Research Article

Effectiveness Of Exercise Rehabilitation In Postmenopausal Women With Osteoporosis: A Systematic Review

Essraa Amin Abd El-Hamid[1]*, Amira E. M. Abd ElHay[2], Reham hamed Saad hamza[3], Abeer M. Yousef[4], Mohamed Mohamed Mazen[5], Rabab A. Mohamed[6], Amira Hassan Abdelaziz[7]

[1]Lecturer of physical therapy for woman health Al Hayah University in Cairo, Essraa.hl@gmail.com
[2]Faculty of Applied Medical Sciences, Rehabilitation sciences Department, Al al-BAYT University, Mafraq, Jordon ORCID number: 0009-0001-5000-5729, dr.amira.ezzat.pt@gmail.com amira.ezzat@aabu.edu.jo
[3]Lecturer of physical therapy for women health department, At el Galala University, Orcid number 0009-0015-1611, Rehamhamza722@gmail.com
[4]Department of Physical Therapy, College of Applied Medical Sciences, Qassim University, Buraydah 51452, Saudi Arabia. Email: a.aboelaish@qu.edu.sa , https://orcid.org/ 0000-0002-2926-7660 Basic Science Department, Faculty of Physical Therapy, Cairo University, Egypt., abeer.mahmoud28@yahoo.com
[5]5Department of Physical Therapy, College of applied medical sciences,Qassim university ,Buraydah 51452, Saudi Arabia, https://orcid.org/0000-0001-8969-7841, Department of Basic Sciences, Faculty of Physical Therapy, Delta University for Science and Technology, Gamasa, Egypt, Mmazen.pt@icloud.com
[6]Department of Physical Therapy, College of Applied Medical Sciences, Qassim University, Buraydah 51452, Saudi Arabia. Email: r.shoala@qu.edu.sa , https://orcid.org/0000-0002-1826-5387 , Basic Science Department, Faculty of Physical Therapy, Cairo University, Egypt
[7]Lecturer of Physical therapy for woman health, Department of Physical Therapy For Paediatrics and Women Health ,Faculty of Physical Therapy, Ahram Canadian University(ACU), Giza, Egypt, Orcid:0009-0008-9578-3517, Amira.hassan@acu.edu.eg

Abstract

Background: Postmenopausal osteoporosis is characterized by low bone mass, deterioration of bone microarchitecture and an increased risk of fragility fracture. Exercise rehabilitation may include resistance and impact training, aerobic and weight-bearing activity, balance and multicomponent programmes, mind–body exercise, whole-body vibration and exercise delivered alongside nutritional or pharmacological management. The evidence is diverse and often difficult to compare. Objective: To synthesize available evidence on exercise-based rehabilitation for postmenopausal women with osteoporosis or low bone mass, focusing on bone mineral density, bone turnover, muscle strength, balance and physical function, falls, fractures, pain, quality of life and safety. Methods: This draft was developed by cross-checking indexed reviews and primary-study information available through 17 November 2026, including PubMed records and open-access publisher pages. It uses a PRISMA-informed structure and proposes reproducible searches for MEDLINE/PubMed, Embase, Scopus, CENTRAL, CINAHL and PEDro. It is not presented as a completed de novo systematic review: database exports, duplicate removal, independent screening and full-text extraction have not been completed for this manuscript. Results: Recent syntheses report that exercise improves bone mineral density in postmenopausal women. A 2025 network meta-analysis of 49 papers (3,360 women) ranked combined aerobic and resistance training highest, and a 2025 network meta-analysis of 55 randomized trials (3,453 participants) suggested that multicomponent, mind–body and combined training may improve bone density. A 2025 meta-analysis of 17 randomized trials (690 participants) found that resistance training improved bone density at the lumbar spine, femoral neck and total hip, although heterogeneity was high. When exercise was added to medication or supplements, a 2024 meta-analysis of 19 studies (1,249 participants) found no significant overall bone-density benefit at the main sites but did find improved physical performance. A 2026 meta-analysis of 18 randomized trials reported low-certainty evidence of improved functional mobility and very-low-certainty evidence for balance, and pooled analyses in adults suggest a lower incidence of fractures with exercise. Evidence for whole-body vibration is conflicting. These findings support the clinical relevance of exercise rehabilitation but do not establish one universally superior protocol. Conclusion: Exercise rehabilitation for postmenopausal women with osteoporosis should be individualized according to bone density, fracture history, falls risk, comorbidity, current medication and personal goals. The key research need is rigorous, transparent comparison of clearly described exercise programmes using standardized measures and meaningful follow-up. No new pooled effect estimate or PRISMA study count is claimed in this draft.

Keywords: Postmenopausal Osteoporosis, Exercise-Based Rehabilitation, Bone Mineral Density, Resistance Training, Physical Function and Balance, Gyssens category.

1. Introduction

Postmenopausal osteoporosis is a systemic skeletal disorder characterized by reduced bone mass and deterioration of bone microarchitecture, which together increase bone fragility and the risk of fracture (Kanis et al., 2013; LeBoff et al., 2022). Estrogen deficiency after menopause accelerates bone resorption and leads to progressive loss of bone mineral density (BMD) (Li et al., 2025; Liu et al., 2024). Osteoporotic fractures, particularly of the hip and spine, are associated with pain, loss of independence, reduced quality of life and increased mortality, and they impose a substantial burden on health systems (Cummings & Melton, 2002; LeBoff et al., 2022). The clinical significance of osteoporosis therefore

extends beyond bone density alone and includes muscle weakness, impaired balance, fear of falling, postural change and limitation of daily activity (Brooke-Wavell et al., 2022; Li et al., 2026).

Management of postmenopausal osteoporosis combines adequate calcium and vitamin D intake, pharmacological treatment for women at higher fracture risk, falls prevention and exercise (Bai et al., 2025; LeBoff et al., 2022). Exercise rehabilitation is a core non-pharmacological component, with treatment goals that may include preserving or increasing bone mass, improving muscle strength and balance, reducing falls, improving posture, relieving pain after vertebral fracture and supporting confidence and participation in physical activity (Beck et al., 2017; Brooke-Wavell et al., 2022; Giangregorio et al., 2014). Mechanical loading is thought to stimulate bone formation, while muscle-strengthening and balance training address the falls-related risk factors that precipitate many fractures (Brooke-Wavell et al., 2022; Zhao et al., 2025).

Exercise for osteoporosis encompasses a broad range of approaches. Resistance and impact training are intended to deliver osteogenic loading; aerobic and weight-bearing activity such as walking, jogging and dance provide lower-magnitude loading together with cardiovascular benefit; balance and multicomponent programmes target falls risk; mind–body practices such as Tai Chi and Baduanjin emphasize posture, control and low-impact movement; and whole-body vibration (WBV) delivers mechanical stimulation through a platform with little voluntary effort (Li et al., 2024; Liu et al., 2024; Ma et al., 2025). Guidance from Australia, Canada and the United Kingdom recommends progressive resistance and balance training together with weight-bearing or impact activity tailored to the person's fracture history and ability, and it emphasizes safe movement and appropriate supervision (Beck et al., 2017; Brooke-Wavell et al., 2022; Giangregorio et al., 2014). The UK consensus statement notes that evidence of significant harm from physical activity is limited and that the benefits generally outweigh the risks, while advising that people with vertebral fracture or multiple low-trauma fractures should usually limit impact to about the level of brisk walking and avoid postures involving a high degree of spinal flexion (Brooke-Wavell et al., 2022). The LIFTMOR randomized trial showed that a brief, supervised, high-intensity resistance and impact programme was efficacious and was accompanied by a single minor adverse event in carefully screened postmenopausal women with low bone mass (Watson et al., 2018). Whether such programmes generalize to less selected or less closely supervised populations remains uncertain.

Earlier syntheses, including the 2011 Cochrane review, indicated that exercise can modestly improve BMD in postmenopausal women but left uncertainty about fracture outcomes (Howe et al., 2011). The literature has since expanded considerably. Recent systematic reviews and network meta-analyses have compared exercise types, examined the influence of intensity, frequency and duration, and added outcomes such as bone turnover, physical performance, falls and fractures (Hejazi et al., 2025; Li et al., 2025; Ma et al., 2025; Zhang et al., 2025; Zhao et al., 2025). However, these reviews differ in how they define the population (postmenopausal women in general versus women with osteopenia or osteoporosis), in their comparators (no exercise, usual care, supplements or medication) and in their eligibility criteria, and they draw heavily on overlapping primary trials. Their findings therefore cannot simply be added together, and apparent disagreements may reflect differences in design rather than in underlying effects (Hsu et al., 2024; Yin et al., 2024).

Furthermore, the assessment of exercise rehabilitation requires consideration of several outcome domains. BMD measured by dual-energy X-ray absorptiometry (DXA) is the most commonly reported outcome, but it is a surrogate measure, and the absolute differences between exercise and control groups are often small (Hejazi et al., 2025). Muscle strength, balance, mobility, falls, fractures, pain and quality of life are at least as important to women and clinicians, yet they are measured less consistently. Variation in exercise dose, supervision, adherence and follow-up further complicates comparison, and published guidelines themselves often specify exercise characteristics incompletely (Iolascon et al., 2021). Benefits may also decline after training stops (Gombarčíková et al., 2025), which makes long-term adherence and follow-up essential considerations.

Accordingly, a systematic synthesis of the available evidence is warranted to evaluate exercise-based rehabilitation for postmenopausal women with osteoporosis or low bone mass. This review aims to examine the effects of exercise on bone mineral density, bone turnover, muscle strength, balance and physical function, falls, fractures, pain, quality of life and safety. By considering differences in participant characteristics, exercise type and dose, treatment context and outcome measurement, the review seeks to clarify the current evidence base, identify areas of uncertainty and inform future research and individualized rehabilitation planning.

2. Methods

2.1. Study Design And Reporting Framework

This study is designed to synthesize the available evidence on the effectiveness of exercise-based rehabilitation in postmenopausal women with osteoporosis or low bone mass. The review will examine exercise programmes delivered as stand-alone interventions and as additions to nutritional or pharmacological management, while distinguishing between the two. Women with vertebral fracture will be considered as a distinct clinical subgroup because their exercise needs and safety considerations differ.

The review will follow the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) reporting guideline (Page et al., 2021). The review protocol, eligibility criteria, search strategy, study selection process, data extraction procedures and methods of evidence synthesis are to be defined, and preferably registered, before formal screening begins. The completed manuscript will report the procedures actually undertaken and will not present proposed methods as completed research activities.

2.2 Research Question

The primary research question is:

1. What is the effectiveness of exercise rehabilitation in improving bone mineral density, physical function and fracture-related outcomes in postmenopausal women with osteoporosis?
2. The review will also address the following secondary questions:
3. Which exercise interventions have been investigated in postmenopausal women with osteoporosis or low bone mass?
4. What effects do these interventions have on bone mineral density at the lumbar spine, femoral neck and total hip, and on bone turnover markers?
5. What effects do they have on muscle strength, balance, mobility, falls, fractures, pain and quality of life?
6. Do outcomes differ according to exercise type, dose, supervision, baseline bone density, vertebral fracture status or concurrent pharmacological treatment?
7. What is known about safety, adherence and the persistence of benefit after training stops, and what methodological limitations and evidence gaps should be addressed in future research?

2.3 Eligibility Criteria

Eligibility criteria will be structured according to the Population, Intervention, Comparison, Outcomes and Study design (PICOS) framework.

- **Population:** Studies involving postmenopausal women with osteoporosis (a T-score of −2.5 or lower, a clinical diagnosis of osteoporosis, or a prior fragility fracture) will be considered. Studies of women with osteopenia or low bone mass will be included as a separately analyzed stratum. Studies of mixed-sex samples will be eligible only if data for women can be extracted separately. Secondary osteoporosis, such as glucocorticoid-induced or cancer-treatment-induced bone loss, will be excluded.

- **Interventions:** Eligible interventions include resistance training, impact and jumping exercise, aerobic and weight-bearing exercise, high-intensity interval training, balance and multicomponent programmes, back-extensor and posture exercise, mind–body exercise (for example, Tai Chi, Baduanjin and other qigong forms), aquatic exercise, whole-body vibration and other clearly described exercise approaches, whether supervised or home-based. Exercise delivered together with calcium, vitamin D or osteoporosis medication will be considered separately from exercise alone.

- **Comparators:** Eligible comparison conditions may include no exercise, usual activity or usual care, health education, low-intensity or stretching control programmes, supplements or medication alone, or an alternative exercise programme. Comparative effectiveness will be assessed only where the study design permits meaningful comparison.

- **Outcomes:** Primary outcomes include areal BMD at the lumbar spine, femoral neck and total hip measured by DXA, and low-trauma fractures. Secondary outcomes include bone turnover markers, muscle strength, balance and mobility (for example, the Timed Up and Go test, Berg Balance Scale and 30-second sit-to-stand test), falls, pain, health-related quality of life, posture or kyphosis, adverse events, adherence and outcomes after training has stopped.

- **Study Designs:** Randomized controlled trials and other eligible comparative clinical studies will be prioritized. Nonrandomized intervention studies may be included if they meet the prespecified eligibility criteria. Reviews may be used to identify relevant primary studies and to contextualize the findings, but review-level and primary-study evidence will be distinguished to avoid double-counting participants or results.

2.4 Information Sources And Search Strategy

A comprehensive literature search is planned for MEDLINE/PubMed, Embase, Scopus, the Cochrane Central Register of Controlled Trials (CENTRAL), CINAHL and PEDro. Reference lists of relevant systematic reviews and included primary studies will also be examined to identify additional eligible publications.

The search strategy will combine controlled vocabulary, where available, and free-text terms related to postmenopausal osteoporosis and exercise rehabilitation. Search terms will include variations of the following concepts:

- “postmenopausal osteoporosis”
- “postmenopausal women”
- “osteopenia” and “low bone mass”
- “exercise therapy”
- “resistance training”
- “impact exercise”
- “aerobic exercise”
- “Tai Chi” and “Baduanjin”
- “whole-body vibration”
- “bone mineral density”
- “falls” and “fractures”
- “physical function”
-

A draft PubMed search string is:
("osteoporosis, postmenopausal"[MeSH Terms] OR "postmenopausal osteoporosis" OR "postmenopausal women" OR osteopenia OR "low bone mass") AND ("exercise therapy"[MeSH Terms] OR exercise OR "resistance training" OR "impact exercise" OR "aerobic exercise" OR "Tai Chi" OR "whole-body vibration" OR "physical therapy") AND ("bone density"[MeSH Terms] OR "bone mineral density" OR fractures OR falls OR "physical function")
The final search strategies will be adapted to the indexing system and syntax of each database. The date of the final search, complete database-specific search strings, filters and numbers of retrieved records will be documented to support reproducibility.

2.5 Study Selection

All retrieved records will be compiled for duplicate identification and removal. Titles and abstracts will then be screened against the predefined eligibility criteria, followed by full-text assessment of potentially relevant publications.

Where feasible, two reviewers will independently conduct study selection and resolve disagreements through discussion or consultation with a third reviewer. Reasons for excluding studies at the full-text stage will be recorded. The selection process will be summarized in a PRISMA flow diagram, reporting the actual numbers of records identified, duplicates removed, records screened, full texts assessed and studies included.

2.6 Data Extraction

Data will be extracted using a standardized form developed for the review. The following information will be collected where available:

- Author, publication year, country and study design.
- Participant characteristics, sample size, age, years since menopause, baseline BMD or T-score, vertebral fracture history and current osteoporosis medication.
- Type of exercise intervention and comparator.

- Exercise prescription: frequency, intensity, session duration, programme length, progression, supervision, setting and provider.
- Adherence, attendance and any co-interventions such as calcium, vitamin D or medication.
- Outcome measures, measurement sites and timing of assessments.
- Main findings, including between-group differences and within-group changes where appropriate.
- Adverse events, limitations and follow-up duration, including any detraining period.
-

Data extraction will distinguish findings from primary studies from conclusions reported in existing reviews. Missing or insufficiently reported information will be identified rather than inferred.

2.7 Risk Of Bias And Certainty Of Evidence

The methodological quality of included studies will be assessed using tools appropriate to their design. For randomized controlled trials, the Cochrane Risk of Bias 2 (RoB 2) tool may be used (Sterne et al., 2019). For nonrandomized intervention studies, an appropriate tool, such as ROBINS-I, will be considered according to the study design and review scope (Sterne et al., 2016). The PEDro scale may be used as a complementary indicator of trial quality.

The certainty of evidence for important outcomes will be assessed using the GRADE approach when sufficient information is available (Guyatt et al., 2008). Considerations include risk of bias, inconsistency, indirectness, imprecision and publication bias where assessable. Because blinding of participants and instructors is rarely possible in exercise trials, risk of bias related to performance and measurement will be considered explicitly.

2.8 Data Synthesis

Study characteristics, exercise programmes, outcome measures and findings will initially be summarized descriptively. Studies will be grouped according to exercise type, clinical context and relevant outcome domain.

A quantitative meta-analysis will be considered only when studies are sufficiently comparable in terms of participants, interventions, comparators, outcomes and follow-up. Appropriate effect measures and confidence intervals will be reported where the available data permit their calculation, and statistical heterogeneity will be assessed using suitable methods when meta-analysis is justified. Network meta-analysis will be considered only if the evidence network is adequately connected and the transitivity assumption is plausible.

If substantial clinical or methodological heterogeneity prevents meaningful pooling, a structured narrative synthesis will be undertaken. Exploratory subgroup analyses may consider osteoporosis versus osteopenia, exercise dose, supervision, vertebral fracture status and concurrent pharmacological treatment. Findings from exercise combined with nutritional or pharmacological management will be presented separately from those concerning exercise alone.
No pooled effect estimate will be generated without appropriate primary-study data. The final synthesis will clearly distinguish statistically demonstrated effects, descriptive observations and conclusions limited by uncertainty in the available evidence.

3. Results

3.1 Overview Of The Available Evidence

The available literature indicates that exercise rehabilitation for postmenopausal women with osteoporosis encompasses a range of interventions intended to preserve or increase bone mass, improve muscle strength and balance, reduce falls and fractures, and support physical function and quality of life. These interventions include resistance and impact training, aerobic and weight-bearing exercise, multicomponent and combined programmes, mind–body exercise, whole-body vibration and exercise delivered alongside calcium, vitamin D or medication.

The evidence base includes randomized controlled trials, nonrandomized studies, systematic reviews, network meta-analyses, an overview of reviews and consensus statements. The available studies differ in participant age, baseline bone density, fracture history, exercise dose, supervision, outcome measures and follow-up. Importantly, many reviews draw on overlapping primary trials, so review-level sample sizes cannot be summed and are reported here only to describe each review's scope.

Hejazi et al. (2025) included 40 studies with 2,230 postmenopausal women aged 50 to 60 years and reported that aerobic, resistance and combined training improved BMD at the lumbar spine, total hip, femoral neck and trochanter, although the mean differences were small (0.01 to 0.02 g/cm² at most sites). Li et al. (2025) analyzed 49 papers with 3,360 women across eight intervention categories, and Ma et al. (2025) analyzed 55 randomized trials with 3,453 participants in a network meta-analysis restricted to women aged 60 years or older. Most recently, Li et al. (2026) pooled 18 randomized trials in women with osteoporosis or low bone mass to examine fall-related functional performance.

3.2 Characteristics Of The Evidence

The characteristics of the principal published reviews identified for this synthesis are summarized in Table 1.

Table 1. Characteristics of relevant published reviews

Review	Scope and evidence base	Main contribution
Hsu et al. (2024)	19 articles, 1,249 participants; exercise added to medication or supplements versus medication or supplements alone	No significant overall BMD gain at the main sites, although combining several exercise types improved lumbar spine BMD; exercise improved physical performance
Zhao et al. (2025)	17 randomized trials, 690 participants; resistance training	Improved lumbar spine, femoral neck and total hip BMD with high heterogeneity; subgroup signals for higher intensity, three sessions weekly and longer duration
Li et al. (2025)	Network meta-analysis of 49 papers, 3,360 women; eight intervention categories	Ranked combined aerobic and resistance training highest for BMD
Ma et al. (2025)	Network meta-analysis of 55 randomized trials, 3,453 participants; women aged 60 years or older	Suggested that mind–body, multicomponent and combined training may improve BMD; further rigorous trials needed
Bai et al. (2025)	13 randomized trials; exercise plus calcium and vitamin D versus calcium and vitamin D alone	Greater lumbar spine and femoral neck BMD; shorter programmes (6 months or less) yielded larger gains
Liu et al. (2024)	Network meta-analysis of 33 randomized trials, 3,658 women; traditional Chinese fitness exercises	Taiji and Yijinjing improved lumbar BMD compared with conventional rehabilitation; few trials per intervention
Yin et al. (2024)	Overview of 15 systematic reviews of whole-body vibration	Most reviews rated critically low in quality; no clear BMD advantage established
Hoffmann et al. (2023)	11 controlled exercise studies in adults reporting low-trauma fractures	Lower incidence of major osteoporotic fractures with exercise (rate ratio 0.75, 95% CI 0.54–0.94)
Li et al. (2026)	18 randomized trials, 1,181 participants; fall-related functional performance	Low-certainty improvement in Timed Up and Go and 30-second sit-to-stand; Berg Balance Scale result very uncertain

Note: This table summarizes published reviews rather than a newly completed systematic search. Reviews overlap in their primary studies, so participant numbers should not be summed. The full texts and reference lists should be examined to establish the final set of eligible primary studies.

3.3 Findings By Exercise Intervention

3.3.1 Resistance And Impact Training

Resistance and impact training are intended to deliver the high-magnitude, high-rate loading to which bone responds. In a meta-analysis of 17 randomized trials with 690 participants, Zhao et al. (2025) reported that resistance training improved BMD at the lumbar spine (standardized mean difference [SMD] 0.88, 95% CI 0.21–1.56), femoral neck (SMD 0.89, 95% CI 0.40–1.39) and total hip (SMD 0.30, 95% CI 0.10–0.50), whereas the trochanteric result did not reach statistical significance. Heterogeneity was high at the lumbar spine and femoral neck (I^2 = 91% and 87%). Subgroup analyses suggested significant effects at several sites with training at 70% or more of one-repetition maximum, three sessions per week and longer programmes, but these subgroup findings are exploratory and the authors called for further high-quality trials. Other meta-analyses have examined how exercise intensity, progression and frequency moderate bone responses (Kistler-Fischbacher et al., 2021; Shojaa et al., 2020; Zitzmann et al., 2022).

The LIFTMOR randomized trial provides the most widely cited primary evidence for high-intensity loading. Watson et al. (2018) randomized 101 postmenopausal women with low bone mass (mean age 65 years) to eight months of twice-weekly, 30-minute supervised high-intensity resistance and impact training (five sets of five repetitions at more than 85% of one-repetition maximum) or a home-based low-intensity programme. The supervised programme was superior for lumbar spine BMD (2.9% versus −1.2%) and femoral neck BMD (0.3% versus −1.9%) and for all measured functional performance outcomes. Compliance was high and the only adverse event reported was a minor lower-back spasm. The authors emphasized that these results were obtained under highly supervised conditions in otherwise healthy women, which limits generalization to women with multiple fractures, severe osteoporosis or comorbidity.

3.3.2 Aerobic, Weight-Bearing And Multicomponent Training

Network meta-analyses allow several exercise types to be compared simultaneously, although they depend on assumptions about transitivity and on a limited number of trials per node. Li et al. (2025) ranked combined aerobic and resistance training highest for BMD, with aerobic exercise and resistance training alone also showing significant effects at the lumbar spine, and with whole-body vibration and resistance training showing significant effects at the femoral neck. Ma et al. (2025) found that multicomponent training improved femoral neck BMD compared with control (mean difference 0.02 g/cm², 95% credible interval 0.01–0.04) and concluded that mind–body, multicomponent and combined training may improve BMD in women aged 60 years or older, while calling for further rigorously designed trials.

Zhou et al. (2026) pooled 27 randomized trials with 2,183 participants with osteoporosis or low bone mass to compare aerobic exercise prescriptions for lumbar BMD. Higher-intensity programmes, sessions of 30 to 59 minutes, four to five sessions per week and a 24-week duration ranked highest. The authors cautioned that intensity should be increased progressively for safety, and they noted that blinding was rarely possible and that some included trials allocated participants by preference. Detraining is a further concern: in a systematic review that identified 1,161 records but included only three studies, Gombarčíková et al. (2025) reported that resistance, aerobic and high-intensity interval training performed two to five times per week improved or maintained BMD, particularly at the lumbar spine and proximal femur, and that benefits declined gradually within a few months after exercise stopped.

3.3.3 Mind–Body And Traditional Chinese Exercise

Mind–body and traditional Chinese exercises such as Tai Chi (Taiji), Baduanjin and Yijinjing are low-impact options that may be acceptable to women who cannot tolerate or do not wish to perform loading exercise. Liu et al. (2024) conducted a network meta-analysis of 33 randomized trials involving 3,658 postmenopausal women. Taiji (SMD 0.72, 95% CI 0.22–1.21) and Yijinjing (SMD 0.51, 95% CI 0.03–0.99) were significantly superior to conventional rehabilitation for lumbar BMD, and Baduanjin combined with medication ranked highest in probability analyses. The authors cautioned that the numbers of trials and participants for individual interventions were limited and that definitive conclusions require further high-quality studies.

Findings across reviews are not entirely consistent. Ma et al. (2025) identified a possible benefit of mind–body training, and Bai et al. (2025) reported that mind–body exercise, together with whole-body vibration, showed the greatest benefit when exercise was combined with calcium and vitamin D. By contrast, other network meta-analyses ranked combined aerobic and resistance training highest (Li et al., 2025). Differences in the populations, comparators and exercise categories included probably explain much of this variation, and the evidence does not justify treating mind–body exercise as a replacement for progressive resistance training where the latter is safe and feasible.

3.3.4 Whole-Body Vibration

Whole-body vibration has attracted interest because it requires little voluntary effort. Li et al. (2024) pooled 13 randomized trials with 783 postmenopausal women with osteoporosis and reported small improvements in lumbar spine BMD (weighted mean difference 0.018 g/cm², 95% CI 0.004–0.032) and femoral neck BMD (0.005 g/cm², 95% CI 0.001–0.011) and a reduction in pain, with no significant effect on muscle mass or fat mass. In the network meta-analysis by Li et al. (2025), whole-body vibration showed a significant effect at the femoral neck.

However, an overview of 15 systematic reviews found that only two were rated as low or moderate quality using AMSTAR-2 and 13 as critically low, that the reviews overlapped heavily in their included trials, and that whole-body vibration did not show a significant overall advantage for BMD in postmenopausal women (Yin et al., 2024). Only five

of the reviews reported adverse events and none reported severe events. The overview authors did not recommend whole-body vibration for improving BMD, while acknowledging that it may have value in maintaining BMD. Overall, evidence for whole-body vibration remains conflicting and of limited certainty.

3.3.5 Bone Turnover Markers And Exercise Combined With Nutritional Or Pharmacological Management

Zhang et al. (2025) conducted a meta-analysis of randomized trials of exercise and bone metabolism in postmenopausal women and concluded that exercise reduced bone resorption and promoted bone formation. Aerobic exercise lowered the resorption marker C-terminal telopeptide of type I collagen (CTX), and both aerobic and resistance exercise increased osteocalcin. Bone turnover markers change more quickly than BMD and may help to explain the mechanisms of exercise, but they are intermediate outcomes and do not by themselves demonstrate clinical benefit.

Evidence on exercise added to other treatments depends strongly on the comparator. Bai et al. (2025) pooled 13 randomized trials and found that, compared with calcium and vitamin D supplementation alone, combining exercise with supplementation increased lumbar spine BMD (SMD 0.31, 95% CI 0.06–0.55) and femoral neck BMD (SMD 0.47, 95% CI 0.09–0.84), with shorter programmes (6 months or less) yielding larger gains than longer ones. In contrast, Hsu et al. (2024) pooled 19 articles with 1,249 participants comparing exercise added to osteoporosis medication or supplements with medication or supplements alone and found no significant overall improvement in BMD at the lumbar spine, femoral neck, trochanter or total hip. A subgroup that combined several exercise types did show improved lumbar spine BMD (SMD 0.37, 95% CI 0.01–0.72), and exercise improved physical performance. These results suggest that, in women already receiving treatment, exercise may be more clearly justified by its effects on physical function than by additional BMD gains.

3.3.6 Balance, Physical Function And Falls

Li et al. (2026) pooled 18 randomized trials (21 intervention arms, 1,181 participants) of exercise in postmenopausal women with osteoporosis or low bone mass. Exercise reduced Timed Up and Go time (mean difference −1.57 seconds, 95% CI −2.52 to −0.63) and increased 30-second sit-to-stand repetitions (mean difference 3.88, 95% CI 1.93–5.83), whereas the effect on the Berg Balance Scale was highly uncertain (mean difference 3.37 points, 95% CI −2.68 to 9.43). Heterogeneity was high (I^2 above 80% for each outcome), prediction intervals crossed the null, and certainty of evidence was low for the first two outcomes and very low for the third. The authors found no evidence that programmes with higher reported consistency with American College of Sports Medicine recommendations performed better, and they emphasized that these tests are measures of fall-related function, not of actual falls or fractures.

Evidence for falls themselves comes mainly from broader populations. A Cochrane review of exercise for preventing falls in community-dwelling older people found that exercise reduces the rate of falls (Sherrington et al., 2019), and balance and strength training are central to osteoporosis exercise guidance (Beck et al., 2017; Brooke-Wavell et al., 2022). Whether falls-prevention effects in women with osteoporosis are of the same magnitude has not been established by the studies summarized here.

3.3.7 Fracture Outcomes

Fracture is the outcome of greatest clinical importance, but it is infrequently reported in exercise trials. Kemmler et al. (2013) pooled ten controlled exercise trials in older adults and found fewer overall fractures in exercise groups (relative risk 0.49, 95% CI 0.31–0.76), with some evidence of publication bias; the result for vertebral fractures (relative risk 0.56, 95% CI 0.30–1.04) was borderline non-significant. Hoffmann et al. (2023) later pooled 11 controlled studies and reported a lower incidence of major osteoporotic fractures with exercise (rate ratio 0.75, 95% CI 0.54–0.94). Subgroup analyses did not demonstrate significant differences according to intensity progression or study duration, and the authors concluded that diverging study and exercise characteristics prevented reliable recommendations for specific exercise protocols. Both reviews addressed adults broadly rather than exclusively women with diagnosed osteoporosis, so their applicability to this population should be interpreted with caution.

3.3.8 Rehabilitation After Vertebral Fracture

Women with vertebral fracture represent a distinct clinical context in which exercise aims to reduce pain, improve posture and mobility, and restore confidence. A Cochrane review found moderate-quality evidence that exercise probably improves physical performance, specifically the Timed Up and Go test, after vertebral fracture, with uncertain effects on other outcomes and few adverse events reported (Gibbs et al., 2019). A subsequent meta-analysis of 12

randomized trials with 1,289 participants reported that resistance and balance training improved quality of life, pain, Timed Up and Go performance, fear of falling and kyphosis, with larger effects when training continued for more than 10 weeks (Guo et al., 2023). The UK consensus statement recommends that people with vertebral fracture prioritize spinal extension and postural exercise, avoid sustained or loaded spinal flexion, and usually limit impact to about the level of brisk walking (Brooke-Wavell et al., 2022).

3.4 Summary of Outcome Domains

The outcome domains addressed across the literature are summarized in Table 2.

Table 2. Exercise rehabilitation outcomes and interpretation

Outcome domain	Examples of assessment	Interpretation for exercise rehabilitation in osteoporosis
Bone mineral density	DXA areal BMD at the lumbar spine, femoral neck, total hip and trochanter	Surrogate indicator of bone strength; absolute exercise effects are often small and heterogeneous
Bone turnover	Serum CTX, P1NP and osteocalcin	Reflects short-term bone resorption and formation; intermediate rather than clinical outcome
Muscle strength	Leg press, grip strength and back-extensor strength tests	Indicates capacity to generate force; relevant to falls risk and function
Balance and mobility	Timed Up and Go, Berg Balance Scale, 30-second sit-to-stand and functional reach	Assess fall-related function; do not directly measure falls or fractures
Falls and fractures	Falls diaries; radiographic or clinically confirmed low-trauma fractures	Most clinically important outcomes but infrequently reported and require large or long trials
Pain, quality of life and posture	Visual analogue scale, QUALEFFO-41, SF-36 and kyphosis measures	Patient-centred outcomes, particularly important after vertebral fracture
Safety and adherence	Adverse events, attendance and compliance	Determines feasibility and acceptability of higher-intensity or unsupervised programmes
Longer-term outcomes	Follow-up BMD and function after training has stopped	Helps identify persistence of gains and the consequences of detraining

The outcomes reported in individual studies should not be assumed to be interchangeable. In particular, improvements in BMD or in performance tests do not necessarily indicate equivalent reductions in falls or fractures, and changes in bone turnover markers do not by themselves demonstrate clinical benefit.

3.5 Overall Synthesis

The available evidence indicates that exercise rehabilitation is an important component of the management of postmenopausal osteoporosis, but the certainty of evidence differs across intervention types and outcome domains. Most syntheses report that exercise is associated with higher BMD than no exercise, and combined or progressive loading programmes tend to rank highest. Evidence for muscle strength, mobility and quality of life is generally supportive but of low certainty, and evidence for fractures is encouraging but indirect. Evidence for whole-body vibration and for the relative merits of mind–body exercise is conflicting.

The principal limitations of the current evidence include small samples in individual trials, high statistical heterogeneity, variation in exercise prescription and supervision, overlap among reviews, inconsistent outcome measurement, difficulty blinding and limited follow-up. A definitive ranking of exercise interventions cannot be established from the published information summarized here.

4. Discussion

This synthesis indicates that exercise rehabilitation for postmenopausal women with osteoporosis should be understood as a multidimensional intervention rather than a single standardized programme. The available literature addresses preservation of bone density, development of muscle strength, improvement of balance and mobility, relief of pain and promotion of confidence in everyday activity. Reviews broadly agree that exercise is associated with higher BMD than no exercise, and that combined and progressive loading programmes tend to rank highest (Hejazi et al., 2025; Li et al., 2025; Ma et al., 2025). By contrast, Hsu et al. (2024) found no significant overall BMD advantage when exercise was added to medication or supplements. These findings need not be viewed as contradictory. The reviews differ in populations, comparators and baseline bone status, and in women who already receive effective

pharmacological treatment, the incremental BMD effect of exercise may be small, while exercise may still contribute to muscle strength, balance and physical performance.

The absolute BMD differences reported are modest, and heterogeneity is often high (Hejazi et al., 2025; Zhao et al., 2025). BMD is a surrogate, and small differences in density may understate the clinical effect of exercise, which also acts through muscle function and falls risk. Pooled analyses suggest lower fracture incidence with exercise (Hoffmann et al., 2023; Kemmler et al., 2013), but these analyses addressed adults broadly, included few trials, and in one case showed signs of publication bias. Estimates of fracture reduction should therefore be treated as encouraging rather than definitive for women with diagnosed osteoporosis.

Intensity and safety deserve particular attention. High-intensity resistance and impact training produced favourable bone and functional outcomes in the LIFTMOR trial, but under close supervision in screened, otherwise healthy women (Watson et al., 2018). Network meta-analyses of aerobic exercise similarly favour higher intensity, while their authors recommend gradual progression and stratification of falls, cardiopulmonary and fracture risk before prescribing it (Zhou et al., 2026). Guidance emphasizes that benefits generally outweigh risks, that people at risk of falls should start with strength and balance training, and that women with vertebral or multiple low-trauma fractures should usually limit impact and avoid high spinal flexion (Beck et al., 2017; Brooke-Wavell et al., 2022). Exercise prescription should therefore be individualized and, where fracture or falls risk is high, delivered or reviewed by a qualified clinician.

Mind–body exercise and whole-body vibration may be attractive for women who cannot tolerate loading exercise. Network meta-analytic evidence suggests that Taiji, Yijinjing and related practices may improve lumbar BMD, but the numbers of trials per intervention are small (Liu et al., 2024). Evidence for whole-body vibration is conflicting, with small positive pooled effects in some meta-analyses (Li et al., 2024) but critically low confidence in most reviews and no clear BMD advantage in an overview of systematic reviews (Yin et al., 2024). Neither approach is yet supported strongly enough to replace progressive resistance and balance training when the latter is safe and feasible.

An important consideration is the distinction between bone-related and function-related outcomes. Exercise improved Timed Up and Go and sit-to-stand performance with low-certainty evidence, and the effect on the Berg Balance Scale was highly uncertain (Li et al., 2026). These tests are valuable indicators of function, but they are not direct measures of falls or fractures. Patient-centred outcomes such as pain and quality of life are particularly relevant after vertebral fracture, where exercise appears safe and probably improves physical performance (Gibbs et al., 2019; Guo et al., 2023).

Long-term adherence is a further consideration. Benefits appear to decline within months of stopping training (Gombarčíková et al., 2025), and one network meta-analysis noted that very long programmes may be affected by reduced adherence and by limited progression of intensity (Zhou et al., 2026). Bai et al. (2025) found larger BMD gains in shorter programmes, which should not be interpreted as a reason to stop exercising but as a reminder that the rate of gain slows as the skeleton adapts and that varied, progressive stimuli may be needed. Future trials should therefore report adherence, progression and post-intervention follow-up.

A strength of the existing literature is the increasing number of randomized trials and recent systematic reviews addressing exercise type, dose, bone turnover, physical performance and safety, and the availability of consensus guidance to support clinical translation. However, important limitations remain. Individual trials often include small samples, participants vary in age, bone density and fracture history, and exercise prescriptions differ in frequency, intensity, supervision and duration. Many reviews rely on overlapping trials, most analyses are based on immediate post-intervention outcomes, and the certainty of evidence is frequently low.

A further limitation for the present manuscript is that its current synthesis is based on published reviews and accessible primary-study information rather than a completed independent systematic review. The database search, duplicate removal, independent screening, full-text eligibility assessment and standardized extraction of all potentially eligible primary studies have not yet been completed. Consequently, the findings should be interpreted as a preliminary evidence synthesis and not as the final results of a newly completed PRISMA systematic review.

Future research should prioritize adequately powered randomized controlled trials with clearly defined, progressive exercise protocols and appropriate comparison groups, including trials in women with established osteoporosis and in those receiving pharmacological treatment. Studies should report exercise frequency, intensity, duration, progression, supervision, adherence and concurrent treatments in sufficient detail to support replication. A core outcome set would improve comparability across studies and should include DXA BMD, muscle strength, balance and mobility, falls, fractures, pain, quality of life, adverse events and longer-term follow-up. Researchers should also report results according to relevant clinical characteristics, including age, baseline bone density, vertebral fracture status and medication use. Finally, direct comparisons between higher-intensity, mind–body and multicomponent programmes would help establish which approaches provide meaningful additional benefit.

5. Conclusion

Exercise rehabilitation plays an important role in the management of postmenopausal women with osteoporosis by addressing bone density, muscle strength, balance, physical function and, potentially, fracture risk. The available literature describes a broad range of interventions, including resistance and impact training, aerobic and weight-bearing exercise, multicomponent programmes, mind–body exercise and whole-body vibration, as well as exercise combined with nutritional or pharmacological management.

Current evidence suggests that progressive loading and combined programmes are associated with improved bone density and that exercise improves selected measures of physical function. However, differences in study design, participant characteristics, exercise prescription, comparators, outcome measures and follow-up limit direct comparisons and prevent the identification of a single universally superior exercise programme. Evidence for several interventions, including whole-body vibration and some mind–body practices, remains uncertain, and improvements in BMD or performance tests should not automatically be interpreted as reductions in falls or fractures. Rehabilitation should therefore be individualized according to bone density, fracture history, falls risk, comorbidity, current treatment and the woman's goals, with progression and supervision matched to her risk. Future research should use rigorous comparative designs, standardized outcome measures, clearly reported exercise prescriptions and longer follow-up to establish the effectiveness and clinical relevance of different exercise approaches. Hence, the current evidence supports individualized, progressive, goal-directed exercise rehabilitation for postmenopausal women with osteoporosis, although stronger evidence is needed to identify the most effective programmes and to improve long-term outcomes. This review is limited by the incomplete database search, study selection, data extraction and risk-of-bias assessment, as well as by heterogeneity in participants, interventions, outcome measures and follow-up periods. Therefore, the findings should be interpreted cautiously until a comprehensive and reproducible systematic review is completed.

References

1. Bai, J., Huang, W., Yan, R., & Du, X. (2025). Effects of combined exercise and calcium/vitamin D supplementation on bone mineral density in postmenopausal women: A systematic review and meta-analysis. Nutrients, 17(24), Article 3866. https://doi.org/10.3390/nu17243866
2. Beck, B. R., Daly, R. M., Singh, M. A. F., & Taaffe, D. R. (2017). Exercise and Sports Science Australia (ESSA) position statement on exercise prescription for the prevention and management of osteoporosis. Journal of Science and Medicine in Sport, 20(5), 438–445. https://doi.org/10.1016/j.jsams.2016.10.001
3. Brooke-Wavell, K., Skelton, D. A., Barker, K. L., Clark, E. M., De Biase, S., Arnold, S., Paskins, Z., Robinson, K., Lewis, R. M., Tobias, J. H., Ward, K. A., Whitney, J., & Leyland, S. (2022). Strong, steady and straight: UK consensus statement on physical activity and exercise for osteoporosis. British Journal of Sports Medicine, 56(15), 837–846. https://doi.org/10.1136/bjsports-2021-104634
4. Cummings, S. R., & Melton, L. J. (2002). Epidemiology and outcomes of osteoporotic fractures. The Lancet, 359, 1761–1767. https://doi.org/10.1016/S0140-6736(02)08657-9
5. Daly, R. M., Dalla Via, J., Duckham, R. L., Fraser, S. F., & Helge, E. W. (2019). Exercise for the prevention of osteoporosis in postmenopausal women: An evidence-based guide to the optimal prescription. Brazilian Journal of Physical Therapy, 23, 170–180. https://doi.org/10.1016/j.bjpt.2018.11.011
6. Giangregorio, L. M., Papaioannou, A., MacIntyre, N. J., Ashe, M. C., Heinonen, A., Shipp, K., et al. (2014). Too Fit To Fracture: Exercise recommendations for individuals with osteoporosis or osteoporotic vertebral fracture. Osteoporosis International, 25(3), 821–835. https://doi.org/10.1007/s00198-013-2523-2

7. Gibbs, J. C., MacIntyre, N. J., Ponzano, M., Templeton, J. A., Thabane, L., Papaioannou, A., & Giangregorio, L. M. (2019). Exercise for improving outcomes after osteoporotic vertebral fracture. Cochrane Database of Systematic Reviews, 7, CD008618.
8. Gombarčíková, T., Svobodová, L., Svobodová, A., & Gimunová, M. (2025). The effect of physical activity intervention and detraining on postmenopausal osteopenia and osteoporosis: A systematic review. Frontiers in Sports and Active Living, 7, Article 1655404. https://doi.org/10.3389/fspor.2025.1655404
9. Guo, S., Chen, P., Yuan, W., Liu, D., Wang, S., & Hu, Z. (2023). Effects of resistance and balance exercises for athletic ability and quality of life in people with osteoporotic vertebral fracture: Systematic review and meta-analysis of randomized control trials. Frontiers in Medicine, 10, Article 1135063. https://doi.org/10.3389/fmed.2023.1135063
10. Guyatt, G. H., Oxman, A. D., Vist, G. E., Kunz, R., Falck-Ytter, Y., Alonso-Coello, P., & Schünemann, H. J. (2008). GRADE: An emerging consensus on rating quality of evidence and strength of recommendations. BMJ, 336, 924–926. https://doi.org/10.1136/bmj.39489.470347.AD
11. Hejazi, K., Askari, R., & Hofmeister, M. (2022). Effects of physical exercise on bone mineral density in older postmenopausal women: A systematic review and meta-analysis of randomized controlled trials. Archives of Osteoporosis, 17, Article 102. https://doi.org/10.1007/s11657-022-01140-7
12. Hejazi, K., Rahimi, G. R. M., & Hofmeister, M. (2025). Impact of exercise modalities on bone health: A meta-analysis of aerobic, resistance, and combined training on bone mineral density in postmenopausal women. Archives of Osteoporosis, 20(1), Article 105. https://doi.org/10.1007/s11657-025-01594-5
13. Higgins, J. P. T., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M. J., & Welch, V. A. (Eds.). (2024). Cochrane handbook for systematic reviews of interventions. Cochrane. https://training.cochrane.org/handbook/current
14. Hoffmann, I., Kohl, M., von Stengel, S., Jakob, F., Kerschan-Schindl, K., Lange, U., Peters, S., Schoene, D., Sieber, C., Thomasius, F., Bischoff-Ferrari, H. A., Uder, M., & Kemmler, W. (2023). Exercise and the prevention of major osteoporotic fractures in adults: A systematic review and meta-analysis with special emphasis on intensity progression and study duration. Osteoporosis International, 34(1), 15–28. https://doi.org/10.1007/s00198-022-06592-8
15. Howe, T. E., Shea, B., Dawson, L. J., Downie, F., Murray, A., Ross, C., Harbour, R. T., Caldwell, L. M., & Creed, G. (2011). Exercise for preventing and treating osteoporosis in postmenopausal women. Cochrane Database of Systematic Reviews, 2011(7), CD000333. https://doi.org/10.1002/14651858.CD000333.pub2
16. Hsu, H.-H., Chiu, C.-Y., Chen, W.-C., Yang, Y.-R., & Wang, R.-Y. (2024). Effects of exercise on bone density and physical performance in postmenopausal women: A systematic review and meta-analysis. PM&R, 16(12), 1358–1383.
17. Iolascon, G., de Sire, A., Curci, C., Paoletta, M., Liguori, S., Calafiore, D., et al. (2021). Osteoporosis guidelines from a rehabilitation perspective: Systematic analysis and quality appraisal using AGREE II. European Journal of Physical and Rehabilitation Medicine, 57, 273–279. https://doi.org/10.23736/S1973-9087.21.06581-3
18. Kanis, J. A., McCloskey, E. V., Johansson, H., Cooper, C., Rizzoli, R., & Reginster, J. Y. (2013). European guidance for the diagnosis and management of osteoporosis in postmenopausal women. Osteoporosis International, 24, 23–57. https://doi.org/10.1007/s00198-012-2074-y
19. Kemmler, W., Häberle, L., & von Stengel, S. (2013). Effects of exercise on fracture reduction in older adults: A systematic review and meta-analysis. Osteoporosis International, 24(7), 1937–1950. https://doi.org/10.1007/s00198-012-2248-7
20. Kistler-Fischbacher, M., Weeks, B. K., & Beck, B. R. (2021). The effect of exercise intensity on bone in postmenopausal women (part 2): A meta-analysis. Bone, 143, Article 115697. https://doi.org/10.1016/j.bone.2020.115697
21. LeBoff, M. S., Greenspan, S. L., Insogna, K. L., Lewiecki, E. M., Saag, K. G., Singer, A. J., & Siris, E. S. (2022). The clinician's guide to prevention and treatment of osteoporosis. Osteoporosis International, 33, 2049–2102. https://doi.org/10.1007/s00198-021-05900-y
22. Li, Q., Liang, L., Gao, C., & Zong, B. (2024). Therapeutic effects of whole-body vibration on postmenopausal women with osteoporosis: A systematic review and meta-analysis. Brazilian Journal of Medical and Biological Research, 57, Article e13996. https://doi.org/10.1590/1414-431X2024e13996
23. Li, S., Pan, N., Niu, L., Yao, M., Zhao, S., Liu, C., & Li, D. (2026). Effects of exercise interventions on fall-related functional performance in postmenopausal women with osteoporosis or low bone mass: A systematic review and meta-analysis with an exploratory analysis of reported consistency with ACSM recommendations. Frontiers in Physiology, 17, Article 1903705. https://doi.org/10.3389/fphys.2026.1903705
24. Li, X., Zhu, J., Xu, L., Zhang, H., Fu, X., & Wang, Y. (2025). Effect of different types of exercise on bone mineral density in postmenopausal women: A systematic review and network meta-analysis. Scientific Reports, 15(1), Article 11740. https://doi.org/10.1038/s41598-025-94510-3
25. Liu, S., Wu, S., Qi, J., & Wang, L. (2024). Effect of traditional Chinese fitness exercises on bone mineral density in postmenopausal women: A network meta-analysis of randomized controlled trials. Frontiers in Endocrinology, 15,

Article 1323595. https://doi.org/10.3389/fendo.2024.1323595
26. Ma, M., Su, W., & Liu, D. (2025). Effects of different exercise interventions on bone mineral density in elderly postmenopausal women: A network meta-analysis. Frontiers in Physiology, 16, Article 1633913. https://doi.org/10.3389/fphys.2025.1633913
27. Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., et al. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ, 372, Article n71. https://doi.org/10.1136/bmj.n71
28. Sherrington, C., Fairhall, N. J., Wallbank, G. K., Tiedemann, A., Michaleff, Z. A., Howard, K., Clemson, L., Hopewell, S., & Lamb, S. E. (2019). Exercise for preventing falls in older people living in the community. Cochrane Database of Systematic Reviews, 2019(1), CD012424. https://doi.org/10.1002/14651858.CD012424.pub2
29. Shojaa, M., von Stengel, S., Schoene, D., Kohl, M., Barone, G., Bragonzoni, L., et al. (2020). Effect of exercise training on bone mineral density in post-menopausal women: A systematic review and meta-analysis of intervention studies. Frontiers in Physiology, 11, Article 652. https://doi.org/10.3389/fphys.2020.00652
30. Sterne, J. A. C., Hernán, M. A., Reeves, B. C., Savović, J., Berkman, N. D., Viswanathan, M., et al. (2016). ROBINS-I: A tool for assessing risk of bias in non-randomised studies of interventions. BMJ, 355, Article i4919. https://doi.org/10.1136/bmj.i4919
31. Sterne, J. A. C., Savović, J., Page, M. J., Elbers, R. G., Blencowe, N. S., Boutron, I., et al. (2019). RoB 2: A revised tool for assessing risk of bias in randomised trials. BMJ, 366, Article l4898. https://doi.org/10.1136/bmj.l4898
32. Watson, S. L., Weeks, B. K., Weis, L. J., Harding, A. T., Horan, S. A., & Beck, B. R. (2018). High-intensity resistance and impact training improves bone mineral density and physical function in postmenopausal women with osteopenia and osteoporosis: The LIFTMOR randomized controlled trial. Journal of Bone and Mineral Research, 33(2), 211–220. https://doi.org/10.1002/jbmr.3284
33. Yin, S., Liu, Y., Zhong, Y., & Zhu, F. (2024). Effects of whole-body vibration on bone mineral density in postmenopausal women: An overview of systematic reviews. BMC Women's Health, 24(1), Article 444. https://doi.org/10.1186/s12905-024-03290-x
34. Zhang, W., Li, X., He, Q., & Wang, X. (2025). Effects of exercise on bone metabolism in postmenopausal women: A systematic review and meta-analysis of randomized controlled trials. Frontiers in Endocrinology, 16, Article 1597046. https://doi.org/10.3389/fendo.2025.1597046
35. Zhao, F., Su, W., Sun, Y., Wang, J., Lu, B., & Yun, H. (2025). Optimal resistance training parameters for improving bone mineral density in postmenopausal women: A systematic review and meta-analysis. Journal of Orthopaedic Surgery and Research, 20, Article 523. https://doi.org/10.1186/s13018-025-05890-1
36. Zhou, X., Yang, N., Xi, C., Ji, J., & Xu, T. (2026). A network meta-analysis of the effects of different aerobic exercise prescriptions on bone density in osteoporosis patients. Frontiers in Endocrinology, 17, Article 1828031. https://doi.org/10.3389/fendo.2026.1828031
37. Zitzmann, A. L., Shojaa, M., Kast, S., Kohl, M., von Stengel, S., Borucki, D., et al. (2022). The effect of different training frequency on bone mineral density in older adults: A comparative systematic review and meta-analysis. Bone, 154, Article 116230. https://doi.org/10.1016/j.bone.2021.116230