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The Impact of Vitamin D and Omega-3 Fatty Acid Supplementation on Muscle Health, Physical Performance, and Sarcopenia Prevention – A Review of Studies

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Abstract
This review aims to assess the impact of vitamin D and omega-3 supplementation on muscle health, physical performance, and sarcopenia prevention. The analysis includes randomized controlled trials (RCTs), systematic reviews, meta-analyses, observational studies, and narrative reviews. Vitamin D regulates calcium metabolism, myocyte proliferation, and muscle regeneration, with deficiency linked to weakened strength and increased fall risk. However, the effects on physical performance are inconclusive, depending on 25(OH)D levels, dosage, and supplementation duration.

Omega-3 fatty acids demonstrate anti-inflammatory effects, supporting muscle regeneration and function, particularly with resistance training. Some studies show beneficial effects on isometric strength, but their impact on muscle mass is inconsistent. Sarcopenia prevention studies suggest that supplementation, combined with physical activity, may be effective, though evidence on muscle mass remains unclear. In conclusion, vitamin D and omega-3 supplementation may support muscle function, particularly in deficient individuals, but further research is needed to assess their impact on physical performance and sarcopenia prevention. Long-term studies on optimal dosages, intervention duration, and synergistic effects with physical activity are required.

Keywords: vitamin D, omega-3 fatty acids, physical performance, sarcopenia.

Introduction

Skeletal muscle health is crucial for maintaining physical fitness and quality of life, particularly in the context of an aging population and an increasing number of physically active individuals. Sarcopenia, defined as the progressive loss of muscle mass and strength, poses a significant health problem, increasing the risk of falls, disability, and decreased quality of life. In the search for effective strategies to support muscle function, increasing attention is being paid to vitamin D and omega-3 fatty acid supplementation. Both of these nutrients play an important role in regulating metabolic processes in muscle tissue, and deficiencies may contribute to impaired muscle function and decreased physical performance.

Vitamin D is primarily known for its role in regulating calcium-phosphorus balance and maintaining bone health, but an increasing body of research highlights its significance in muscle metabolism. It influences myocyte proliferation and differentiation, and may also support muscle regeneration after exercise. Vitamin D deficiency is associated with an increased risk of muscle weakness and reduced mobility, particularly in older adults. Despite numerous studies, its impact on physical performance remains inconclusive – while some studies suggest benefits from supplementation, others show no significant effect on muscle strength or endurance.

Omega-3 fatty acids, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), are known for their anti-inflammatory properties and their influence on muscle protein metabolism. They are believed to support muscle regeneration and prevent atrophy, particularly in older adults and athletes. Some studies suggest that omega-3 supplementation may increase muscle strength and support adaptation to resistance training; however, the effects on muscle mass remain inconsistent. Furthermore, omega-3 fatty acids may potentially reduce oxidative stress and modulate inflammatory processes, which may be important for sarcopenia prevention.

Existing research on the impact of vitamin D and omega-3 supplementation on muscle health provides conflicting results, which may stem from differences in study protocols, supplementation dosages, duration of interventions, and baseline levels of these nutrients in the body. The aim of this review is to synthesize the current scientific evidence on the effects of vitamin D and omega-3 supplementation on muscle function, physical performance, and sarcopenia prevention, with a particular focus on the mechanisms of action and potential clinical applications.

Methodology

This review included scientific articles published between 2020 and 2025 that addressed the effects of vitamin D and omega-3 fatty acid supplementation on muscle health, physical performance, and the prevention of sarcopenia. The literature search was conducted in the PubMed database, including only peer-reviewed publications available in English. The selected time frame was intended to reflect the most recent scientific evidence related to the research topic.

The analysis encompassed various types of studies, including randomized controlled trials (RCTs), systematic reviews, meta-analyses, observational studies, and narrative reviews. Inclusion criteria comprised studies evaluating the effects of vitamin D and/or omega-3 fatty acid supplementation on muscle function, strength, regeneration, and the prevention of sarcopenia. Studies involving healthy adults, athletes, and older individuals at risk of sarcopenia were included. Studies were excluded if they lacked complete clinical data, had not been peer-reviewed, or focused exclusively on metabolic biomarkers without assessing muscle function. Key study parameters were analyzed, including the scope of interventions, duration of supplementation, sample size, measurement methodology, and primary outcomes related to muscle strength, physical performance, and muscle regeneration. Variations in study protocols were also considered, including differences in supplement dosage, assessment methods of muscle function, and potential confounding factors such as physical activity level, diet, and general health status of participants.

This review covered a broad range of studies, including investigations into the role of vitamin D in muscle regeneration and myocyte proliferation, the effectiveness of supplementation among athletes, and the influence of omega-3 fatty acids on inflammation reduction and muscle protein metabolism. Studies addressing sarcopenia prevention and the effects of supplementation on muscle strength and physical performance in older adults were also included.

The primary aim of this paper was to provide a synthetic summary of the available evidence and to critically evaluate the methodological quality of the included studies. Particular attention was given to discrepancies between study findings, potential methodological limitations, and the influence of confounding variables on data interpretation. The review also aimed to identify existing research gaps and propose directions for future studies that may contribute to a better understanding of the role of vitamin D and omega-3 fatty acids in muscle function.

Results

The impact of vitamin D on muscle health and function

Vitamin D plays a key role in calcium metabolism, myocyte proliferation, and muscle tissue regeneration. However, its effect on muscle function remains inconclusive. Safai Haeri et al. (2023) demonstrated that vitamin D levels correlated with gait speed ($r = 0.19$; $p = 0.0041$), but not with grip strength ($r = -0.05$; $p = 0.4686$), suggesting a selective effect on mobility rather than muscle strength.

In the context of muscle recovery and adaptation to exercise, Agoncillo et al. (2023) conducted a systematic review highlighting the role of vitamin D in myocyte differentiation and proliferation, as well as post-exercise recovery. Żebrowska et al. (2020) found that a three-week supplementation with 2000 IU of vitamin D per day in ultramarathon runners significantly reduced levels of troponin ($p = 0.004$), creatine kinase ($p < 0.05$), and TNF-α ($p < 0.03$), suggesting a protective effect on muscles under high physical stress.
However, Bello et al. (2021) emphasized that vitamin D's effect on muscle recovery is primarily due to its anti-inflammatory properties, rather than a direct influence on repair processes. Additionally, a meta-analysis by Bislev et al. (2021) found no significant improvements in muscle strength or physical performance following supplementation, and even reported slight declines in physical fitness test results. Bollen et al. (2022) noted that vitamin D may influence muscles via effects on mitochondrial function and muscle protein proteolysis.

Omega-3 fatty acids and muscle health

Omega-3 fatty acids, particularly EPA and DHA, exhibit anti-inflammatory properties and may support muscle protein metabolism. Kyriakidou et al. (2022) showed that a four-week omega-3 supplementation reduced pro-inflammatory cytokines such as interleukin-6, but had no statistically significant effect on muscle damage biomarkers (CK and TNF-α).
A meta-analysis by Huang et al. (2020) indicated that omega-3 supplementation at doses over 2 g/day may increase muscle mass and improve sit-to-stand test performance. Dalle et al. (2021) confirmed that omega-3s can enhance lower limb isometric strength in combination with resistance training, although they had no significant effect on lean body mass.
Regarding mechanisms of action, Therdyothin et al. (2025) reported that the effect of omega-3s on muscle protein synthesis (MPS) remains ambiguous-no significant changes in MPS rate were observed, though a positive effect on whole-body protein synthesis was noted. Ferguson et al. (2021) highlighted the potential of omega-3s to prevent muscle atrophy during immobilization, suggesting possible applications in rehabilitation.

Vitamin D and omega-3 supplementation in the prevention and treatment of sarcopenia

The effect of supplementation on sarcopenia remains inconclusive. Sutherland et al. (2023) found that higher levels of 25(OH)D were associated with increased grip strength and lower sarcopenia risk, though the impact on muscle mass was minimal. Abiri et al. (2020) emphasized that vitamin D deficiency increases the risk of falls and impaired muscle function.
In a meta-analysis, Uchida et al. (2024) reported that omega-3 supplementation combined with resistance training increased muscle strength but had no effect on muscle mass. Tseng et al. (2023) confirmed that high-dose omega-3 supplementation (>2.5 g/day) provided the greatest benefits in improving muscle strength in individuals at risk of sarcopenia. Cannataro et al. (2024) noted that the mechanisms behind these effects require further investigation.

The impact of vitamin D and omega-3 on physical performance

The influence of supplementation on physical performance remains under investigation. De la Puente Yagüe et al. (2020) indicated that vitamin D deficiency in athletes may increase injury risk and impair recovery. Wyatt et al. (2024) showed that vitamin D supplementation may improve VO_2max and anaerobic power, though its effect on muscle strength and sprint speed requires further study.

Regarding omega-3s, Cannataro et al. (2024) and Fernández-Lázaro et al. (2024) suggested that supplementation may support recovery by reducing inflammation and oxidative stress. Iolascon et al. (2021) emphasized the important role of vitamin D in muscle recovery after injury, particularly through its effect on satellite cell activity. Uchitomi et al. (2020) noted that vitamin D supplementation may help maintain physical fitness in athletes.

An interventional study by Chou et al. (2024), as part of the VITAL trial, found that two-year supplementation with vitamin D3 (2000 IU/day) and omega-3 (1 g/day) had no significant impact on grip strength, gait speed, or balance in healthy adults, suggesting limited effectiveness in improving physical performance in this population.

Discussion

Interpretation of results and their relevance in the context of current knowledge

The review of available studies confirmed that both vitamin D and omega-3 fatty acids play a significant role in maintaining muscle health. However, research findings indicate that their impact is not unequivocal and depends on several factors, such as baseline levels of these compounds in the body, age, physical activity level, and the presence of chronic diseases.

In the case of vitamin D, study results are particularly varied. Safai Haeri et al. (2023) demonstrated that vitamin D levels were correlated with gait speed, yet no significant relationship was found between vitamin D levels and handgrip strength. This may suggest that vitamin D affects specific aspects of muscle function and that its effectiveness may depend on additional factors, such as physical activity or sun exposure.

Regarding muscle regeneration, Agoncillo et al. (2023) emphasized that vitamin D supports the proliferation and differentiation of myocytes, which may be crucial for repair processes. The study by Żebrowska et al. (2020) showed that supplementation with 2000 IU of vitamin D daily in ultramarathon runners reduced levels of creatine kinase and troponin, suggesting a protective effect under conditions of intense physical exertion. However, Bello et al. (2021) pointed out that the beneficial impact of vitamin D on muscle regeneration is primarily due to its anti-inflammatory properties rather than direct support for muscle repair mechanisms.

In the context of omega-3 fatty acids, their influence on muscle function may result mainly from inflammation reduction and the potential regulation of muscle protein metabolism. Kyriakidou et al. (2022) demonstrated that four weeks of omega-3 supplementation reduced interleukin-6 levels but had no statistically significant effect on muscle damage biomarkers such as creatine kinase or TNF-α. Similarly, Therdyothin et al. (2025) noted that the effect of omega-3 on muscle protein synthesis (MPS) remains inconclusive-no significant changes in MPS rate were observed, although a positive impact on whole-body protein synthesis was noted.

Analysis of study discrepancies

Discrepancies in findings on vitamin D and omega-3 supplementation may result from several key factors. One of them is the baseline status of these compounds in study participants. Many studies indicate that the greatest benefits are observed in individuals with deficiencies (Abiri et al., 2020; Sutherland et al., 2023). This may explain why in the study by Chou et al. (2024), involving healthy adults, supplementation produced no significant effects.

Another factor is the combination of supplementation with physical activity. Studies by Uchida et al. (2024) and Tseng et al. (2023) demonstrated that omega-3 provided the greatest improvement in muscle strength when combined with resistance training. This suggests that supplementation alone, without concurrent muscle stimulation through physical activity, may not yield expected results.

Differences in research protocols, including intervention duration and supplement dosage, may also affect outcomes. Chou et al. (2024) conducted a two-year intervention that showed no supplementation effect, whereas shorter interventions often indicated positive outcomes (Żebrowska et al., 2020).

Molecular mechanisms also appear relevant. Bollen et al. (2022) highlighted that vitamin D may act by affecting mitochondria and muscle protein proteolysis, whereas Ferguson et al. (2021) noted that omega-3 may protect against muscle atrophy in immobilized individuals, which constitutes an important area for further investigation.

Directions for future research

To better understand the impact of vitamin D and omega-3 supplementation on muscle health, future research should focus on several key aspects. One of them is determining optimal dosages and supplementation protocols. Existing studies show significant variability in both dosage and duration, making it difficult to draw definitive conclusions. Long-term randomized controlled trials (RCTs) comparing different dosing strategies based on baseline vitamin D and omega-3 levels are necessary.

The analysis of long-term effects remains an important issue. Most studies focus on short-term interventions lasting several weeks to months. Prospective cohort studies tracking muscle function, sarcopenia progression, and physical performance over several years are needed. This approach would help assess the sustainability of supplementation benefits and its potential for age-related muscle loss prevention.

Future studies should also explore interactions between supplementation and other metabolic factors, such as diet, physical activity level, genetics, and gut microbiota. In particular, advanced analytical techniques should be applied to determine how vitamin D and omega-3 affect muscle metabolism at the cellular and genetic levels. Techniques such as gene expression analysis, metabolic profiling, and microbiota composition assessments may offer valuable insights into their mechanisms of action.

Moreover, studies employing modern imaging technologies such as magnetic resonance imaging (MRI) or magnetic resonance spectroscopy (MRS) are warranted to more accurately evaluate the impact of supplementation on muscle structure and function.

Another key direction is evaluating the synergistic effects of vitamin D and omega-3 combined with resistance training. Although existing studies suggest potential benefits, high-quality RCTs are lacking, especially in different age and population groups.

There is also a need for studies involving high-risk populations, such as older adults, post-hospitalization patients, and individuals with chronic diseases (e.g., type 2 diabetes, osteoporosis). Intervention trials in these groups may clarify whether supplementation can be an effective preventive and therapeutic strategy.

In conclusion, future research should not only confirm the effectiveness of vitamin D and omega-3 supplementation in improving muscle function but also precisely define the underlying mechanisms and optimal implementation strategies across various populations.

Practical implications and clinical applications

Vitamin D and omega-3 fatty acid supplementation may play an important role in maintaining muscle health and preventing its decline; however, its effectiveness depends on many factors, such as age, physical activity level, diet, and baseline nutritional status. This is particularly relevant for the prevention and treatment of sarcopenia, the progressive loss of muscle mass and strength in older adults. Vitamin D deficiency is prevalent in this group and is associated with impaired muscle function and increased risk of falls and fractures. Supplementation may support neuromuscular function and help maintain mobility, particularly in individuals with low vitamin D levels. Meanwhile, omega-3 fatty acids, due to their anti-inflammatory properties and positive effects on protein metabolism, may contribute to improved muscle strength and serve as a valuable component in sarcopenia prevention strategies.

In the context of sports, vitamin D and omega-3 supplementation may support recovery and adaptation to physical training. Vitamin D may reduce the risk of injury and enhance performance through its effects on muscle function and calcium metabolism. Omega-3 fatty acids, through anti-inflammatory effects, may accelerate recovery and reduce muscle damage, which is especially important for athletes undergoing intense training loads.

The potential of supplementation extends to rehabilitation and regenerative medicine. Individuals with limited mobility-e.g., after long-term hospitalization, injuries, or surgery—often experience rapid muscle loss. In such cases, omega-3 supplementation may support regenerative processes and reduce muscle catabolism, thereby shortening recovery time. Including vitamin D in rehabilitation strategies may further enhance muscle function by stimulating satellite cell activity and supporting neuromuscular coordination.

A key aspect of clinical application is individualization. Not all individuals will benefit equally, as effectiveness depends on baseline levels, lifestyle, and diet. Monitoring vitamin D and omega-3 concentrations before initiating supplementation could allow more precise dosing and identification of those most likely to benefit, while avoiding unnecessary supplementation in individuals with optimal levels.

Despite promising evidence on the effects of vitamin D and omega-3 on muscle health, further research is needed to determine optimal dosages, intervention duration, and target populations. Incorporating these supplements into clinical practice should be tailored to individual needs rather than considered a universal solution. Supplementation with vitamin D and omega-3 holds practical potential for sarcopenia prevention, muscle recovery support in athletes, and rehabilitation strategies-but its effectiveness, especially in the long term, requires further investigation.

Conclusions

The review of available studies suggests that supplementation with vitamin D and omega-3 fatty acids may support muscle health, enhance physical performance, and contribute to the prevention of sarcopenia. However, the findings are inconsistent. Vitamin D plays a crucial role in calcium metabolism, myocyte proliferation, and muscle regeneration. Its deficiency is associated with reduced muscle strength and increased risk of falls in older adults. Some studies indicate potential benefits of supplementation, including reductions in muscle damage markers and improved mobility, particularly in individuals with low vitamin D levels. Nonetheless, meta-analyses do not confirm a clear effect on muscle strength and physical performance, suggesting that the efficacy of supplementation depends on baseline 25(OH)D levels, dosage, and intervention duration.

Omega-3 fatty acids possess anti-inflammatory properties and may support muscle regeneration and protein metabolism. Some studies suggest they may improve lower-limb isometric strength and aid post-exercise recovery, especially when combined with resistance training. However, their impact on muscle mass and protein synthesis remains inconclusive. The effects of supplementation may vary depending on age, physical activity level, and overall health status, with higher doses appearing to offer more noticeable benefits.

In summary, vitamin D and omega-3 supplementation may be beneficial, particularly for individuals with deficiencies. However, there is a lack of definitive evidence on their direct effects on physical performance and sarcopenia prevention, highlighting the need for further research. Determining optimal dosages and supplementation protocols, as well as analyzing their interactions with physical activity, remains essential. Personalized supplementation, tailored to lifestyle and dietary habits, may enhance effectiveness. Long-term clinical trials are needed to better define the actual role of vitamin D and omega-3 fatty acids in maintaining muscle health and their potential application in clinical practice.

Disclosure

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References:
1. Abiri, B., & Vafa, M. (2020). Vitamin D and muscle sarcopenia in aging. *Advances in Experimental Medicine and Biology, 1260*, 15–24. https://doi.org/10.1007/978-1-0716-0471-7_2
2. Agoncillo, M., Yu, J., & Gunton, J. E. (2023). The role of vitamin D in skeletal muscle repair and regeneration in animal models and humans: A systematic review. *Nutrients, 15*(20), 4377. https://doi.org/10.3390/nu15204377
3. Bello, H. J., Caballero-García, A., Pérez-Valdecantos, D., Roche, E., Noriega, D. C., & Córdova-Martínez, A. (2021). Effects of vitamin D in post-exercise muscle recovery: A systematic review and meta-analysis. *Nutrients, 13*(11), 4013. https://doi.org/10.3390/nu13114013
4. Bislev, L. S., Grove-Laugesen, D., & Rejnmark, L. (2021). Vitamin D and muscle health: A systematic review and meta-analysis of randomized placebo-controlled trials. *Journal of Bone and Mineral Research, 36*(9), 1721–1731. https://doi.org/10.1002/jbmr.4412
5. Bollen, S. E., Bass, J. J., Fujita, S., Wilkinson, D. J., Hewison, M., & Atherton, P. J. (2022). The vitamin D/vitamin D receptor (VDR) axis in muscle atrophy and sarcopenia. *Journal of the International Society of Sports Nutrition, 17*(1), 67. https://doi.org/10.1186/s12970-020-00347-8
6. Cannataro, R., Abrego-Guandique, D. M., Straface, N., & Cione, E. (2024). Omega-3 and sports: Focus on inflammation. *Life, 14*(10), 1315. https://doi.org/10.3390/life14101315

7. Chou, S. H., Cook, N. R., Kotler, G., Kim, E., Copeland, T., Lee, I. M., Cawthon, P. M., Buring, J. E., Manson, J. E., & LeBoff, M. S. (2024). Effects of supplemental vitamin D3, omega-3 fatty acids on physical performance measures in the VITamin D and OmegA-3 TriaL. *The Journal of Clinical Endocrinology & Metabolism, 109*(4), e150. https://doi.org/10.1210/clinem/dgae150
8. Dalle, S., Van Roie, E., Hiroux, C., Vanmunster, M., Coudyzer, W., Suhr, F., Bogaerts, S., Van Thienen, R., & Koppo, K. (2021). Omega-3 supplementation improves isometric strength but not muscle anabolic and catabolic signaling in response to resistance exercise in healthy older adults. *The Journals of Gerontology: Series A, 76*(2), 209–218. https://doi.org/10.1093/gerona/glaa309
9. De la Puente Yagüe, M., Collado Yurrita, L., Ciudad Cabañas, M. J., & Cuadrado Cenzual, M. A. (2020). Role of vitamin D in athletes and their performance: Current concepts and new trends. *Nutrients, 12*(2), 579. https://doi.org/10.3390/nu12020579
10. Ferguson, E. J., Seigel, J. W., & McGlory, C. (2021). Omega-3 fatty acids and human skeletal muscle. *Current Opinion in Clinical Nutrition & Metabolic Care, 24*(3), 193–200. https://doi.org/10.1097/MCO.0000000000000723
11. Fernández-Lázaro, D., Arribalzaga, S., Gutiérrez-Abejón, E., Azarbayjani, M. A., Mielgo-Ayuso, J., & Roche, E. (2024). Omega-3 fatty acid supplementation on post-exercise inflammation, muscle damage, oxidative response, and sports performance in physically healthy adults: A systematic review of randomized controlled trials. *Nutrients, 16*(13), 2044. https://doi.org/10.3390/nu16132044
12. Huang, Y. H., Chiu, W. C., Hsu, Y. P., Lo, Y. L., & Wang, Y. H. (2020). Effects of omega-3 fatty acids on muscle mass, muscle strength, and muscle performance among the elderly: A meta-analysis. *Nutrients, 12*(12), 3739. https://doi.org/10.3390/nu12123739
13. Iolascon, G., Moretti, A., Paoletta, M., Liguori, S., & Di Munno, O. (2021). Muscle regeneration and function in sports: A focus on vitamin D. *Medicina, 57*(10), 1015. https://doi.org/10.3390/medicina57101015
14. Kyriakidou, Y., Wood, C., Ferrier, C., & Dolci, A. (2022). The effect of omega-3 polyunsaturated fatty acid supplementation on exercise-induced muscle damage. *Journal of the International Society of Sports Nutrition, 19*(1), 17. https://doi.org/10.1186/s12970-020-00405-1
15. Safai Haeri, N., Perera, S., & Greenspan, S. L. (2023). The association of vitamin D with bone microarchitecture, muscle strength, and mobility performance in older women in long-term care. *Bone, 171*, 116867. https://doi.org/10.1016/j.bone.2023.116867
16. Sutherland, J. P., Zhou, A., & Hyppönen, E. (2023). Muscle traits, sarcopenia, and sarcopenic obesity: A vitamin D Mendelian randomization study. *Nutrients, 15*(12), 2703. https://doi.org/10.3390/nu15122703
17. Therdyothin, A., Prokopidis, K., Galli, F., Witard, O. C., & Isanejad, M. (2025). The effects of omega-3 polyunsaturated fatty acids on muscle and whole-body protein synthesis: A systematic review and meta-analysis. *Nutrition Research, 115*, nuae055. https://doi.org/10.1093/nutrit/nuae055

18. Tseng, P. T., Zeng, B. Y., Zeng, B. S., Liao, Y. C., Stubbs, B., Kuo, J. S., Sun, C. K., Cheng, Y. S., & Chen, Y. W. (2023). Omega-3 polyunsaturated fatty acids in sarcopenia management: A network meta-analysis of randomized controlled trials. *Ageing Research Reviews, 89*, 102014. https://doi.org/10.1016/j.arr.2023.102014
19. Uchida, Y., Tsujib, K., & Ochi, E. (2024). Effects of omega-3 fatty acids supplementation and resistance training on skeletal muscle. *Clinical Nutrition ESPEN, 58*, 66–73. https://doi.org/10.1016/j.clnesp.2024.03.019
20. Uchitomi, R., Oyabu, M., & Kamei, Y. (2020). Vitamin D and sarcopenia: Potential of vitamin D supplementation in sarcopenia prevention and treatment. *Nutrients, 12*(10), 3189. https://doi.org/10.3390/nu12103189
21. Wyatt, P. B., Reiter, C. R., & Vap, A. R. (2024). Effects of vitamin D supplementation in elite athletes: A systematic review. *Orthopaedic Journal of Sports Medicine, 12*(1), 23259671231220371. https://doi.org/10.1177/23259671231220371
22. Żebrowska, A., et al. (2020). The effect of vitamin D supplementation on serum total 25(OH) levels and biochemical markers of skeletal muscles in runners. *JISSN, 17*(1), 47. https://doi.org/10.1186/s12970-020-00347-8