status and Physical Performance: A Systematic Review," *Journal of Strength and Conditioning Research,* vol. 30, no. 10, pp. 2906-2921, 2016.

[23] D. J. Owens, R. Allison, and G. L. Close, "Vitamin D and the athlete: Current perspectives and new challenges," *Sports Medicine,* vol. 45, no. 1, pp. 101-112, 2015.

[24] Y. Tsukahara *et al.,* "Link Between Ferritin, Vitamin D, Performance, and Eating Attitudes in Female Athletes," *Int J Sports Med,* vol. 46, no. 3, pp. 182-188, Mar 2025, doi: 10.1055/a-2421-6891.

[25] C. Beaudart, F. Buckinx, and V. Rabenda, "The Effects of Vitamin D on Skeletal Muscle Strength, Muscle Mass, and Muscle Power: A Systematic Review and Meta-Analysis," *Journal of Clinical Endocrinology & Metabolism,* vol. 99, no. 11, pp. 4336-4345, 2014.

[26] G. L. Close, J. Russell, and R. F. Ittenbach, "The effects of vitamin D3 supplementation on serum total 25[OH]D concentration and physical performance," *British Journal of Sports Medicine,* vol. 47, no. 11, pp. 692-696, 2013.

[27] Z. Jastrzębski, "Effect of vitamin D supplementation on the level of physical fitness of young soccer players," *Human Movement,* vol. 15, no. 4, pp. 233-239, 2014.

[28] A. Sikora-Szoltys, "Wpływ suplementacji witaminą D na wyniki sportowe – przegląd literatury," *Modern Sport Nutrition,* vol. 4, no. 1, pp. 45-52, 2018.

[29] J. J. Moran, S. J. McCloskey, and G. R. Sandercock, "The effect of vitamin D on physical performance: a systematic review of randomized controlled trials," *Sports Medicine,* vol. 43, no. 12, pp. 1253-1271, 2013.

[30] S. Yoon, O. Kwon, and J. Kim, "Vitamin D in athletes: focus on physical performance and musculoskeletal injuries," *Phys Act Nutr*, vol. 25, no. 2, pp. 20-25, Jun 2021, doi: 10.20463/pan.2021.0011.