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REVIEW

Effectiveness and safety of physical exercise and health education for the management of osteoporotic vertebral fractures: a systematic review and meta-analysis

M. Fernández-González[1] · M. Mora-Traverso[2,3,4] · P. Molina-Garcia[5,6,7] · R. Prieto-Moreno[8,9,10,11] · M. Ortiz-Piña[12] · J. Contreras-Gutiérrez[13,14] · P. Ariza-Vega[1,4,7]

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Abstract

Osteoporotic vertebral fractures (OVFs) are the second most common fractures in osteoporosis, often leading to reduced functional capacity, chronic pain, and lower quality of life. Physical exercise and health education are considered promising options for managing these symptoms. To determine the effectiveness and safety of exercise and health education compared to usual care in patients with OVFs. A literature search up to April 2024 was conducted in PubMed, Scopus, Web of Science, and the Cochrane Library. Clinical trials involving adults with OVFs were included, focusing on physical capacity (primary outcome) and other health outcomes. Study selection, bias assessment, and data extraction were independently conducted by two authors, with a third author resolving conflicts. Nineteen studies were included in the meta-analysis of exercise interventions. Exercise interventions were analyzed using a standardized mean difference (SMD) meta-analysis, with additional sensitivity analyses. Physical exercise significantly improves functional capacity (SMD −0.41; 95% CI −0.69 to −0.14; *p* 0.003), aerobic capacity, balance, trunk muscle strength, pain, and quality of life in patients with OVF. No significant effects were observed on thoracic posture or fear of falling. Adverse event risk was low (6%), comparable to usual care or daily activities. Health education interventions (two studies) were synthetized narratively, both showing improvements in pain, mobility, and patient knowledge. Physical exercise is effective and safe in the recovery of OVFs; thus, its prescription is recommended. Most interventions focus first on core strength and motor control and then on aerobic and resistance training. Further evidence is needed to demonstrate the effectiveness of health education.

Keywords Health education · Osteoporosis · Physical exercise · Vertebral fracture

Introduction

Osteoporotic vertebral fractures (OVF) are the second most common osteoporotic injury [1, 2], affecting around 20% of the population in Europe [3]. The lifetime risk of such fractures ranges from 40 to 50% in women and 13–22% in men [4, 5], highlighting a critical challenge for healthcare systems due to the associated increased mortality and substantial clinical impacts [6, 7]. People with OVFs experience impairment of physical function, which leads to the limitation to perform activities of daily living as one of the most significant consequences [8, 9]. Pain exacerbates this issue, negatively affecting motivation, social relationships, and overall quality of life [9–11].

Rehabilitation treatments, including exercise and health education, are normally recommended for a multidisciplinary biopsychosocial recovery approach for OVF patients [8, 12]. Exercise clinical guidelines for people with OVFs recommend interventions that focus on improving functional capacity, balance, back extensor endurance, spinal mobility, and pain management, mainly through resistance training, balance, and aerobic exercise [13, 14]. Enhancing health literacy in patients helps to actively manage their condition, which is essential for effective treatment, through aspects such as safe movements, pharmacological management, preventable risk factors, nutrition, and adherence to treatment [14, 15]. Previous systematic reviews [16–18] have examined the effectiveness of physical exercise and health education in treating OVFs, but they were inconclusive and highlighted significant limitations.

Therefore, the first aim of this systematic review and meta-analysis was to determine the effects of two

Extended author information available on the last page of the article

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rehabilitation treatments, exercise and health education, on relevant clinical outcomes such as functional capacity in patients with OVFs, compared to no treatment (a common scenario in many healthcare systems) or usual care. The second objective was to specifically assess the safety of exercise by studying adverse events during its implementation in people with OVFs.

Methods

This systematic review was registered in the International Prospective Register of Systematic Reviews PROSPERO with register number CRD42024547826. To carry out this study, the guidelines of the PRISMA Declaration for systematic reviews and meta-analyses (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) were followed [19].

Eligibility

To carry out this systematic review, inclusion criteria were based on the following PICOS criteria: (1) population: participants over 18 years diagnosed with osteoporotic vertebral fractures; (2) intervention: exercise and/or health education-based intervention; (3) comparison: the inclusion of any control group, as those not receiving any treatment or those receiving the conventional treatment offered by healthcare systems; (4) outcomes: physical capacity and any other outcome related to health; and (5) study design: clinical trials including randomized control trials, quasi-experimental trials, and pilot studies. Articles were excluded if they (1) had a different study design, such as single-case studies, editorials, or systematic reviews; (2) included populations whose vertebral fractures were caused by other conditions, such as cancer; and (3) were published in languages other than English and Spanish.

Search strategy and study selection

The databases Medline, Web of Science, Scopus, and the Cochrane Library were researched from their inception to April 2024. The search strategy is available in Table A.1. Two independent researchers (M.F-G and J.C-G) carried out the study selection process, and any discrepancies were resolved by a third researcher (P.M-G). The systematic review software COVIDENCE (Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia, available at www.covidence.org) was used in the study selection process.

Data extraction

The following information of each study was extracted: (1) author's name, publication year, and country; (2) study design; (3) participant information; (4) time since fracture; (5) outcomes included; (6) measurement instruments used; (7) intervention time and follow-up; (8) intervention information; (9) control group information. Two researchers (M.F-G and J.C-G) performed data extraction, and any discrepancies were resolved by a third researcher (P.M-G).

Risk of bias

To perform the risk of bias assessment, the Joanna Briggs Institute Critical Appraisal Tool for Systematic Reviews checklists [20] was used. This tool evaluates aspects such as randomization, allocation concealment, similarity of groups at baseline, blinding of outcome assessors, completeness of follow-up, and reliability of outcome measurement. Two items for randomized controlled trials (items 4 and 5) were removed because they referred to the blinding of participants, which was not possible because of the intervention type (exercise and/or health education). Each item has four answer choices: "yes" (criterion met), "no" (criterion not met), "unclear," or "not applicable." Studies were classified as low risk (≤ 1 high risk/unclear criterion), moderate risk (2 high risk/unclear), or high risk (≥ 3 high risk/unclear). Two investigators (M.F-G and J.C-G) performed individual risk of bias assessment in each study, and any discrepancies were resolved by a third investigator (P.M-G).

Meta-analysis

The reduced number of studies regarding health education interventions made it impossible to include them in the meta-analysis. For the effectiveness meta-analysis, the mean difference (physical exercise intervention vs. control/usual care) in continuous outcome variables after therapy was used to calculate the total effect size. Several methodological decisions were applied to ensure consistency in the data analyzed: (1) In studies with multiple intervention arms, only the one most closely aligned with a structured physical exercise protocol was selected; (2) for multiple post-intervention time points, the assessment closest to the end of the intervention was chosen; (3) when multiple instruments assessed the same outcome, the most frequently used tool across all included studies was selected; and (4) only outcomes reported by a minimum of two studies were included in the meta-analysis [21]. The reported standard deviations were used and, if not reported, were calculated using reported standard error or confidence intervals (CIs) following the Cochrane Handbook for Systematic Reviews of Interventions [21]. Eight studies reported changes from baseline values instead of post-intervention values but were included in the meta-analysis, as they could be assumed to address the same intervention effect [21]. Since the included studies had assessed the outcome measures using different scales, we used a uniform scale involving the standardized mean difference (SMD). For outcome categories containing multiple assessment tools, the direction of effect was determined by the most frequently reported instrument in the meta-analysis; results from other tools were inverted to align with this convention. The Higgins I^2 statistic and p value were used to test the heterogeneity of included studies, which were classified as not important (0–30%), moderate (30–50%), substantial (50–75%), or considerable (75–100%) [22]. Depending on heterogeneity, a meta-analysis was performed using either the generic inverse variance random-effects model or fixed-effects model.

Three sensitivity analyses were performed: (1) to test the robustness of the results, (2) to evaluate the presence of publication bias, and (3) to examine whether several mediators might influence the results of the meta-analyses. For the robustness analysis, studies were removed one at a time and we tested whether the overall effect size (i.e., Z-score and p value) was significantly modified in magnitude or direction. The publication bias was assessed by a funnel plot and the Egger regression asymmetry test, using the small sample bias-corrected standardized mean difference (Hedges' g) as the effect size metric. It is noted that applying Egger's test to standardized mean differences can lead to inflated false-positive results because the standardized mean difference and standard error are not independent. To address this issue, we used a modified version of the standard error proposed by Pustejovsky and Rodgers [23]. The influence of mediators was analyzed via meta-regressions, including the following factors: publication year, exercise type (i.e., 1—home-based, 2—supervised strength, 3—supervised balance and strength, 4—supervised balance, strength, and aerobic exercise), type of control group (i.e., 1—no treatment or usual care, 2—health education), intervention duration, follow-up time, and the average age of participants.

For the safety meta-analysis, we calculated the risk difference based on the number of major and minor adverse events relative to the total number of participants, both in the exercise and control groups. We used the Mantel–Haenszel statistical methods, anticipating a low number of events, and we planned to use a fixed-effects model due to low heterogeneity. A risk difference greater than 0 indicated a higher risk for exercise training, and a risk difference less than 0 indicated a lower risk for exercise training [24].

This last analysis was conducted with the {meta} package in RStudio version 3.2.1. The meta-analysis was performed using the Review Manager Version 5.3 (The Nordic Cochrane Center, The Cochrane Collaboration, 2014, Copenhagen, Denmark), and the meta-regression with the RStudio statistical program (version 1.4.1106, R Core Team 2020; R Foundation for Statistical Computing, Vienna, Austria; using the {meta} and {metafor} packages [25, 26].

Results

In the original search, a total of 1610 articles were identified, of which 656 duplicates were removed and 412 were excluded using a reference management tool. Finally, a total of 21 articles were included in this systematic review based on the previously established inclusion criteria. The selection process is presented in Fig. 1.

Characteristics of the included studies

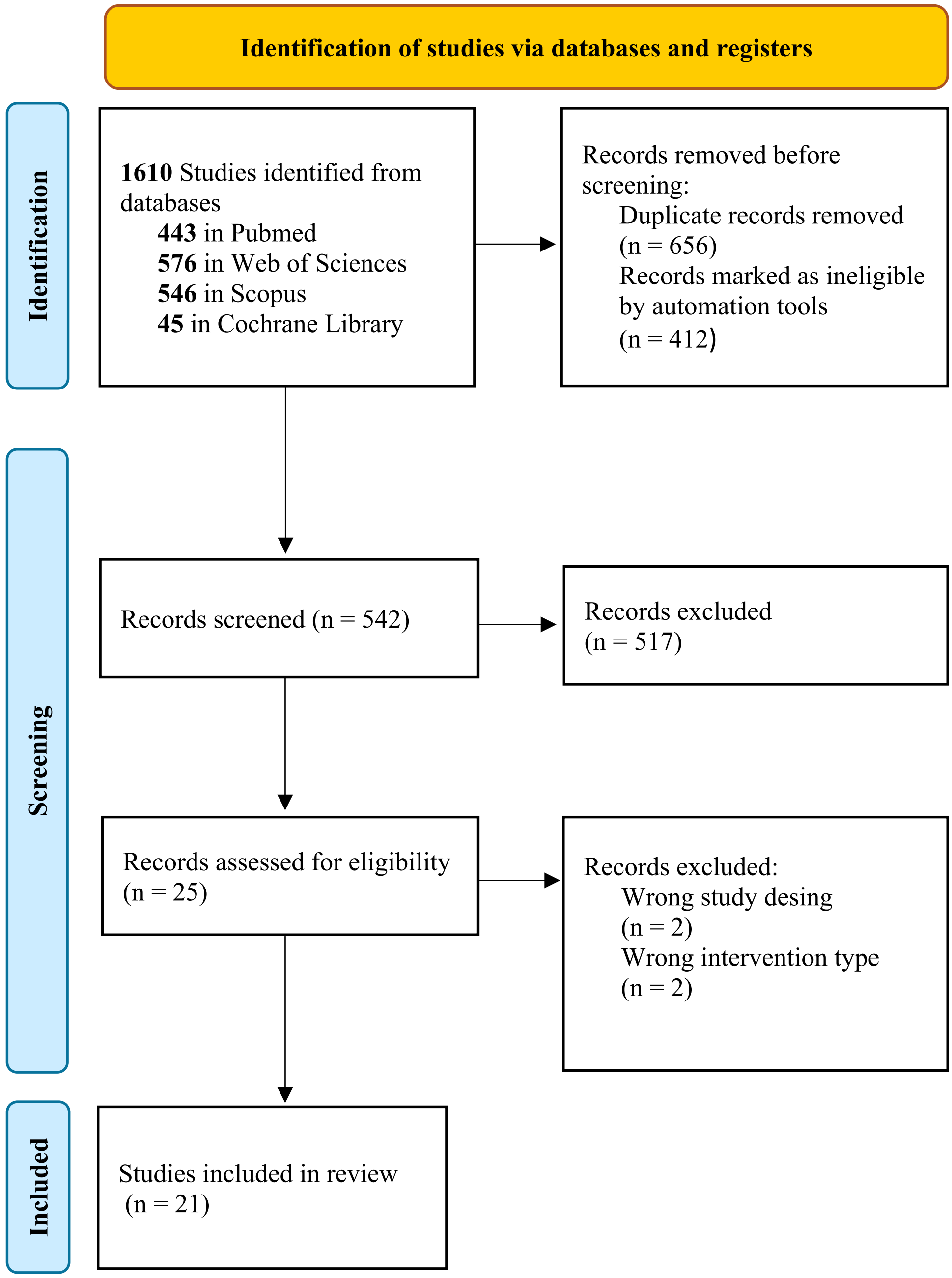
The main characteristics of the included studies are described in Table 1. The studies consisted of randomized controlled trials, except for three quasi-experimental studies [27–29] and a pilot study [30]. All the included studies were published between 1998 [31] and 2024 [32], with most conducted in Northern Europe, followed by Australia, the USA, and Asia. The total sample consisted of 2076 participants, with a mean age (± standard deviation) of 72.77 (± 5.57) years.

Most studies included only women in their samples, except for six [27, 30, 32–34, 45] that included both male and female participants. The time from fracture to study inclusion varied, with some studies not specifying a timeframe, while others required the fracture to have occurred at least 3 months [30, 34, 44, 45] or at least 6 months [29, 36–38, 40] before the intervention.

In regard to the included outcomes and assessment tools, functional capacity was the most evaluated domain, measured in 14 studies (66.7%). The Timed Up and Go (TUG) test was the predominant instrument within this domain, employed in 11 studies [28, 31, 33–35, 37–39, 41, 44, 47]. Self-reported pain was the second most frequent outcome, assessed in 12 studies (57.1%), with the Visual Analogue Scale (VAS) being the most common tool, used in 9 studies [28, 29, 34, 35, 37–41]. Quality of life was evaluated in 11 studies (52.4%), where the QUALEFFO-41 questionnaire was the instrument of choice in 8 instances [30, 33–35, 37, 38, 45, 46]. Other domains were quantified less frequently: balance was assessed in 10 studies (47.6%), thoracic posture in 8 studies (38.1%), trunk muscle endurance in 6 studies (28.6%), and aerobic capacity in 5 studies (23.8%). These domains utilized a wider variety of specific tests, indicating a lower degree of standardization for these particular outcomes.

Regarding the types of interventions, two studies focused exclusively on health education programs [27, 32]. Most interventions focused on multicomponent physical exercise programs. A total of six studies focused their physical exercise programs on core strength and motor control combined with aerobic training [29, 33, 35, 36, 43, 44], while two studies added resistance training to the abovementioned

Fig. 1 PRISMA flowchart of the systematic review process



components [38, 39] and only one study combined all four elements: core strength, motor control, resistance, and aerobic exercise [28]. Seven of them included only core strength and motor control [31, 34, 37, 40–42, 47]. Two of the included studies combined resistance and aerobic exercise [45, 46] and finally, one physical exercise program focused on mindfulness and yoga [30]. To summarize, the most common interventions were those targeting core strength and motor control (35%), followed by core strength, motor control, and aerobic programs (30%), resistance and aerobic programs (10%), core strength, motor control, resistance, and aerobic exercise (5%), and mindfulness and yoga (5%).

Risk of bias

Tables A.2, A.3, and A.4 show the assessment of risk of bias. One of the included studies was not assessed because the full text was not available, so data were not sufficient to complete the assessment [47].

Among the 17 randomized controlled trials included, 14 (82%) presented a low risk of bias and 3 (18%) showed a high risk of bias. The main sources of bias were related to the blinding of outcome evaluators, the identification and control of potential confounders, and the reporting of per-protocol and intention-to-treat analyses. Most studies

Table 1 Characteristics of the included studies

Reference; country	Design	Participants (*N*, % women, mean age ± SD) by group	Time since OVF	Outcomes	Assessment tools	Intervention time; assessment time	Intervention	Control group
Barker et al. [33]; United Kingdom 2020	RCT	Exercise: 216 (85.6% women; 72.2 ± 8.4 y) Manual: 202 (85.6% women; 72.4 ± 9.3 y) SSPT: 195 (88.7% women; 71.9 ± 9.6 y)	Not specific time	Trunk muscle strength/endurance, thoracic posture QoL	TLS and QUALEFFO-41	12 weeks; 4 months	Core strength, balance, aerobic (combination)	Single session of health education
Bennell et al. [34]; Australia 2010	RCT	IG: 11 (63.6% women; 66.2 ± 8.0 y) CG: 9 (100% women; 66.3 ± 11.8 y)	Between 3 and 2 months	Functional capacity, trunk muscle strength/endurance, pain, and QoL	TUG, TLS, VAS, and QUALEFFO-41	10 weeks; 11 weeks	Core strength, motor control (home-based)	Usual care
Bergland et al. [35]; Norway 2011	RCT	IG: 47 (100% women; 70.8 ± 5.9 y) CG: 42 (100% women; 72.0 ± 5.8 y)	Recent fractures excluded	Functional capacity, balance, and QoL	TUG, FR, and QUALEFFO-41	3 months; 3 months	Core strength, aerobic, balance (supervised)	Maintain current lifestyle
Bergström et al. [36]; Sweden 2011	RCT	IG: 20 (100% women; 73.2 ± 8.9 y) CG: 16 (100% women; 74.1 ± 6.0 y)	More than 18 months	Trunk muscle strength/endurance and thoracic posture	Isometric dynamometer and kyphometer	4 months; 4 months	Core strength, resistance (supervised)	Usual care
Çergel et al. [37]; Turkey 2019	RCT	SE: 20 (100% women; 58.90 ± 4.70 y) HE: 20 (100% women; 60.20 ± 7.57 y) CG: 20 (100% women; 59.65 ± 6.45 y)	6 months	Functional capacity trunk muscle strength/endurance, thoracic posture, pain, and QoL	TUG, TLS, dynamometer, and QUALEFFO-41	6 weeks; 6 weeks	Core strength (supervised)	Continue their daily life
Evstigneeva et al. [38]; Russia 2016	RCT	IG: 40 (100% women; 70.7 ± 8.1 y) CG: 38 (100% women; 67.6 ± 7.0 y)	6 months	Functional capacity, balance, thoracic posture, and QoL	TUG, STS, Master® System NeuroCom®, and QUALEFFO-41	12 months; 12 months	Core strength, resistance (supervised)	Maintain their current lifestyle

Table 1 (continued)

Reference; country	Design	Participants (*N*, % women, mean age ± SD) by group	Time since OVF	Outcomes	Assessment tools	Intervention time; assessment time	Intervention	Control group
Gibbs et al. [39]; Canada and Australia 2020	RCT	IG: 71 (100% women; 76.4 ± 6.4 y) CG: 70 (100% women; 77.0 ± 7.3 y)	Not specific time	Functional capacity, balance, trunk muscle strength/endurance, pain, and QoL	SPPB, BOOMER, EQ5D-3 L, and VAS	8 months; 12 months	Core strength, resistance, balance (home-based)	Calls about general health or social discussion
Gold et al. [40]; EEUU 2004	RCT	IG: 94 (100% women; 80.2 ± 4.8 y) CG: 91 (100% women; 82.0 ± 6.2 y)	6 months	Trunk muscle strength/endurance and pain	Isometric arque measured by the B-200 Isostation for trunk strength GSI and FSI	6 months; 6 months	Core strength, resistance (supervised + health education)	Health education about general concerns
Karakasidou et al. [41]; Greece 2013	RCT	IG: 10 (100% women; 69.3 ± 4.4 y) CG: 10 (100% women; 67.6 ± 6.4 y)	5 months	Thoracic posture and pain	Digital inclinometer for spinal curvatures and VAS	3 months; 3 months	Motor control (supervised)	Walking and swimming
Grahn Kronhed et al. [30]; Sweden 2022	Pilot study with randomized groups	IG: 8 (100% women; 71.3 ± 5.3 y) CG: 7 (100% women; 72.4 ± 6.5 y)	3 months	Pain and QoL	VAS, EQ-5D, and QUALEFFO-41	10 weeks; 10 weeks	Mindfulness, yoga (supervised)	10 theory sessions, focus on physical activity, pharmacological treatment, nutrition, balance, pain, and ergonomic aspects
Liang et al. [27]; China 2023	Quasi-experimental controlled trial	IG: 36 (75% women; 77.8 ± 6.6 y) CG: 36 (86.1% women; 74.7 ± 7.2 y)	Not specific time	Pain, understanding of health education, exercise compliance, and satisfaction	Investigation Form for Health Education Awareness, evaluation of adherence a prescribed post-operative functional exercises and JOA Score and Health Education Satisfaction Survey	Hospital stay; during hospitalization, at discharge, 6 h–3 days post-surgery and 1 week post-surgery	Core strength, health education (combination)	Usual health education, with basic health-related information

Table 1 (continued)

Reference; country	Design	Participants (*N*, % women, mean age ± SD) by group	Time since OVF	Outcomes	Assessment tools	Intervention time; assessment time	Intervention	Control group
Liao et al. [32]; Taiwan 2024	RCT	IG: 87 (100% women; 66.9 ± 4.8 y) CG: 84 (100% women; 66.5 ± 7.4 y)	Not specific time	Pain, QoL, and pharmacological management	Brief Pain Inventory (Chinese version) and SF-36	Single-session web-based; 1 month	Core strength, health education (home-based)	Routine outpatient treatment and nursing guidance
Maffei et al. [29]; Italy 2022	Quasi-experimental controlled trial	IG: 12 (100% women; 66.67 ± 1.24 y) CG: 9 (100% women; 51.50 ± 3.28 y)	Between 6 and 12 months	Aerobic exercise capacity and balance	6MWT and Tinetti scale	6 months; 6 months	Aerobic, core strength, resistance (supervised)	Maintain their current lifestyle
Malmros et al. [31]; Denmark 1998	RCT	IG: 27 (100% women; 65 [62–70] y) CG: 25 (100% women; 68 [64–71] y)	3 months	Balance, trunk muscle strength/endurance, and pain	Cusam questionnaire, Chattecx Balance System, strain gauge dynamometer for back extensors, abdominal flexors, and VAS	10 weeks; 10 weeks	Core strength, balance (supervised)	Maintain their daily life
Marini et al. [28]; Italy 2019	Quasi-experimental controlled trial	IG: 26 (100% women; 67.6 ± 4.6 y) CG: 18 (100% women; 67.4 ± 4.7 y)	Not specific time	Aerobic exercise capacity, balance, pain, and QoL	6MWT, Tinetti Scale, VAS, and ECOS-16	6 months; 6 months	Aerobic, core strength, resistance (supervised)	Maintain their current lifestyle
Miko et al. [42]; Hungary 2016	RCT	IG: 50 (100% women; 69.3 ± 4.6 y) CG: 50 (100% women; 69.1 ± 5.3 y)	Not specific time	Functional capacity and balance	TUG, the Berg Balance Scale, and Romberg	12 months; 12 months	Core strength, motor control (supervised)	Regular osteoporosis treatment
Olsen and Bergland [43]; Norway 2014	RCT	IG: 47 (100% women; 70.4 ± 5.9 y) CG: 42 (100% women; 72.0 ± 5.6 y)	Recent fractures excluded	Functional capacity	Various physical performance tests including walking speed	3 months; 3 months	Core strength, aerobic (supervised)	Maintain their current activity level

Table 1 (continued)

Reference; country	Design	Participants (*N*, % women, mean age ± SD) by group	Time since OVF	Outcomes	Assessment tools	Intervention time; assessment time	Intervention	Control group
Papaioannou et al. [44]; Canada 2003	RCT	IG: 37 (100% women; 71.6 ± 7.3 y) CG: 37 (100% women; 72.2 ± 8.0 y)	3 months	Functional capacity	TUG	6 months; 6 months	Core strength, resistance, aerobic (combination)	Continue with their usual activities
Spångeus et al. [45]; Sweden 2023	RCT	TG: 5 (100% women; 72 [67–82] y) T + E: 9 (100% women; 72 [60–81] y) T + Y: 7 (100% women; 72 [63–81] y)	3 months	Functional capacity, pain, and QoL	NRS, STS, flamingo test, SF-36, and QUALEFFO-41	10 weeks; 10 weeks	Core strength, resistance, balance, yoga/mindfulness (combination)	10 theory sessions, focus on physical activity, pharmacological treatment, nutrition, balance, pain, and ergonomic aspects
Stanghelle et al. [46]; Norway 2020	RCT	IG: 76 (100% women; 74.7 ± 6.1 y) CG: 73 (100% women; 73.7 ± 5.6 y)	Not specific time	Functional capacity, aerobic exercise capacity, balance, pain, and QoL	Habitual walking speed, FSST, FR, Senior Fitness Test, QUALEFFO-41, and SF-36	3 months; 3 months	Core strength, resistance, balance (supervised)	Maintain their usual activities
Yang et al. [47]; China 2007	RCT		Not specific time	Functional capacity, balance, and pain	TUG, FR, and VAS	4 weeks; 4 weeks	Core strength, motor control (supervised)	Usual pharmacological care

CG control group, *FR* functional reach, *HE* home-based exercise, *IG* intervention group, *QoL* quality of life, *RCT* randomized controlled trial, *SE* supervised exercise, *SSPT* single session of physiotherapy, *TG* theory group, *T + E* theory and exercise, *T + Y* theory and yoga/mindfulness reliably measured outcomes (82%) and performed appropriate statistical analyses (88%), also providing adequate information on randomization procedures and baseline comparability between groups. As for the quasi-experimental studies, two were rated as low risk of bias and one as moderate. These studies met most of the quality criteria, except for participant inclusion (66%), group differences before the intervention, and the appropriate use of statistical analysis, which was only fulfilled by one study (33%). Overall, the quasi-experimental studies demonstrated acceptable methodological quality, though further improvement is needed in reporting baseline comparability and statistical analyses.

Effectiveness of exercise on functional and aerobic capacity, balance, trunk muscle strength/endurance, and quality of life

A total of 16 trials [28, 29, 31, 33–40, 42, 44–47] evaluated the effects of physical exercise on desired outcomes. Ten studies assessed functional capacity, 4 evaluated aerobic exercise capacity, 10 of them evaluated balance, 7 analyzed trunk muscle strength/endurance, and 9 trials evaluated quality of life. Analyses by study level showed a significant heterogeneity, except for aerobic exercise capacity, and balance ($I^2 = 0\%$, 44% and 0%, respectively). Considering all the included studies, we found more favorable results for the physical exercise interventions in terms of functional capacity (SMD −0.41; 95% CI −0.69, −0.14), aerobic exercise capacity (SMD 25.29; 95% CI 5.33, 45.26), balance (SMD 0.35; 95% CI 0.16, 0.53), trunk muscle strength/endurance (SMD 0.69; 95% CI 0.22, 1.16), and quality of life (SMD 0.48; 95% CI 0.13, 0.82). All results are shown in Fig. 2. No publications bias was detected in any analysis (Figure A.1). Results were robust for all variables except aerobic exercise capacity, which lost statistical significance after removing the study by Marini, S. et al. [28] (Table A.5). Meta-regression analyses showed that some moderators influenced the effects of exercise interventions. Functional capacity was better in younger patients than in older ones ($\beta = 0.14$; $p = 0.020$). The effects on balance were better with multicomponent interventions (core stability, motor control, resistance training, and aerobic) compared to less comprehensive or unsupervised home interventions ($\beta = 0.20$; $p = 0.031$). Aerobic exercise capacity and quality of life were not affected by any moderator ($p > 0.050$).

Effects of exercise on thoracic posture and pain

A total of 12 trials [28, 33, 34, 36–41, 45–47] evaluated the effects of physical activity on undesired outcomes. Ten studies examined pain and six measured thoracic posture. Analyses by study level showed a significant heterogeneity for pain ($I^2 = 72\%$). Considering all the included studies, we found favorable results in terms of pain (SMD −0.42; 95% CI −0.72, −0.12). However, although there was a trend toward improvement thoracic posture (SMD −0.11; 95% CI −0.28, 0.06), this was not significant. Results were robust for all variables (Table A.5). Meta-regression analyses showed that some thoracic posture was influenced by the type of control group ($\beta = -0.25$; $p = 0.006$), respectively. Pain was not affected by any moderator ($p > 0.050$) (Fig. 3).

Effectiveness of health education interventions

As mentioned above, two studies focused exclusively on health education interventions [27, 32]. Both studies highlight the positive impact of health education on pain management for patients with OVF. Research by Liang et al. [27] found that medical-nurse integrated education delivered during hospitalization, both prior to and after percutaneous vertebroplasty, improved elderly patients' knowledge, exercise adherence, and satisfaction, while reducing back pain. Similarly, the study carried out by Liao et al. [32] showed that a web-based app enhanced pain relief, mobility, and quality of life for female patients, also clarifying misconceptions about analgesics. Both studies underscore the value of targeted health education in managing chronic pain and mobility issues; however, they differ in their delivery methods—Liang's study emphasized in-person medical-nurse integration, while Liao's study focused on a digital platform.

Safety of exercise interventions

Overall, the probability of having an adverse event in patients with OVF while conducting exercise interventions was low. The probability of experiencing a minor adverse event while exercising in people with OVF was approximately 6.30%. Minor adverse events are defined as pain or discomfort that does not require withdrawal from the intervention. The probability of experiencing a major adverse event, such as an injury or accident leading to the withdrawal of the intervention, is about 1.65%. The risk difference compared to controls, which mainly involved continuing daily life or usual care, did not show a significantly higher risk when practicing physical exercise (Figure A.2). For minor adverse events, the risk difference was + 2% ($p = 0.09$). For major adverse events, the risk difference was + 1% ($p = 0.360$). Overall, the total adverse events showed a risk difference of + 2% ($p = 0.07$).

Discussion

To the best of our knowledge, this is the most comprehensive systematic review and meta-analysis evaluating the effectiveness and safety of physical exercise and health education

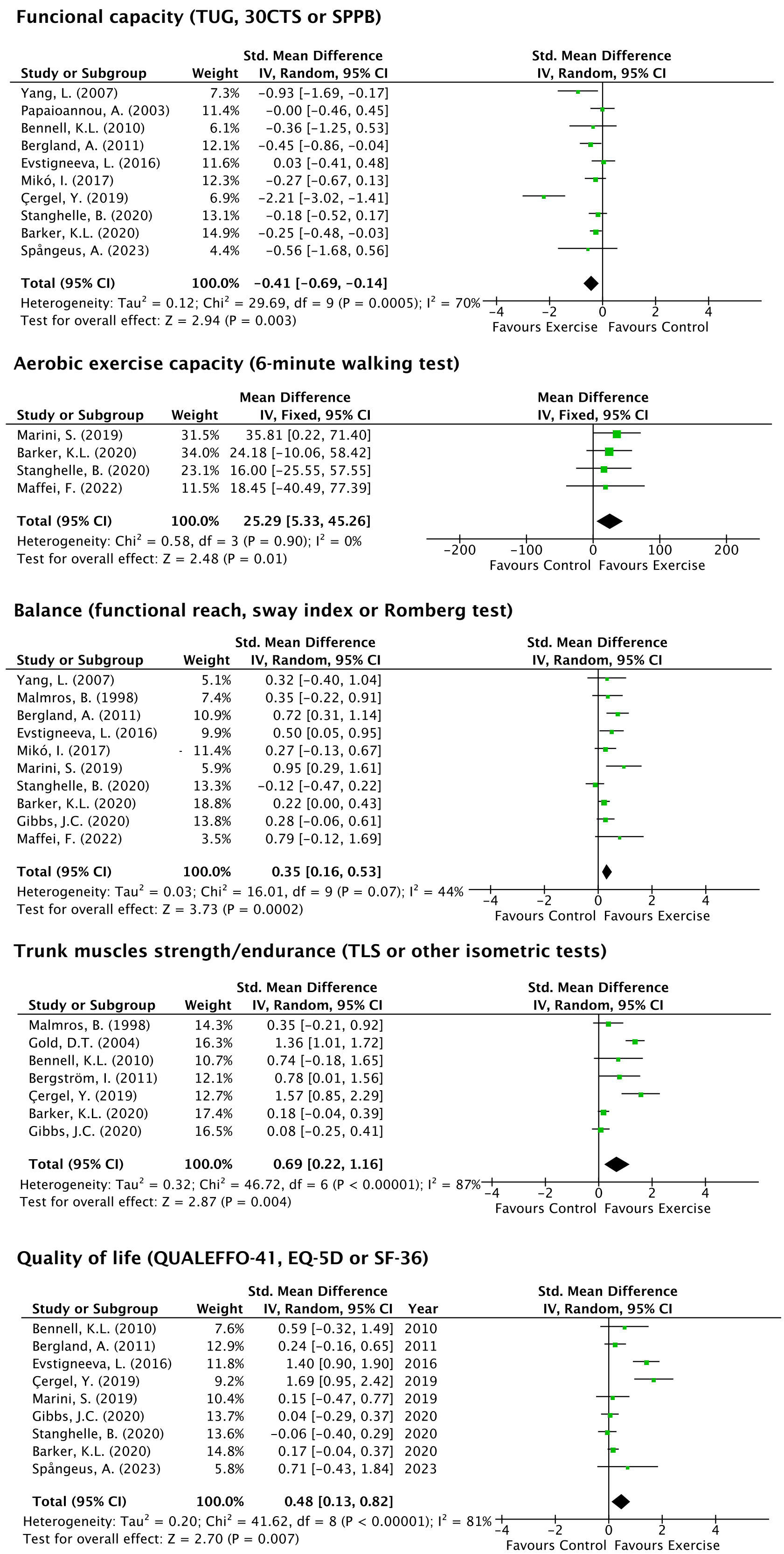


Fig. 2 Pooled standardized mean difference for the change in desired outcomes functional capacity, aerobic exercise capacity, balance, trunk muscle strength/endurance, and quality of life. *TUG* Timed Up and Go, *30CTS* 30-s Chair Stand Test, *SPPB* Short Physical Performance Battery, *TLS* Time Loaded Standing, *QUALEFFO-41* 41-Item Quality of Life Questionnaire of the European Foundation for Osteoporosis, *EQ-5D* EuroQol instrument, *SF-36* 36-Item Short Form Health Survey

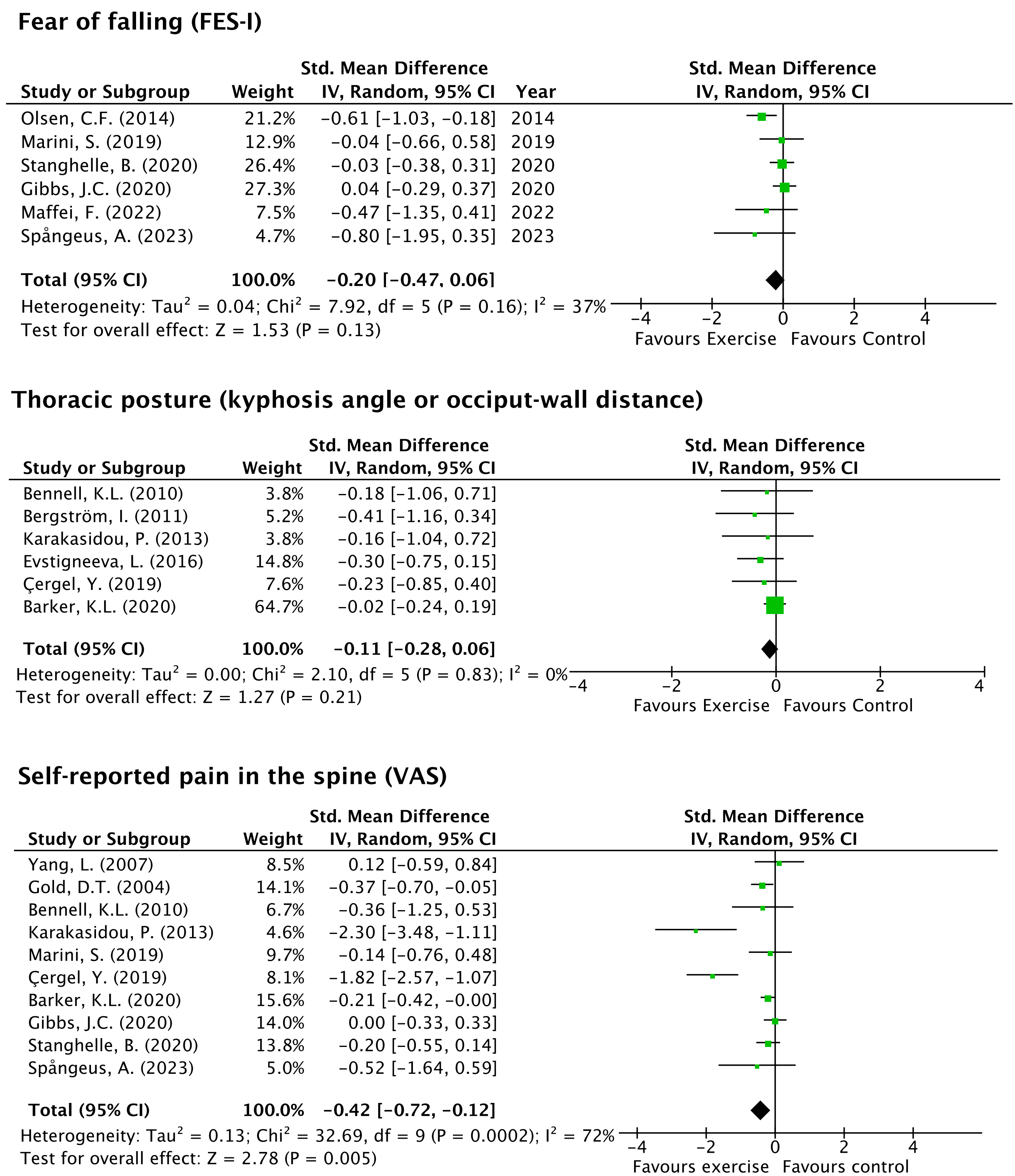


Fig. 3 Pooled standardized mean difference for the change in undesired outcomes, thoracic posture and pain. *VAS* Visual Analogue Scale

interventions in patients with OVF. Compared with three recent meta-analyses, our review offers several important distinctions and methodological strengths. First, we included a larger number of trials specifically targeting patients with osteoporotic vertebral fractures, while some previous reviews combined different osteoporosis populations or fracture types [16]. Second, our review evaluates both physical exercise and health education interventions, whereas most prior meta-analyses focused only on exercise programs [18]. Third, we conducted meta-regression and sensitivity analyses to explore heterogeneity and identify the exercise modalities associated with the greatest benefits. Finally, we provide a comprehensive assessment of multiple outcomes, including safety, functional capacity, balance, aerobic fitness, pain, and quality of life. Together, these factors support the robustness and added value of the present review compared with previous studies.

Our findings confirm that physical exercise is effective in patients with OVF, significantly improving physical health, enhancing functional capacity, aerobic fitness, balance, trunk muscle strength, and quality of life. Regarding safety, the risk of adverse events during exercise interventions is low, around 6%, showing no significant increase in risk compared to usual care or continuing with daily life.

Notably, most clinical trials have focused on exercise interventions, with only two focusing exclusively on health education [27, 32]. Over half of the studies included were published after 2016, reflecting the growing interest and need for updated reviews, especially those focusing on non-pharmacological approaches. Previous reviews indicated that physical exercise programs incorporating resistance and balance training can improve pain, physical function, and quality of life in these patients [16–18]. However, our research offers the most robust evidence to date. This work highlights the benefits of physical exercise interventions on aerobic exercise capacity and balance in patients with OVF. Additionally, our research supports exercise programs—including motor control, resistance, and aerobic elements—to maximize benefits. For instance, our findings highlight the impact of these interventions on aerobic fitness and balance, while the effects on thoracic posture remain uncertain, warranting further investigation. It is possible that the limited effects observed on thoracic posture are related to the relatively short duration of the interventions included and to fixed structural deformities in the spine resulting from the vertebral fractures themselves, which may restrict postural correction through exercise alone.

The positive effects of exercise observed in this systematic review come from interventions that are mostly focused on core strength and motor control, often combined with aerobic components, sometimes include resistance training, and rarely, yoga practices. Since trunk endurance plays an essential role in standing balance [48] interventions that incorporate trunk muscle training analytically can lead to meaningful improvements in functional tasks such as rising from a chair or walking quickly over short distances, which can be transferred to activities of daily living [49]. Our meta-regression analyses help us define the exercise modalities with the most optimal results for each outcome. For instance, the interventions with the greatest benefits for balance are those supervised and multicomponent, including trunk muscle strengthening, balance, and aerobic components [16, 28, 33, 34, 37, 41, 45, 46].

Likewise, our systematic review has summarized improvements in aerobic exercise capacity, measured by the 6-min walk test, with an increase of 25 m (SMD 25.29; 95% CI 5.33, 45.26) in this test. According to previous literature [50], we can see that the findings of our study are included in the minimal clinically important difference for change ranged from 14.0 to 30.5 m. The few studies included in this systematic review that have measured the benefits of physical exercise on aerobic exercise capacity [28, 29, 46] have included cardiorespiratory conditioning, strength, and stretching exercises as components of their intervention.

Our review has reported the significant decrease in back pain in patients with OVF through physical exercise, especially in those programs involving supervised progressive multicomponent training that focuses on balance and strength training focusing on the extensor muscles of the back and postural [16, 28, 33, 34, 37, 41, 45, 46].

The studies included in this review that used interventions based solely on health education showed improvements in health literacy, pain, and quality of life in patients with OVF compared with the control group. These results contrast with previous studies in patients with osteoporosis, which found no improvement in quality of life through interventions focused solely on the provision of health education [15, 51]. Some studies in this review integrated health education as part of a multimodal program, and all of them reported good results when combining physical exercise and health education in terms of pain reduction and improved quality of life [35, 43]. Future health education interventions should be carried out in this population, as they can empower patients and actively involve them in their recovery process, contributing to a better use of the health resources [52].

This systematic review has several clinical implications that may be useful in the development of new interventions. On the one hand, our work points out the main effects of different types of physical exercise interventions (i.e., balance exercises, back extensor muscle strengthening and postural exercises) on variables such as low back pain. Moreover, our study has also found that exercise interventions have a greater impact on functional capacity in patients closer to 60 years old than to 70. This suggests that further refinement of exercise interventions for the older population is needed, presenting a future challenge [53]. Finally, exercises that consistently appear in all the studies included in this review (i.e., balance exercises, core stability and postural exercises) suggest a clear direction for future research [28, 33–35, 37–39, 45, 46]. Future research should address the considerable heterogeneity in exercise interventions observed across studies. Specifically, it is necessary to determine which types of exercise are most effective and safe for patients with OVF, as well as which are most likely to be adhered to over the long term. Furthermore, given potential cost and accessibility considerations, especially in some countries, it would be valuable to investigate whether home-based exercise programs can achieve comparable safety and effectiveness to supervised interventions. Addressing these questions will help optimize exercise prescriptions and improve the feasibility and sustainability of interventions in real-world settings.

It is important to note that this study is not free of limitations. Firstly, we found only two studies focused solely on health education interventions, so we could not synthesize the evidence with a meta-analysis as we did for exercise interventions. This highlights the need for more literature on health education. Secondly, our analysis was limited by an inability to conduct sensitivity analyses on longer-term outcomes, as only a minority of studies reported follow-up data beyond the immediate post-intervention period. Thirdly, we found high heterogeneity in most of our analyses, probably due to the variety of measurement instruments used. However, to address this, we applied the random effect model in all meta-analyses. Fourthly, several relevant risks of bias were identified: the blinding of evaluators, the identification of potential confounders, the information about per-protocol and intention-to-treat analyses, and the reliable measurement of outcomes, which was fulfilled by 82% of the studies. In addition, we could not assess the study by Yang et al. [47] due to the unavailability of its full text. Future studies need to consider these limitations. Fifthly, some results were inconsistent and heavily influenced by one study, such as the results on aerobic capacity, which changed after excluding the study by Marini et al. [28]. Lastly, the reliability of the safety data is limited by the inconsistent reporting and collection of adverse events across studies. This is likely because safety was not the primary outcome, leading to a lack of detailed monitoring protocols. However, most of the studies were robust. But there are also important strengths to highlight: firstly, the prospective registration of the protocol in the Prospero database, which adds transparency and reduces the likelihood of reporting bias; secondly, a comprehensive and systematic search of databases (Medline, WOS, Scopus, and Cochrane Library); and lastly, a quantitative synthesis of evidence (meta-analysis) to pool estimates of effect as well as sensitivity analyses (meta-regression, publication bias, and publication bias), for better interpretation of results. Additionally, it is important to note that the benefits of interventions may not be maintained over time. Some studies measured outcomes immediately after the intervention, while only a few included follow-up assessments after a period of time. This makes it difficult to draw firm conclusions regarding the sustainability of effects. Furthermore, the long-term effects and safety of exercise and health education interventions in patients with OVF remain uncertain. Future research should include extended follow-up periods to evaluate whether the observed improvements in physical function, balance, pain, and quality of life are maintained over time and to confirm long-term safety.

Conclusion

In conclusion, our results confirm that exercise has positive effects in patients with osteoporotic vertebral fracture, improving functional capacity, aerobic capacity, balance, trunk strength, pain, and quality of life, although it does not significantly benefit thoracic posture. The risk of adverse events while exercising is low and not significantly greater than with usual care or daily life. Most interventions focus on core strength and motor control, often combined with aerobic components and sometimes including resistance training; therefore, it is recommended to follow similar modalities to obtain optimal results. Additionally, our results show that supervised and multicomponent interventions appear to have better improvements in some clinical outcomes. Overall, these findings support the prescription of physical exercise programs as a non-pharmacological alternative for people with osteoporotic vertebral fracture, although more evidence is needed to demonstrate the effectiveness of health education.

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Declarations

Conflicts of interest None.

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Authors and Affiliations

M. Fernández-González[1] · M. Mora-Traverso[2,3,4] · P. Molina-Garcia[5,6,7] · R. Prieto-Moreno[8,9,10,11] · M. Ortiz-Piña[12] · J. Contreras-Gutiérrez[13,14] · P. Ariza-Vega[1,4,7]

✉ P. Molina-Garcia
Pablomolinag5@gmail.com; pablomolinag5@ugr.es

1 Department of Physiotherapy, Faculty of Health Science, University of Granada, Granada, Spain

2 Department of Physical Medicine and Nursing, Faculty of Health Sciences, University of Zaragoza, Aragon, Spain

3 IBiOPS. Instituto de Investigación Sanitaria Aragón, Universidad de Zaragoza, Aragon, Spain

4 PA-HELP "Physical Activity for HEaLth Promotion" Research Group, Department of Physical Education and Sports, Faculty of Sport Science, University of Granada, Granada, Spain

5 Faculty of Education and Sport Sciences, University of Granada (Melilla Campus), Calle Santander 1, 52005 Melilla, Spain

6 Department of Physical Education and Sports, Faculty of Sport Sciences, Sport and Health University Research Institute (iMUDS), University of Granada, Granada, Spain

7 Instituto de Investigación Biosanitaria ibs, Granada, Spain

8 Nursing Research, Innovation and Development Centre of Lisbon (CIDNUR), Nursing School of Lisbon (ESEL), Lisbon, Portugal

9 SPORT Research Group (CTS-1024), CIBIS (Centro de Investigación para el Bienestar y la Inclusión Social) Research Center, University of Almería, Almería, Spain

10 Biomedical Research Unit, Torrecárdenas University Hospital, 04009 Almería, Spain

11 Department of Education, Faculty of Education Sciences, University of Almería, Almería, Spain

12 Department of Physical Therapy, Occupational Therapy, Rehabilitation and Physical Medicine, Faculty of Health Sciences, Rey Juan Carlos University, Madrid, Spain

13 Centro de Investigación en Tecnologías para la Sociedad (C+), Facultad de Ingeniería, Universidad del Desarrollo, Santiago de Chile, Chile

14 Facultad de Medicina CAS , Universidad del Desarrollo, Santiago de Chile, Chile