Public Health in Practice 7 (2024) 100495

Contents lists available at ScienceDirect

Public Health in Practice

journal homepage: www.sciencedirect.com/journal/public-health-in-practice

The effect of physical activity on vitamin D: A systematic review and meta-analysis of intervention studies in humans

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ARTICLE INFO

Keywords:
Vitamin D
25(OH)D
Physical activity
Systematic review
Meta-analysis

ABSTRACT

Objectives: Cross-sectional studies demonstrate a positive association between higher physical activity and serum 25-hydroxyvitamin D (25(OH)D) concentration. However, whether this association is causal is unclear. We conducted a systematic review to identify intervention studies that examined the effect of physical activity on serum 25(OH)D concentration in humans.
Study design: Systematic review and meta-analysis.
Methods: We searched PubMed, Scopus and Web of Science to identify full-text peer-reviewed articles published in English from inception until January 2023. Eligible studies were randomised controlled trials or quasi-experimental studies. We used random effects meta-analysis to calculate the weighted mean difference (WMD) in the change in 25(OH)D concentration between physical activity and control groups. We used the revised Cochrane risk-of-bias tool for randomized trials (RoB 2) to assess the methodological quality of included studies.
Results: We included 32 articles in the systematic review and 24 in the meta-analysis. The intervention varied from resistance and weight-bearing exercises (n = 13) to aerobic exercises (n = 10), moderate and moderate-to-vigorous exercises (n = 5), aquatic exercise (n = 2), and multicomponent traditional exercises (n = 2) (Tai Chi and Yijinjing). The WMD in 25(OH)D in the physical activity and control groups was 9.51 and 4.87, respectively (between-group mean difference 4.64, $p = 0.002$). However, the difference was only evident in studies that implemented the intervention outdoors (n = 3; between-group mean difference 17.33, $p < 0.0001$); when the intervention was indoors there was no significant effect of physical activity on 25(OH)D (n = 16; between-group mean difference 1.80, $p = 0.113$).
Conclusions: This meta-analysis of physical activity interventions in humans showed that physical activity does not lead to increased 25(OH)D independently of time outdoors. However, most studies were under-powered, in many the exercise was low intensity, and vitamin D was not the primary outcome.

1. Introduction

Vitamin D can be synthesised in the skin following exposure to ultraviolet (UV) B radiation from sunlight. It can also be obtained from dietary sources or from vitamin D supplements. Vitamin D is hydroxylated in the liver to form 25-hydroxyvitamin D (25(OH)D), the serum concentration of which is used as the clinical indicator of vitamin D status. The role of vitamin D in maintaining bone health is well-established [1]. Observational studies, randomised controlled trials, and Mendelian randomisation studies suggest that vitamin D may also play a role in a wide range of other health outcomes such as cancer mortality [2], risk and severity of infection [3,4], and autoimmune diseases [5,6].

It is possible that physical activity could influence serum 25(OH)D concentration. Fat-soluble vitamins, including vitamin D, are stored in adipose tissues. Higher body fat mass is associated with a lower rise in 25(OH)D concentration following supplementation, probably caused by vitamin D accumulation in adipose tissue [7]. It has been suggested that

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https://doi.org/10.1016/j.puhip.2024.100495
Received 30 July 2023; Accepted 27 March 2024
Available online 30 March 2024

exercise can increase serum 25(OH)D concentration by stimulating its release from adipose tissue due to lipolysis [8].

A narrative review of observational, cross-sectional and cohort studies found that 25(OH)D concentration was higher in those who undertook more physical activity, irrespective of whether it occurred indoors or outdoors [9]. Several cross-sectional studies published subsequent to the review have reported similar findings [10–17]. However, the positive association between physical activity and vitamin D from these observational studies may be due to confounding by other factors such as body mass index, overall health status, and vitamin D intake from food and supplements.

In light of the potential importance of physical activity in avoiding vitamin D deficiency, and inclusion of advice about the benefits of physical activity for vitamin D in existing guidelines [18], we aimed to systematically review and meta-analyse data from intervention studies that reported the effect of a physical activity intervention on serum 25 (OH)D concentration.

2. Methods

We conducted a systematic review and meta-analysis according to the PRISMA updated guideline for reporting systematic reviews [19]. The protocol for this review was registered with the International Prospective Register of Systematic Reviews (PROSPERO; CRD42020171025; https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=171025).

2.1. Data sources

We searched PubMed, Scopus and Web of Science to identify eligible articles published between database inception and January 2023. We searched reference and citation lists of included studies and reviews to capture any publications missed through our search. We did not search for unpublished studies or other literature. The search terms are presented in Supplement A.

2.2. Inclusion and exclusion criteria

The inclusion criteria were: published in English; included human participants of any age or sex; reported the effect of a physical activity intervention (either indoors or outdoors) on serum/plasma 25(OH)D concentration. We excluded studies that also provided vitamin D supplementation as part of the intervention protocol, unless the same supplement dose was provided to the intervention and control groups. Studies were excluded from the meta-analysis if the pre- and post-intervention data were not presented or were not able to be extracted from the published figures. However, these studies were included in the systematic review if a description of the difference between the intervention and control groups was reported.

2.3. Data extraction

Two reviewers (SRK, REN) screened the title and abstract of studies identified, excluded those that were clearly irrelevant and reviewed the full text of all potentially eligible studies. Any disagreements were resolved by consensus or by consulting a third reviewer (AK). SRK and MC independently extracted data from the included studies. We extracted: year of publication; author; study design; country of origin; characteristics of the study population (i.e., recruitment framework, age, sex); details of the intervention (i.e., intervention design, type and components of the intervention, location of the intervention (indoors, outdoors, not stated but presumed indoors, not reported), length of the intervention, whether the intervention was supervised, use of vitamin D supplement); and outcome (i.e., serum 25(OH)D concentration and associated measure of variability before and after the intervention, 25 (OH)D assay technique used). If the location of the intervention was not explicitly stated, we inferred the location, where possible, from the description of the intervention. Where we were unable to determine the location, the study location was labelled as 'not reported.'

For all studies, the mean, standard deviation (SD) (or equivalent), and number of participants for baseline and post-intervention measurement of serum 25(OH)D were recorded. Serum 25(OH)D concentration presented as nanograms per millilitre was converted to nanomoles per litre. If necessary, we calculated SDs from the standard error of the mean or 95% confidence interval (CI).

2.4. Risk of bias assessment

Two reviewers (SRK, MC) independently assessed the methodological quality of the articles using the revised Cochrane risk-of-bias tool for randomized trials (RoB 2) [20]. All five domains from the tool were used to assess the quality of the studies: randomisation process, effect of assignment to intervention, missing outcome data, measurement of the outcome, and selection of the reported result. The questions in each domain that were addressed to assess each study can be found in Supplement B. Each domain was scored as low, some concerns, or high risk of bias; the tool algorithm was then used to reach a judgement of the overall risk-of-bias across domains. Any disagreement between the two reviewers were resolved through discussion with REN.

2.5. Statistical analyses

The primary outcome was the difference in the change in 25(OH)D concentration (nmol/L) from pre- to post-intervention between the intervention and control groups. The SD of the change (i.e., post – pre) was obtained by using the formula:

$$SD_{change} = \sqrt{SD_{pre}^2 + SD_{post}^2 - 2 \times \rho \times SD_{pre} \times SD_{post}}$$

where SD_{pre} represents the SD of the baseline (i.e., pre-intervention) measure, SD_{post} represents the SD of post-intervention measure, and ρ represents the correlation coefficient between pre- and post-intervention measures. Given the unavailability of ρ values, we assumed $\rho = 0.50$, as used elsewhere [21].

We used random-effects meta-analysis using inverse variance models to calculate the pooled unstandardised weighted mean difference (WMD) in the change in serum 25(OH)D concentration from baseline to post-intervention between the physical activity and control groups. Statistical heterogeneity was assessed by calculating I^2 statistics. In addition to our overall meta-analysis, we estimated the effects of physical activity on serum 25(OH)D concentration according to whether the physical activity intervention occurred indoors or outdoors. Studies where the location was not reported were excluded from the subgroup analysis. If the studies contained multiple intervention and control arms (e.g., one arm performed physical activity outdoors and one arm performed indoors), they were treated as separate studies for the purposes of the meta-analysis.

3. Results

3.1. Search results

We identified 946 articles through our database searches and three additional articles were identified through reference list searches. After removing duplicates, the titles and abstracts of 667 articles were screened; 123 full-text articles were assessed for eligibility, 32 were included in the review [22–53] and 24 in the meta-analysis [22–26,29, 31–38,40–43,45–49,51] (Fig. 1).

3.2. Characteristics of included studies

Thirty-one studies were randomised controlled trials (RCTs) and one

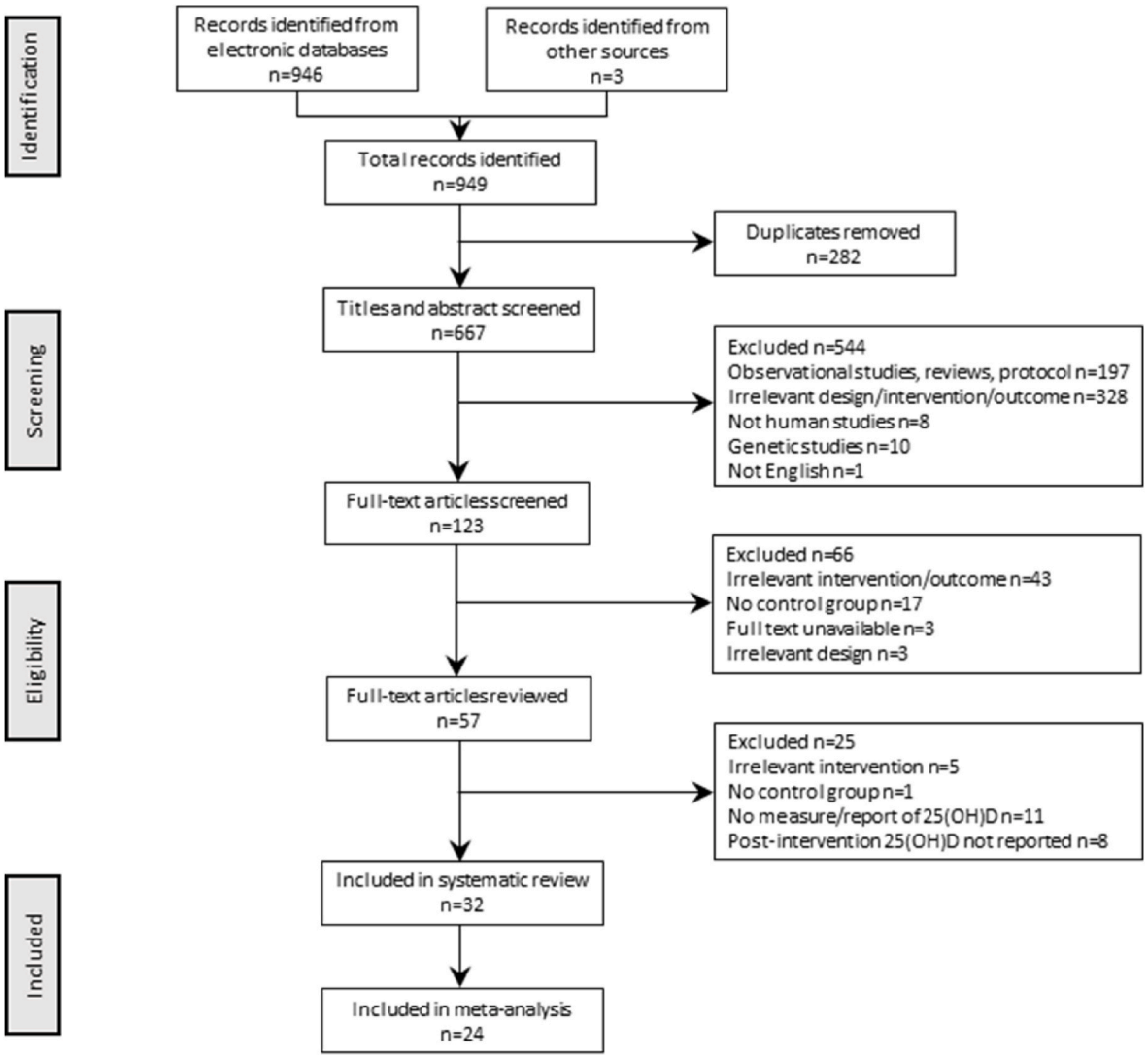

Fig. 1. PRISMA flow diagram for study inclusion.

was a quasi-experimental study [29]. The included studies were conducted between 1999 and 2022. Ten studies were conducted in Europe, 10 in the Asia-Pacific region, seven in the Middle East, three in Brazil and two in the United States. Table S1 presents the characteristics of the included studies.

3.3. Participant characteristics

The total number of participants per study varied from 13[28] to 855 [39]. Only five studies recruited more than 100 participants [24,27,39,44,46]. Twelve studies recruited only female participants and six only male participants. Population groups included pregnant women, breast cancer survivors, post-menopausal women, pre-menopausal women, healthy men, athletes, and people with specific medical diagnoses (adults and children with obesity, children with autism spectrum disorder, cystic fibrosis, adults with type II diabetes, multiple sclerosis, people with metabolic syndrome, haemodialysis patients, and acute hip fracture patients).

3.4. Intervention details

The physical activity interventions varied widely. The interventions were reported as moderate or moderate-to-vigorous intensity (n = 5); aerobic (n = 10); resistance training and weight-bearing (n = 13); aquatic (n = 2); Dynamic Flamingo (DF) exercise: standing on one leg for 1 min three times per day, Tai Chi and walking (n = 1); and Yijinjing (traditional Chinese mind-body exercise) combined with resistance training (n = 1).

In most studies the physical activity interventions were supervised but two home-based physical activity programs were unsupervised [26,40] and two studies had both supervised training sessions and unsupervised home-based sessions [39,44]. Six studies did not clearly state whether the physical activity sessions were supervised or not [36,38,46–48,52]. The frequency of the physical activity interventions ranged from once a week to once daily, with the length of each session ranging from 30 to 75 min. Four studies clearly stated that the physical activity sessions were carried out indoors, and we were able to infer that the physical activity was conducted indoors for an additional 11 studies. However, for six studies we were unable to deduce the location of intervention from the description given. One study had separate intervention arms for indoors and outdoors physical activity [31] and two studies specifically designed the intervention to take place outdoors [36,48]. In one study, participants were encouraged to be moderately physically active and were supplied with a pedometer; however, no information was included in the paper about the location of their activity. The participants in this study also had access to a supervised session at a fitness centre [44].

Thirty studies had one intervention and one control arm. One study

had two separate intervention arms – indoors physical activity and outdoors physical activity – and one control arm [31]. Another study in athletes included three separate intervention and three control arms, for each of three separate sports (6 arms in total) [35].

The interventions in the control group were: no intervention (n = 16); vitamin D or vitamin D and calcium (n = 9; the intervention group received the same dose); placebo tablets of vitamin D (n = 2); non-exercise intervention (n = 3) such as health education classes, sham exercise training (breathing and stretching) combined with nutrition counselling, and cognitive training. In one study, the control group were encouraged to maintain a lifestyle based on standard medical care for diabetic patients that included a minimum of 150 min per week exercise [52]. One study maintained usual medical care in bariatric surgery patients in the control group [45].

3.5. Risk-of-bias

No studies were assessed to have an overall low risk-of-bias; 29 studies had some concerns and three had high risk-of-bias (Table S2).

3.6. Effect of physical activity on 25(OH)D concentration

The meta-analysis included 24 studies in total, representing 27 different intervention groups (Fig. 2). Three of the interventions occurred outdoors, 18 indoors or presumed to be indoors and six were not reported. The pre- and post-intervention serum 25(OH)D concentrations reported for each study are presented in Table S3. Overall, the intervention group had an average of 4.64 nmol/L greater increase in 25(OH)D concentration from baseline to post-intervention compared to the control group (95% CI: 1.76 to 7.52; p = 0.002); the heterogeneity was 88.5% (p < 0.0001). In studies where the physical activity intervention took place indoors or was presumed to be indoors there was minimal difference between the intervention and control groups (between-group mean difference 1.80; 95% CI: -0.43 to 4.02; p = 0.113), whereas there was a large, statistically significant difference when the intervention took place outdoors (between-group mean difference 17.33; 95% CI: 14.59 to 20.07; p < 0.0001). However, only three studies designed the intervention to take place outdoors and the sample sizes in these studies were small (45, 30 and 37, respectively) [31,36,48].

Eight studies were not included in the meta-analysis due to the way the results were presented. Four of these, all of which were conducted indoors or indoors-presumed, reported that the change in 25(OH)D concentration from baseline to post-intervention differed minimally between the intervention and control groups [27,50,52,53]. Three studies found a greater change in the intervention group compared with the control group [30,39,44]. Of these, one was carried out indoors and possibly outdoors and found a significantly higher increase in 25(OH)D concentration in the intervention group compared to the control group (p = 0.009) [44]. Two others took place indoors; one reported a slightly greater increase in 25(OH)D concentration in the intervention group (1.9 nmol/L; p = 0.048) [39] and the other reported a 6.25 nmol/L increase in 25(OH)D concentration in the intervention group and a 2.5 nmol/L decrease in the control group post-intervention [30]. One study, presumably conducted indoors, reported a decrease in 25(OH)D concentration in both intervention and control groups. However, the decrease was much larger in the intervention group than the control group (55 nmol/L vs 35 nmol/L, respectively) [28].

4. Discussion

In this systematic review and meta-analysis of intervention studies we found that physical activity does not influence serum 25(OH)D concentration independently of time outdoors. However, there was considerable variability across the physical activity intervention in

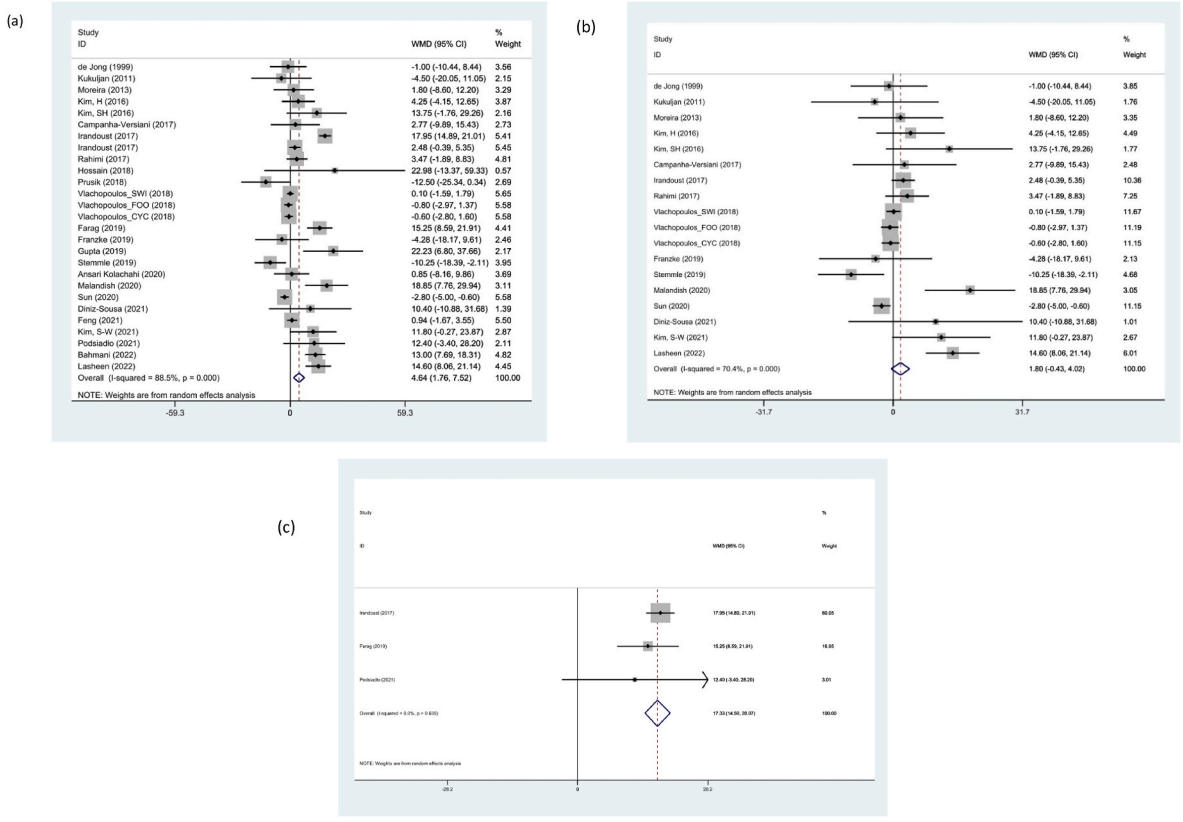

Fig. 2. Random effects meta-analysis of: (a) all studies; (b) studies conducted indoors or indoor-presumed; and (c) studies conducted outdoors. The estimate is the weighted mean difference in the change in serum 25(OH)D concentration between the intervention and control groups.

terms of the type and frequency of exercise and the length of the intervention; few studies explored the effect of high-intensity exercise.

It has been hypothesised that physical activity might influence serum 25(OH)D concentration by increasing fat metabolism, leading to the release of vitamin D and/or its metabolites from adipose tissue [58]. This hypothesis has been supported by the many observational studies that have shown positive effects of physical activity on 25(OH)D concentration or vitamin D status [54–57]. However, observational data are difficult to interpret due to the challenges in controlling for confounding factors including time outdoors. Some observational studies have found that the effect persists after controlling for sun exposure [54], and that both indoor and outdoor physical activity lead to increased 25(OH)D concentration after mutual adjustment [57]. However, time outdoors is extremely difficult to measure, and the dose of UV radiation received while outdoors is difficult to measure [59], limiting the ability to control for confounders. Some studies have concluded that much of the effects of physical activity on vitamin D is attributable to time outdoors. For example, one study reported effects of physical activity on 25(OH)D concentration in the months when there was sufficient UV-B radiation to manufacture vitamin D, but not in those months with limited UV-B radiation [56]; if physical activity has an independent effect on vitamin D this difference would not have been observed. Given the somewhat intractable problem of controlling for confounding, experimental evidence is needed to determine whether physical activity, independently of time outdoors or sun exposure, influences vitamin D.

Our findings suggest that it is unlikely that physical activity, in the absence of time outdoors, has any clinically meaningful effect on vitamin D status. However, many of the studies were in people with a clinical condition, and for the most part the exercise regimen administered was relatively modest. It is plausible that high dose (frequency and length) and intensity of physical activity would lead to increased 25 (OH)D concentration. In addition, the baseline 25(OH)D concentration was in the sufficient range in many studies, and there is some evidence that physical activity may only be beneficial in the presence of vitamin D deficiency [58]. Nevertheless, as vitamin D deficiency is a clinical condition warranting rapid correction through supplementation, this question is of limited clinical relevance.

This analysis has strengths and limitations. Despite our comprehensive review of the literature, it is possible that we might have failed to identify some studies that reported on the effect of physical activity on 25(OH)D concentration. For most studies, change in 25(OH)D concentration was not the primary or secondary outcome, frequently being reported incidentally, making it challenging to identify all relevant publications. Most studies recruited people from selected population subgroups, limiting generalisability to the wider population, and most had small sample size, and were statistically under-powered. There was variability in the laboratory assays used to determine 25(OH)D concentration and not all laboratories were taking part in a quality assurance program; measurement error may have reduced the ability of studies to detect the effect of a physical activity intervention. The quality of the included studies was moderate, with no studies classified as having low risk of bias. Not all studies described whether the physical activity intervention occurred indoors or outdoors; in some, but not all, we were able to infer the location from the description of the intervention. Finally, participants were not blinded to whether they were in the intervention or control group, and it is plausible that being randomised to a physical activity intervention could have resulted in other changes that could have influenced 25(OH)D concentration.

The studies of indoors physical activity interventions suggest that there is minimal effect of physical activity on 25(OH)D concentration. There was a large effect when physical activity interventions were delivered outdoors, but this was based on only three small studies, and increased sun exposure is most likely responsible for this effect. Regular physical activity clearly has a range of physical and psychological benefits, so it is vital that campaigns continue to promote this as an effective health promotion measure. However, physical activity indoors should not be promoted specifically as a measure to mitigate the risk of vitamin D deficiency. This should be reflected as existing guidelines are updated.

Financial support

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhip.2024.100495.

References

[1] K.J. Segheto, M. Pereira, D. Silva, C.J. Carvalho, F.R. Massardi, A.M. Kakehasi, et al., Vitamin D and bone health in adults: a systematic review and meta-analysis, Ciên. Saúde Colet. 26 (8) (2021) 3221–3244, https://doi.org/10.1590/1413-81232021268.15012020.

[2] N. Keum, Q. Chen, D. Lee, J. Manson, E. Giovannucci, Vitamin D supplementation and total cancer incidence and mortality by daily vs. infrequent large-bolus dosing strategies: a meta-analysis of randomised controlled trials, Br. J. Cancer (2022) 1–7, https://doi.org/10.1038/s41416-022-01850-2.

[3] D.A. Jolliffe, Jr CA. Camargo, J.D. Sluyter, M. Aglipay, J.F. Aloia, D. Ganmaa, et al., Vitamin D supplementation to prevent acute respiratory infections: a systematic review and meta-analysis of aggregate data from randomised controlled trials, Lancet Diabetes Endocrinol. 9 (5) (2021) 276–292, https://doi.org/10.1016/S2213-8587(21)00051-6.

[4] H. Pham, M. Waterhouse, C. Baxter, Romero B. Duarte, D.S.A. McLeod, B. K. Armstrong, et al., The effect of vitamin D supplementation on acute respiratory tract infection in older Australian adults: an analysis of data from the D-Health Trial, Lancet Diabetes Endocrinol. 9 (2) (2021) 69–81, https://doi.org/10.1016/S2213-8587(20)30380-6.

[5] M.A. Kriegel, J.E. Manson, K.H. Costenbader (Eds.), Does Vitamin D Affect Risk of Developing Autoimmune Disease?: A Systematic Review, Elsevier, 2011. Semin Arthritis Rheum.

[6] A. Antico, M. Tampoia, R. Tozzoli, N. Bizzaro, Can supplementation with vitamin D reduce the risk or modify the course of autoimmune diseases? A systematic review of the literature, Autoimmun. Rev. 12 (2) (2012) 127–136, https://doi.org/10.1016/j.autrev.2012.07.007.

[7] M. Golzarand, B.W. Hollis, P. Mirmiran, C.L. Wagner, S. Shab-Bidar, Vitamin D supplementation and body fat mass: a systematic review and meta-analysis, Eur. J. Clin. Nutr. 72 (10) (2018) 1345–1357, https://doi.org/10.1038/s41430-018-0132-z.

[8] X. Sun, Z.-B. Cao, H. Taniguchi, K. Tanisawa, M. Higuchi, Effect of an acute bout of endurance exercise on serum 25(OH)D concentrations in young adults, J. Clin. Endocrinol. Metab. 102 (11) (2017) 3937–3944, https://doi.org/10.1210/jc.2017-00146.

[9] M.R. Fernandes, WdR. Barreto, Association between physical activity and vitamin D: a narrative literature review, Rev. Assoc. Med. Bras. 63 (2017) 550–556, https://doi.org/10.1590/1806-9282.63.06.550.

[10] J.T. Hall, M. Ebeling, J.R. Shary, N. Forestieri, C.L. Wagner, The relationship between physical activity and vitamin D status in postpartum lactating and formula-feeding women, J. Steroid Biochem. Mol. Biol. 177 (2018) 261–265, https://doi.org/10.1016/j.jsbmb.2017.08.015.

[11] C. Mortensen, C. Mølgaard, H. Hauger, M. Kristensen, C.T. Damsgaard, Sun behaviour and physical activity associated with autumn vitamin D status in 4-8-year-old Danish children, Publ. Health Nutr. 21 (17) (2018) 3158–3167, https://doi.org/10.1017/s1368980018002094.

[12] A.C.M. da Silva, F.V. Cureau, C.L. de Oliveira, D.T. Giannini, K.V. Bloch, M.C. C. Kuschnir, et al., Physical activity but not sedentary time is associated with vitamin D status in adolescents: study of cardiovascular risk in adolescents (ERICA), Eur. J. Clin. Nutr. 73 (3) (2019) 432–440, https://doi.org/10.1038/s41430-018-0192-0.

[13] C.H. Orces, Association between leisure-time aerobic physical activity and vitamin D concentrations among US older adults: the NHANES 2007-2012, Aging Clin. Exp. Res. 31 (5) (2019) 685–693, https://doi.org/10.1007/s40520-018-1031-9.

[14] A. Bauer, I. Lechner, M. Auer, T. Berger, G. Bsteh, F. Di Pauli, et al., Influence of physical activity on serum vitamin D levels in people with multiple sclerosis, PLoS One 15 (6) (2020) e0234333, https://doi.org/10.1371/journal.pone.0234333.

[15] M. Simunovic, D. Supe-Domic, Z. Karin, M. Degoricija, M. Paradzik, R. Skrabic, et al., The relationship of vitamin D status, adherence to the mediterranean diet, and physical activity in obese children and adolescents, J. Med. Food 24 (4) (2021) 385–393, https://doi.org/10.1089/jmf.2020.0032.

[16] G. Ceolin, S.C. Confortin, A.A.M. da Silva, C.R. Rech, E. d'Orsi, D.K. Rieger, et al., Association between physical activity and vitamin D is partially mediated by adiposity in older adults: EpiFloripa Aging Cohort Study, Nutr. Res. 103 (2022) 11–20, https://doi.org/10.1016/j.nutres.2022.03.001.
[17] S.W. Farrell, K.J. Meyer, D. Leonard, K. Shuval, C.E. Barlow, A. Pavlovic, et al., Physical activity, adiposity, and serum vitamin D levels in healthy women: the Cooper Center longitudinal study, J. Womens Health (Larchmt) 31 (7) (2022) 957–964, https://doi.org/10.1089/jwh.2021.0402.
[18] National Cancer Control Policy contributors, Position statement - risks and benefits of sun exposure, National Cancer Control Policy (2018). Available from: https://wiki.cancer.org.au/policy_mw/index.php?title=Position_statement_-_Risks_and_benefits_of_sun_exposure&oldid=7939.
[19] M.J. Page, J.E. McKenzie, P.M. Bossuyt, I. Boutron, T.C. Hoffmann, C.D. Mulrow, et al., The PRISMA 2020 statement: an updated guideline for reporting systematic reviews, BMJ Br. Med. J. (Clin. Res. Ed.) 372 (2021) n71, https://doi.org/10.1136/bmj.n71.
[20] J.A.C. Sterne, J. Savović, M.J. Page, R.G. Elbers, N.S. Blencowe, I. Boutron, et al., RoB 2: a revised tool for assessing risk of bias in randomised trials, BMJ Br. Med. J. (Clin. Res. Ed.) 366 (2019) l4898, https://doi.org/10.1136/bmj.l4898.
[21] D. Follmann, P. Elliott, I. Suh, J. Cutler, Variance imputation for overviews of clinical trials with continuous response, J. Clin. Epidemiol. 45 (7) (1992) 769–773, https://doi.org/10.1016/0895-4356(92)90054-Q.
[22] N. de Jong, M. Paw, L. de Groot, C. de Graaf, F.J. Kok, W.A. van Staveren, Functional biochemical and nutrient indices in frail elderly people are partly affected by dietary supplements but not by exercise, J. Nutr. 129 (11) (1999) 2028–2036, https://doi.org/10.1093/jn/129.11.2028.
[23] S. Kukuljan, C.A. Nowson, K.M. Sanders, G.C. Nicholson, M.J. Seibel, J. Salmon, et al., Independent and combined effects of calcium-vitamin D3 and exercise on bone structure and strength in older men: an 18-month factorial design randomized controlled trial, J. Clin. Endocrinol. Metab. 96 (4) (2011) 955–963, https://doi.org/10.1210/jc.2010-2284.
[24] L. Moreira, F.C. Fronza, R.N. dos Santos, L.R. Teixeira, L.F. Kruel, M. Lazaretti-Castro, High-intensity aquatic exercises (HydrOS) improve physical function and reduce falls among postmenopausal women, Menopause 20 (10) (2013) 1012–1019, https://doi.org/10.1097/GME.0b013e3182850138.
[25] H. Kim, M. Kim, N. Kojima, K. Fujino, E. Hosoi, H. Kobayashi, et al., Exercise and nutritional supplementation on community-dwelling elderly Japanese women with sarcopenic obesity: a randomized controlled trial, J. Am. Med. Dir. Assoc. 17 (11) (2016) 1011–1019, https://doi.org/10.1016/j.jamda.2016.06.016.
[26] S.H. Kim, Y.U. Cho, S.J. Kim, S. Hong, M.S. Han, E. Choi, The effect on bone outcomes of adding exercise to supplements for osteopenic breast cancer survivors A pilot randomized controlled trial, Cancer Nurs. 39 (2) (2016) 144–152, https://doi.org/10.1097/ncc.0000000000000245.
[27] C. Mason, L. Xiao, I. Imayama, C.R. Duggan, C. Bain, K.E. Foster-Schubert, et al., Effects of weight loss on serum vitamin D in postmenopausal women, Am. J. Clin. Nutr. 94 (1) (2011) 95–103, https://doi.org/10.3945/ajcn.111.015552.
[28] S.M. Marinho, D. Mafra, S. Pelletier, V. Hage, C. Teuma, M. Laville, et al., In hemodialysis patients, intradialytic resistance exercise improves osteoblast function: a pilot study, J. Ren. Nutr.: Off. J. Council Renal Nutr. Nat. Kidney Found. 26 (5) (2016) 341–345, https://doi.org/10.1053/j.jrn.2016.03.002.
[29] L. Campanha-Versiani, D.A.G. Pereira, G.A. Ribeiro-Samora, A.V. Ramos, M.F.H. de Sander Diniz, L.A. De Marco, et al., The effect of a muscle weight-bearing and aerobic exercise program on the body composition, muscular strength, biochemical markers, and bone mass of obese patients who have undergone gastric bypass surgery, Obes. Surg. 27 (8) (2017) 2129–2137, https://doi.org/10.1007/s11695-017-2618-5.
[30] P.D. Freitas, P.G. Ferreira, A.G. Silva, R. Stelmach, R.M. Carvalho-Pinto, F.L. A. Fernandes, et al., The role of exercise in a weight-loss program on clinical control in obese adults with asthma. A randomized controlled trial, Am. J. Respir. Crit. Care Med. 195 (1) (2017) 32–42, https://doi.org/10.1164/rccm.201603-0446OC.
[31] K. Irandoust, M. Taheri, The effect of Vitamin D supplement and indoor vs outdoor physical activity on depression of obese depressed women, Asian J. Sports Med. 8 (3) (2017), https://doi.org/10.5812/asjsm.13311.
[32] N. Rahimi, M. Ali, S. Sharif, A.R. Goharian, A.H. Pour, The effects of aerobic exercises and 25(OH) D supplementation on GLP1 and DPP4 level in Type II diabetic patients, Int. J. Prev. Med. 8 (2017), https://doi.org/10.4103/ijpvm.IJPVM_161_17.
[33] M.J. Hossain, A. Levinson, D. George, J. Canas, S. Kumar, P. Babu Balagopal, Vitamin D status and cardiovascular risk in obesity: effect of physical activity in nonvitamin D supplemented adolescents, Metab. Syndr. Relat. Disord. 16 (4) (2018) 197–203, https://doi.org/10.1089/met.2017.0171.
[34] K. Prusik, J. Kortas, K. Prusik, J. Mieszkowski, J. Jaworska, W. Skrobot, et al., Nordic walking training causes a decrease in blood cholesterol in elderly women supplemented with vitamin D, Front. Endocrinol. 9 (FEB) (2018), https://doi.org/10.3389/fendo.2018.00042.
[35] D. Vlachopoulos, A.R. Barker, E. Ubago-Guisado, C.A. Williams, L. Gracia-Marco, A 9-month jumping intervention to improve bone geometry in adolescent male athletes, Med. Sci. Sports Exerc. 50 (12) (2018) 2544–2554, https://doi.org/10.1249/mss.0000000000001719.
[36] H.A.M. Farag, M.J. Hosseinzadeh-Attar, B.A. Muhammad, A. Esmaillzadeh, A.H. el Bilbeisi, Effects of vitamin D supplementation along with endurance physical activity on lipid profile in metabolic syndrome patients: a randomized controlled trial, Diabetes Metabol. Syndr. 13 (2) (2019) 1093–1098, https://doi.org/10.1016/j.dsx.2019.01.029.
[37] B. Franzke, B. Schober-Halper, M. Hofmann, S. Oesen, A. Tosevska, E.M. Strasser, et al., Fat soluble vitamins in institutionalized elderly and the effect of exercise, nutrition and cognitive training on their status-The Vienna Active Aging Study (VAAS): a randomized controlled trial, Nutrients 11 (6) (2019), https://doi.org/10.3390/nu11061333.
[38] S. Gupta, A. Mukherjee, R. Lodha, M. Kabra, K.K. Deepak, R. Khadgawat, et al., Effects of exercise intervention program on bone mineral accretion in children and adolescents with cystic fibrosis: a randomized controlled trial, Indian J. Pediatr. 86 (11) (2019) 987–994, https://doi.org/10.1007/s12098-019-03019-x.
[39] M.K. Gustafsson, P.R. Romundstad, S.N. Stafne, A.S. Helvik, A.K. Stunes, S. Mørkved, et al., The effect of an exercise program in pregnancy on vitamin D status among healthy, pregnant Norwegian women: a randomized controlled trial, BMC Pregnancy Childbirth 19 (1) (2019) 76, https://doi.org/10.1186/s12884-019-2220-z.
[40] J. Stemmle, A. Marzel, P.O. Chocano-Bedoya, E.J. Orav, B. Dawson-Hughes, G. Freystaetter, et al., Effect of 800 IU versus 2000 IU vitamin D3 with or without a simple home exercise program on functional recovery after hip fracture: a randomized controlled trial, J. Am. Med. Dir. Assoc. 20 (5) (2019) 530, https://doi.org/10.1016/j.jamda.2018.10.013.
[41] S. Ansari Kolachahi, F. AdibSaber, Z.H. Zidashti, A. Elmieh, E. Bidabadi, A. A. Hosseinkhanzadeh, Water-based training in combined with vitamin D supplementation improves lipid profile in children with ASD, Res. Autism Spectr. Disord. 76 (2020), https://doi.org/10.1016/j.rasd.2020.101603.
[42] A. Malandish, B. Tartibian, Z. Sheikhlou, R. Afsargharehbagh, M. Rahmati, The effects of short-term moderate intensity aerobic exercise and long-term detraining on electrocardiogram indices and cardiac biomarkers in postmenopausal women, J. Electrocardiol. 60 (2020) 15–22, https://doi.org/10.1016/j.jelectrocard.2020.03.004.
[43] X. Sun, X.K. Ma, L. Zhang, Z.B. Cao, Effects of resistance training on serum 25(OH) D concentrations in young men: a randomized controlled trial, Nutr. Metab. 17 (1) (2020), https://doi.org/10.1186/s12986-020-00480-w.
[44] M.H. Tanvig, D.M. Jensen, M.S. Andersen, P.G. Ovesen, J.S. Jørgensen, C.A. Vinter, Vitamin D levels were significantly higher during and after lifestyle intervention in pregnancy: a randomized controlled trial, Acta Obstet. Gynecol. Scand. 99 (3) (2020) 350–356, https://doi.org/10.1111/aogs.13722.
[45] F. Diniz-Sousa, L. Veras, G. Boppre, P. Sa-Couto, V. Devezas, H. Santos-Sousa, et al., The effect of an exercise intervention program on bone health after bariatric surgery: a randomized controlled trial, J. Bone Miner. Res. 36 (3) (2021) 489–499, https://doi.org/10.1002/jbmr.4213.
[46] F. Feng, G. Shi, H. Chen, P. Jia, L. Bao, F. Xu, et al., Comprehensive interventions including vitamin D effectively reduce the risk of falls in elderly osteoporotic patients, Orthop. Surg. (2021), https://doi.org/10.1111/os.13009.
[47] S.W. Kim, M.W. Seo, H.C. Jung, J.K. Song, Effects of high-impact weight-bearing exercise on bone mineral density and bone metabolism in middle-aged premenopausal women: a randomized controlled trial, Appl. Sci. 11 (2) (2021), https://doi.org/10.3390/app11020846.
[48] S. Podsiadło, A. Skiba, A. Kałuża, B. Ptaszek, J. Stożek, A. Skiba, et al., Influence of nordic walking training on vitamin d level in the blood and quality of life among women aged 65–74, Healthcare 9 (9) (2021), https://doi.org/10.3390/healthcare9091146.
[49] E. Bahmani, R. Hoseini, E. Amiri, The effect of home-based aerobic training and vitamin D supplementation on fatigue and quality of life in patients with multiple sclerosis during COVID-19 outbreak, Sci. Sports 37 (8) (2022) 710–719, https://doi.org/10.1016/j.scispo.2021.12.014.
[50] Y. Huang, J. Han, Q. Gu, Y. Cai, J. Li, S. Wang, et al., Effect of Yijinjing combined with elastic band exercise on muscle mass and function in middle-aged and elderly patients with prediabetes: a randomized controlled trial, Front. Med. 9 (2022), https://doi.org/10.3389/fmed.2022.990100.
[51] Y.R. Lasheen, S.M. Monir, A.A.B. Elwishy, E.E.S. Abutaleb, Influence of selected aerobic exercises on serum vitamin D level in patients with multiple sclerosis, Egypt. J. Chem. 65 (1) (2022) 657–664, https://doi.org/10.21608/ejchem.2021.84646.4134.
[52] S.W. Mudjanarko, A. Irawati, D. Tinduh, Effects of aerobic exercise on adiponectin levels potentially mediated by vitamin D in type 2 diabetic patients, Endocr. Regul. 56 (3) (2022) 201–208, https://doi.org/10.2478/enr-2022-0021.
[53] X.M. Sun, W.J. Xiao, Z.Y. Li, S.R. Zhou, M.Y. Dong, C. Huang, et al., Does vitamin D supplementation improve bone health, body composition and physical performance beyond endurance exercise in patients with type 2 diabetes: a secondary analysis of randomized controlled trial, Front. Physiol. 13 (2022), https://doi.org/10.3389/fphys.2022.1003572.
[54] R. Scragg, I. Holdaway, R. Jackson, T. Lim, Plasma 25-hydroxyvitamin D 3 and its relation to physical activity and other heart disease risk factors in the general population, Ann. Epidemiol. 2 (5) (1992) 697–703, https://doi.org/10.1016/1047-2797(92)90014-H.
[55] R. Scragg, I. Holdaway, V. Singh, P. Metcalf, J. Baker, E. Dryson, Serum 25-hydroxyvitamin D3 is related to physical activity and ethnicity but not obesity in a multicultural workforce, Aust. N. Z. J. Med. 25 (3) (1995) 218–223, https://doi.org/10.1111/j.1445-5994.1995.tb01526.x.
[56] M.A. Kluczynski, M.J. Lamonte, J.A. Mares, J. Wactawski-Wende, A.W. Smith, C. D. Engelman, et al., Duration of Physical Activity and Serum 25-hydroxyvitamin D Status of Postmenopausal Women, 2011, https://doi.org/10.1016/j.annepidem.2010.11.011.
[57] M. Wanner, A. Richard, B. Martin, J. Linseisen, S. Rohrmann, Associations between objective and self-reported physical activity and vitamin D serum levels in the US

population, Cancer Causes Control 26 (6) (2015) 881–891, https://doi.org/10.1007/s10552-015-0563-y.
[58] J. Zhang, Z.-B. Cao, Exercise: a possibly effective way to improve vitamin D nutritional status, Nutrients 14 (2022) 2652, https://doi.org/10.3390/nu14132652.
[59] L. King, F. Xiang, A. Swaminathan, R.M. Lucas, Measuring sun exposure in epidemiological studies: matching the method to the research question, J. Photochem. Photobiol. B Biol. 153 (2015) 373–379, https://doi.org/10.1016/j.jphotobiol.2015.10.024.