Calcified Tissue International (2020) 106:577–590
https://doi.org/10.1007/s00223-020-00671-w

REVIEW ARTICLE

The Impact of Different Modes of Exercise Training on Bone Mineral Density in Older Postmenopausal Women: A Systematic Review and Meta-analysis Research

Gholam Rasul Mohammad Rahimi[1,2] · Neil A. Smart[3] · Michael T. C. Liang[4] · Nahid Bijeh[1] · Alsaeedi L. Albanaqi[3,5] · Mehrdad Fathi[1] · Arghavan Niyazi[6] · Nasser Mohammad Rahimi[7]

Received: 23 October 2019 / Accepted: 6 February 2020 / Published online: 13 February 2020

Abstract

Effectiveness of exercise on bone mass is closely related to the mode of exercise training regimen, as well as the study design. This study aimed to determine the effect of different modes of exercise training on lumbar spine and femoral neck bone mineral density (BMD) in older postmenopausal women (PMW). PubMed, CINAHL, Medline, Google Scholar, and Scopus databases and reference lists of included studies were searched up until March 25, 2019 for randomized controlled trials (RCTs) that evaluated the effectiveness of various modes of exercise training in PMW. Sixteen RCTs with 1624 subjects were included. Our study found no significant change in both lumbar spine and femoral neck BMD following exercise training (MD: 0.01 g/cm^2; 95% confidence interval (CI) [−0.01, 0.02] and MD: 0.00 g/cm^2; 95% CI [−0.01, 0.01], respectively). However, subgroup analysis by type of exercise training revealed that lumbar spine BMD (MD: 0.01; 95% CI [0.00, 0.02]) raised significantly when whole-body vibration (WBV) was employed as intervention compared with RCTs that utilized aerobic (MD: −0.01; 95% CI [−0.02, −0.01]), resistance (MD: 0.01; 95% CI [−0.04, 0.06]), and combined training (MD: 0.03; 95% CI [−0.01, 0.08]). On the other hand, lumbar spine BMD (MD: −0.01; 95% CI [−0.02, −0.01]) reduced significantly when aerobic exercise training was used as intervention compared with RCTs that utilized resistance training, combined training, and WBV. By contrast, these analyses did not have significant effect on change in femoral neck BMD. WBV is an effective method to improve lumbar spine BMD in older PMW.

Keywords Postmenopausal women · Exercise training · Bone mineral density · Meta-analysis · Randomized controlled trials

Introduction

Osteoporosis is a loss of bone mass with a deterioration of bone quality and increased fracture risk. There is a worldwide epidemic associated with increased fracture risk leading to morbidity, mortality, and socioeconomic burden [1, 2]. Some studies have shown that osteoporosis prevalence

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00223-020-00671-w) contains supplementary material, which is available to authorized users.

✉ Nahid Bijeh
bijeh@um.ac.ir

1 Department of Exercise Physiology, Faculty of Sport Sciences, Ferdowsi University of Mashhad, Mashhad, Iran

2 Department of Sport Sciences, Vahdat Institute of Higher Education, Torbat-e-Jam, Iran

3 School of Science and Technology, University of New England, Armidale, Australia

4 Department of Kinesiology and Health Promotion, California State Polytechnic University, Pomona, CA, USA

5 Turaif General Hospital, Ministry of Health, Turaif, Kingdom of Saudi Arabia

6 Department of Exercise Physiology, Sanabad Golbahar Institute of Higher Education, Golbahar, Iran

7 Department of Sport Sciences, Imam Reza International University, Mashhad, Iran

has increased due to increased life expectancy and sedentary lifestyle, as well as poor dietary habits [3, 4]. Clinically, osteoporosis is a silent disease characterized by increased bone resorption without adequate compensating formation of new bone [5]. After bone mass reaches its peak it remains relatively stable until the onset of menopause in women. Thus, osteoporosis affects postmenopausal women (PMW) because of the suppression or absence of estrogen production [6]. It should be noted that estrogen acts directly on bone by suppression of osteocyte receptors that activate osteoclastic activity.

The rate of change in bone mass and density is greater at sites with predominantly trabecular bone. In older PMW, osteogenic responses with exercise training on bone are more sensitive at the loading sites because PMW over the age of 70 years tend to have lower trabecular and cortical bone mineral density (BMD) and cortical thickness, while younger PMW between 48 and 69 years tend to have higher total cross-sectional area and endosteal circumference [7].

Bones are active dynamic tissues undergoing constant growth via the process of bone modeling and remodeling. Osteocytes are the architect of the bone remodeling process because their interconnected network of cells are capable of detecting mechanical strain and fluid pressure by initiating the process of bone modeling and remodeling. As described by Robling et al. [8], mechanical forces applied to the bone tissue induce interstitial fluid movements along the canaliculi and osteocyte lacunae causing shear stress at the cellular level and deformations of osteocyte plasma membrane. These changes lead to the beginning of the bone remodeling process that stimulates the bone resorption and formation cycle [9]. Removal of these mechanical strains and impact-loading forces, such as physical inactivity or bedrest, lead to low bone mass and BMD. Thus, the application of exercise training with impact loading on bone and whole-body vibration training is to initiate bone formation and prevent bone resorption. Individuals who have BMD value below the osteoporotic level (i.e., femoral or lumbar spine BMD z-score lower than − 2.5 standard deviation of young women), sustained more than half of all hip fractures [10, 11]. Therefore, bone researchers and clinicians believed that biomechanical strength of bone is highly related to BMD, as well as its geometry and microarchitectural parameters.

Another clinical approach to treat or prevent osteoporosis in PMW is by prescribing hormones and anti-resorptive and/or osteogenic medications. This approach has been limited and restricted because of concerns of age-related or polydrug interaction or side effects. Older women worry regarding the increased risk of hormone therapy linked to breast cancer as well as the unfavorable impacts and expense of the added drugs. On the other hand, it has been reported that various modalities of exercise activity including whole-body vibration (WBV) training plays a significant role in preventing bone loss, and sustaining and enhancing BMD [12, 13] without prescribing anti-resorption drug therapy. Bone mass can be maintained or ameliorated with weight-bearing exercise, resistance training or WBV for enhancing of BMD, and promoting physical health and quality of life in PMW [14–16]. For example, two recent meta-analysis studies examining BMD in PMW, reported the beneficial effects of combined resistance training and WBV on BMD, but not isolated resistance training protocols [17, 18]. Mohr and colleagues have also reported an improvement in BMD (leg and hip) in PMW following a 15-week soccer training. Nevertheless, research reported on other exercise modalities in PMW have produced contradictory findings [16, 19–21]. In this regard, the effectiveness of exercise on bone mass is closely related to the mode of exercise training regimen, duration and intensity of exercise, as well as the study design.

Eight meta-analyses on physical activity efficacy in PMW were conducted previously [17, 18, 22–27], nevertheless, their participants' range of age differed from the current meta-analysis. Therefore, the purpose of this study was to carry out a systematic review and meta-analysis to clarify the possible effective type of exercise training on BMD in the lumbar spine and femoral neck in older PMW (60 years or more).

Methods

Data Sources and Searches

We performed a detailed search utilizing PubMed, CINAHL, Medline, Google Scholar, and Scopus databases. Search criteria included a mix of both MeSH and free-text terms relating to the keywords of bone mineral density, postmenopausal, exercise training, resistance training, whole-body vibration, aerobic training, walking, physical activity, high-impact exercise, bone loss and exercise, and bone mass. We employed the Boolean search terms (AND, OR, or NOT) to create the search strategy, merging the search terms of the participation in exercise training and the outcomes (lumbar spine and femoral neck BMD). The search strategy including all the items from database inception was developed until March 25, 2019. Then, following the initial screening, systematic reviews, meta-analyses, and all references were also searched to find further studies.

Study Selection

Exercise training randomized controlled trials (RCTs) and controlled trials in PMW were included. In our meta-analysis, exercise training included aerobic (including aerobic training, walking, and weight-bearing training), resistance (including resistance and impact training), combined (aerobic + resistance), and WBV training. Studies included in this meta-analysis compared older PMW in the training and control groups. Two authors independently reviewed the titles, abstracts, and full texts of convenient articles to detect eligible researches.

Inclusion/Exclusion Criteria

For study identification and selection, the following criteria were applied (1) full-text RCTs and controlled trials published in the English language; (2) health PMW aged ≥ 60 years without hormone replacement therapy (HRT) and systematic exercise (less than 2.5 h per week) before study registration; (3) studies in which participants did not receive supplemental calcium and vitamin D other than their daily requirements during the intervention period; (4) study protocols that employed aerobic, resistance, combined aerobic and resistance, and whole-body vibration training, with an intervention period ≥ 6 months (since this is the minimum period used to employed positive impacts on BMD), in a pre-post design with a non-exercise control group. Review articles, literature reviews, conference, abstracts, and study protocols, as well as studies in which the subjects took part in an exercise regimen during the last 6 months have been excluded.

Outcome Measures

The outcome measure was BMD (lumbar spine and/or femoral regions) assessed using dual-energy x-ray absorptiometry (DEXA) or dual-photon absorptiometry (DPA).

Data Extraction

Four authors independently extracted data from each study included in the review. The information extracted included the following:

1) Author, year of publication, and study design;
2) Demographic characteristics of PMW;
3) Exercise interventions feature;
4) Mean and standard deviation (SD) of continuous outcomes;
5) Details of the biomarker evaluation methodology.

Data Synthesis

For all included studies, we summarized the effect size for any outcome by measuring the mean difference between the exercise and control condition from before and following the intervention. If each article published multiple outcomes for the current study, we estimated and reported separately any outcome. Given the similar methods of reporting techniques for outcomes (both femoral neck and lumbar spine BMD), the mean difference (MD) was used. All analyses were performed applying Review Manager 5.3 (The Nordic Cochrane Centre, Copenhagen, Denmark). Extracted outcome data were completed using the change in the mean and standard deviation (SD) values. The pre-intervention mean was subtracted from the postintervention mean, and the change SD was calculated applying study group subject numbers in conjunction with group p-values or 95% CI where the change in mean and SD was not reported. In studies that reported standard error of the mean (SEM) data instead of the SD, this value was converted to SD [28]. Where data were not shown in text or tables, and authors could not be contacted, data displayed in figures were extracted or obtained where feasible via GetData Graph Digitizer software. Where an article contained a control group and more than one exercise group, we separately labeled each exercise group and adjusted the sample size of the control group according to the number of exercise groups.

A random-effects inverse variance was utilized. To evaluate the heterogeneity among the studies, the I^2 statistic was used, with values > 50% showing substantial heterogeneity [28]. Subgroup analyses were used to recognize potential causes of heterogeneity among the articles. The mode of exercise training (WBV, aerobic, resistance, combined aerobic and resistance) was considered as a predefined source of heterogeneity. We presented meta-analysis applying Forest plots and applied a 5% level of significance to describe the significance of results. The risk of publication bias was measured utilizing funnel plots [29].

Study Quality

Fifteen-point Tool for the Assessment of Study Quality and Reporting in Exercise (TESTEX) scale was utilized for evaluating the study quality and reporting [30]. Two reviewers (GhRMR and AA) independently performed the study quality and reporting assessment, NMR was consulted if discrepancies occurred.

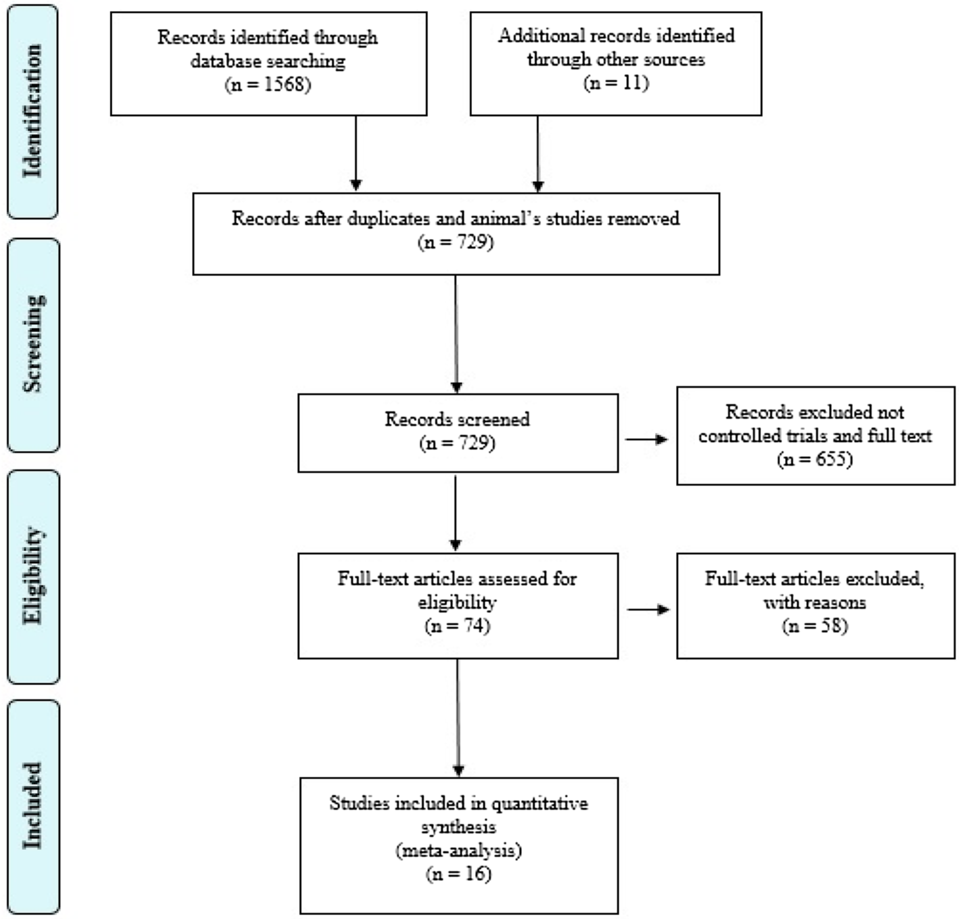
Results

Study and Participant Characteristics

Initially, 1579 articles were found via PubMed, Medline, and Scopus database and hand searching. After duplicate titles, animal studies and exclusion of articles based on abstract and title were removed, 729 full-text articles remained for screening. Full screening resulted in 16 articles meeting the stated inclusion criteria (PRISMA flow diagram; Fig. 1).

The 16 included studies had a total of 1624 participants. There were 903 (55.6%) participants in the exercise group

Fig. 1 PRISMA flow diagram



and 721 (44.4%) in the control group. The mean age of participants in the exercise group and the control group was 69.54 ± 4.25 and 70.21 ± 4.28 years, respectively. All included articles were RCTs promulgated since 1992.

Intervention Details

The studies' intervention period ranged from 24 to 120 weeks, with each session's length of range 12–60 min. The reviewed full-text studies that were excluded are supplied in Supplementary Table S1 with reasons.

Of the 16 [31–46] included studies, four [32, 33, 35, 37] involved resistance training, four [41, 43, 45, 46] examined aerobic training, three [36, 39, 44] investigated whole-body vibration training, and two [38, 40] investigated combined aerobic + resistance training. Other included studies are isolated aerobic and resistance training [31], isolated whole-body vibration and resistance training [34], isolated combined (aerobic + resistance) and whole-body vibration training [42], each one of the above studies was investigated as one study (Table 1).

BMD Assessment

Seven studies [32, 33, 37, 40, 43, 45, 46] assessed BMD (g/cm^2) at the L_2-L_4 spine, three studies [35, 38, 39] assessed BMD (g/cm^2) at the total of lumbar spine, and three studies [34, 42, 44] assessed BMD (g/cm^2) at the L_1–L_4 spine. Moreover, 14 studies [31–41, 43, 45, 46] evaluated BMD (g/cm^2) at the femoral neck region. All included studies assessed BMD employing DEXA method.

Outcome Measures

Change in Lumbar Spine BMD

Thirteen studies [32–35, 37–40, 42–46] providing a total of 1371 participants (18 intervention groups and 13 control groups) reported changes in lumbar spine BMD as an outcome measure. We combined the results employing the random-effects model and revealed no significant change in lumbar spine BMD after exercise training intervention (MD: 0.01 g/cm^2; 95% CI [−0.01, 0.02]; $p = 0.39$; Fig. 2).

Table 1 Characteristics of included studies in the meta-analysis

Study	Years past menopause	Disease	*n* EX (CON)	Age(yrs) Mean ± SD	Modes of exercise	Intervention group: frequency and duration	Control group	Outcomes	Assessment measure/units
Beck and Norling [39]	> 5	None	28 (14)	71.5 ± 9.0	LWBV and HWBV training	Two sessions/week LWBV with frequency of 30 Hz; 8 months	No train	Lumbar spine BMD Femoral neck BMD	- DXA/(g/cm^2) - DXA/(g/cm^2)
Brentano et al. [37]	NM	Low bone mass	19 (9)	64.8 ± 3.3	RT and Circuit training	**RT training:** Three sessions/week × 60 min (2–4 sets × 20–6 reps at 45–80% 1RM, 2 min rest between sets); 24 weeks **Circuit training:** Three sessions/week × 60 min (2–3 sets × 20–10 reps at 45–60% 1RM, no rest between exercises); 24 weeks	No train	Lumbar spine BMD Femoral neck BMD	- DXA/(g/cm^2) - DXA/(g/cm^2)
Brooke-Wavel et al. [43]	5	None	16 (20)	65.3 ± 2.9	Brisk walking	At least 3 times/week × 20 min, completing 280 min each fortnight during the 12 months	No train	Lumbar spine BMD Femoral neck BMD	- DXA/(g/cm^2) - DXA/(g/cm^2)
Chuin et al. [35]	NM	None	11 (7)	66.1 ± 3.3	RT training	Three sessions/week × 60 min, 3 sets × 8 reps at 80% 1RM, 6 months	No train	Lumbar spine BMD Femoral neck BMD	- DXA/(g/cm^2) - DXA/(g/cm^2)
Englund et al. [38]	NM	None	21(19)	73.0 ± 4.25	Combination of RT, aerobic, balance and coordination exercises	Two sessions/week × 50 min; 12 months	No train	Lumbar spine BMD Femoral neck BMD	- DXA/(g/cm^2) - DXA/(g/cm^2)
Korpelainen et al. [41]	NM	Low bone mass	84 (76)	72.8 ± 1.2	Impact exercise training	**Exercise group:** 45 min supervised training + 20 min daily home-based exercise training; 30 months	No train	Femoral neck BMD	- DXA/(g/cm^2)
Lau et al. [45]	NM	None	11 (12)	77.0 ± 3.1	Moderate load-bearing exercise	Four sessions/week × stepped up and down a block (9 inches (23 cm) in height) 100 times + exercised for 15 min at submaximal intensity; 10 months	No train	Lumbar spine BMD Femoral neck BMD	- DXA/(g/cm^2) - DXA/(g/cm^2)

Table 1 (continued)

Study	Years past menopause	Disease	*n* EX (CON)	Age(yrs) Mean ± SD	Modes of exercise	Intervention group: frequency and duration	Control group	Outcomes	Assessment measure/units
Leung et al. [44]	25	None	364 (346)	72.9 ± 7.2	Low-magnitude high-frequency vibration	Five sessions/week × 20 min at 35 Hz; 18 months	No train	Lumbar spine BMD	- DXA/(g/cm²)
Lord et al. [46]	NM	None	68 (70)	71.6 ± 5.3	Weight-bearing exercise	Two sessions/week × 50 min; 42 weeks	No train	Lumbar spine BMD Femoral neck BMD	- DXA/(g/cm²) - DXA/(g/cm²)
Marques et al. [31]	~ 18	None	47 (24)	68.5 ± 5.6	RT and aerobic training	**Resistance exercise training;** 3 sessions/week × 60 min at 60–80% 1RM; 8 months **Aerobic exercise training;** 3 sessions/week × 60 min at 50–85% HRR; 8 months	No train	Femoral neck BMD	- DXA/(g/cm²)
Park et al. [40]	18.5	None	22 (23)	68.4 ± 3.5	RT, weight-bearing, balance, and posture correction training	Three sessions/week × 60 min; 48 weeks	No train	Lumbar spine BMD Femoral neck BMD	- DXA/(g/cm²) - DXA/(g/cm²)
Pruitt et al. [32]	NM	None	15 (11)	68.6 ± 3.8	Low-intensity and High-intensity RT training	**Low-intensity group:** 3 sessions/week × 50–55 min, 3 s × 14 reps at 40% 1RM; 12 months **High-intensity group:** 3 sessions/week × 50–55 min, 1 s × 14 reps and 2 s × 7 reps at 80% 1RM; 12 months	No train	Lumbar spine BMD Femoral neck BMD	- DXA/(g/cm²) - DXA/(g/cm²)
Rhodes et al. [33]	NM	None	20 (18)	68.5 ± 3.4	RT training	**Exercise group:** Three sessions/week × 60 min (3 sets × 8 reps at 75% 1RM); 52-week	No train	Lumbar spine BMD Femoral neck BMD	- DXA/(g/cm²) - DXA/(g/cm²)
Santin-Medeiros et al. [36]	NM	None	19 (18)	82.4 ± 5.7	WBV training	**WBV group:** Two sessions/week × 2 sets × 6 min with frequency of 20 Hz; 8 months	No train	Femoral neck BMD	- DXA/(g/cm²)

Table 1 (continued)

Study	Years past menopause	Disease	*n* EX (CON)	Age(yrs) Mean ± SD	Modes of exercise	Intervention group: frequency and duration	Control group	Outcomes	Assessment measure/units
Verschueren et al. [34]	~ 16	None	47 (24)	64.2 ± 3.4	WBV and RT training	**WBV group:** Three sessions/week × 20 min with frequency of 35–40 Hz; 6 months **RT group:** Three sessions/week × 60 min (first 14 weeks intensity was 2 sets × 15–8 RM; last 10 weeks intensity was 3 sets × 12 RM and 1 set × 8 RM); 6 months	No train	Lumbar spine BMD Femoral neck BMD	- DXA/(g/cm^2) - DXA/(g/cm^2)
Von Stengel et al. [42]	~ 19	None	93 (48)	68.5 ± 3.2	Combined aerobic and resistance training, vibration training	**Combined AE and RT groups:** Two supervised sessions/week × 60 min at 70–80% HRM + 2 home-training session/week × 20 min; 18 months **Vibration group:** Two supervised sessions/week × 60 min with frequency of 25–35 Hz + 2 home-training session/week × 20 min; 18 months	No train	Lumbar spine BMD	- DXA/(g/cm^2)

n number of participants in each group, *LWBV* low-intensity whole-body vibration, *HWBV* high-intensity whole-body vibration, *BMD* bone mineral density, *DXA* dual-energy X-ray absorptiometry, *RT* resistance training, *Rep* repetition, *1RM* one repetition maximum, *Hz* hertz, *NM* no mention, *HRR* heart rate reserve, *AE* aerobic exercise

Study or Subgroup	Exercise Mean	Exercise SD	Exercise Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Beck 2010; HWBV	-0.004	0.5	15	-0.01	0.45	7	0.1%	0.01 [-0.41, 0.42]
Beck 2010; LWBV	0	0.79	13	-0.01	0.45	7	0.1%	0.01 [-0.53, 0.55]
Brentano 2008; CT	0.021	0.078	10	0	0.127	5	1.4%	0.02 [-0.10, 0.14]
Brentano 2008; RT	0	0.088	9	0	0.127	4	1.1%	0.00 [-0.14, 0.14]
Brooke-Wavell 2001	0.004	0.008	16	0.017	0.006	20	31.0%	-0.01 [-0.02, -0.01]
Chuin 2009	-0.0014	0.15	11	-0.0148	0.17	7	0.9%	0.01 [-0.14, 0.17]
Englund 2005	0.03	0.19	21	0.01	0.15	19	1.8%	0.02 [-0.09, 0.13]
Lau 1992	-0.045	0.6803	11	-0.016	0.0315	12	0.1%	-0.03 [-0.43, 0.37]
Leung 2014	0.08	5.7241	364	-0.64	6.3363	346	0.0%	0.72 [-0.17, 1.61]
Lord 1996	0.012	0.204	68	0.004	0.182	70	4.3%	0.01 [-0.06, 0.07]
Park 2008	0.007	0.081	25	-0.072	0.175	25	3.3%	0.08 [0.00, 0.15]
Pruitt 1995; HI	0.007	0.156	7	0	0.154	6	0.7%	0.01 [-0.16, 0.18]
Pruitt 1995; LI	0.005	0.177	7	0	0.154	5	0.6%	0.01 [-0.18, 0.19]
Rhodes 2000	0.03	0.175	20	0	0.17	18	1.6%	0.03 [-0.08, 0.14]
Verschueren 2004; RT	0.001	0.136	22	0.004	0.146	12	2.0%	-0.00 [-0.10, 0.10]
Verschueren 2004; WBV	-0.003	0.144	25	0.004	0.146	12	2.0%	-0.01 [-0.11, 0.09]
Von Stengel 2011; COM	0.019	0.031	50	0.004	0.031	25	23.9%	0.01 [0.00, 0.03]
Von Stengel 2011; WBV	0.014	0.022	51	0.004	0.031	26	25.2%	0.01 [-0.00, 0.02]
Total (95% CI)			745			626	100.0%	0.01 [-0.01, 0.02]

Heterogeneity: Tau² = 0.00; Chi² = 29.46, df = 17 (P = 0.03); I² = 42%
Test for overall effect: Z = 0.86 (P = 0.39)

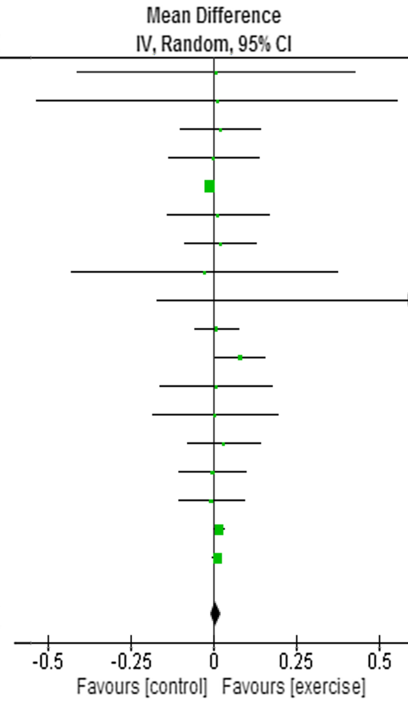


Fig. 2 Forest plot for the lumbar spine BMD changes. *HWBV* high-intensity whole-body vibration, *LWBV* low-intensity whole-body vibration, *RT* resistance training, *CT* circuit training, *COM* combined, *HI* high intensity, *LI* low intensity

Change in Femoral Neck BMD

Fourteen studies providing a total of 778 subjects (19 intervention groups and 14 control groups) reported femoral neck BMD as an outcome measure. Pooled results from the random-effects model illustrated that exercise training did not have a significant effect on femoral neck BMD (MD: – 0.00 g/cm^2; 95% CI [– 0.01, 0.01]; $p = 0.99$; Fig. 3).

Subgroup Analysis for Mode of Exercise Training

The results of the subgroup analyses are demonstrated in Table 2. We stratified studies based on the mode of exercise training (WBV, aerobic, resistance, and combined). These analyses revealed that lumbar spine BMD (MD: 0.01; 95% CI [0.00, 0.02]; $p = 0.02$) raised significantly when WBV training was employed as intervention compared with RCTs that utilized aerobic training (MD: – 0.01; 95% CI [– 0.02, – 0.01]), resistance training (MD: 0.01; 95% CI [– 0.04, 0.06]), and combined training (MD: 0.03; 95% CI [– 0.01, 0.08]). On the other hand, lumbar spine BMD (MD:-0.01; 95% CI [– 0.02, – 0.01]; $p < 0.00001$) reduced significantly when aerobic exercise training was used as intervention compared with RCTs that utilized resistance training, combined training, and whole-body vibration training. By contrast, the subgroup analyses by type of exercise training (whole-body vibration, aerobic, resistance, and combined training) did not have significant impact on change in femoral neck BMD.

Study Quality

The overall quality of included studies was judged to be moderate to good, with a median TESTEX score of 9.5 (range 8–12) of a maximum score of 15 (Table 3). Each one of the criteria of monitoring of physical activity in the control group, intention to treat analyses, and relative training intensity was met in 6 studies. The criteria of assessor blinding were also met in 5 studies, however, the criteria of allocation concealment were met in only 3 studies. The other TESTEX criteria were each met in at least 50% of trials.

Heterogeneity and Publication Bias

Our analyses in both lumbar spine and femoral neck BMD revealed low heterogeneity ($I^2 = 42\%$; $p = 0.03$ and $I^2 = 27\%$; $p = 0.14$, respectively). The Egger plots suggest risk of publication bias was low (Fig. 4a and b).

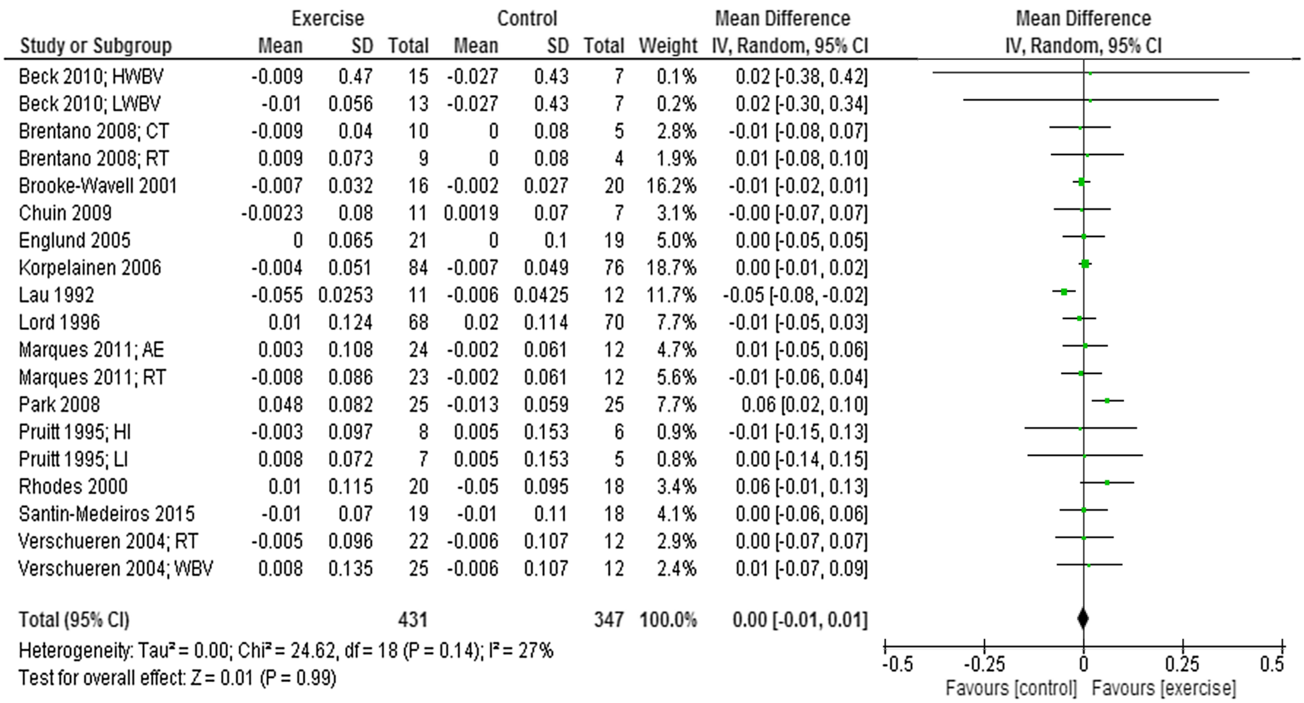


Fig. 3 Forest plot for the femoral neck BMD changes. *HWBV* high-intensity whole-body vibration, *LWBV* low-intensity whole-body vibration, *RT* resistance training, *CT* circuit training, *AE* aerobic exercise, *HI* high intensity, *LI* low intensity

Table 2 Results of subgroup analysis on included RCTs in meta-analysis

Variables	Type of exercise training				All
	Aerobic	Resistance	Combined	Whole-body vibration	
Lumbar spine BMD					
N. studies	2	7	3	6	13
Mean difference (MD)	− 0.01	0.01	0.03	0.01	− 0.01
95% CI	[− 0.02, − 0.01]	[− 0.04, 0.06]	[−0.01, 0.08]	[0.00, 0.02]	[− 0.01, − 0.00]
p-value	**< 0.00001**	0.66	0.13	**0.02**	**0.0003**
I^2 (%)	0	0	2	0	42
Femoral neck BMD					
N. studies	4	8	3	4	14
Mean difference (MD)	− 0.01	0.01	0.02	0.01	− 0.00
95% CI	[− 0.04, 0.01]	[− 0.02, 0.03]	[− 0.03, 0.06]	[− 0.04, 0.05]	[− 0.01, 0.01]
p-value	0.31	0.62	0.45	0.82	0.78
I^2 (%)	71	0	71	0	27

Bold values indicate statistical significance ($p < 0.05$)

Discussion

The primary objective of this study was to undertake a systematic review and meta-analysis of RCTs evaluating the impacts of various types of exercise training on BMD at the lumbar spine and femoral neck in older PMW. The second objective was to assistance provide more evidence on varying modes of exercise training protocols for the aim of determining optimal exercise regimens for older PMW. Our primary analysis shows that various types of exercise training compared to control groups had no significant effects on BMD in either the lumbar spine or the femoral neck. Whereas, the effect of protocols that include WBV appear to be limited to increases in lumbar spine BMD,

Table 3 Study quality assessment of included studies using the tool for the assessment of study quality in exercise (TESTEX)

Study	Eligibility Criteria specified	Randomisation details specified	Allocation concealed	Groups similar at baseline	Assessors blinded	Outcomes measures assessed > 85% participants#	Intention to treat analysis	Reporting between group statistical comparison*	Point measures & measures of variability	Activity monitoring in control group	Relative exercise intensity constant	Exercise volume & Energy expenditure	Overall TESTEX (15)
Beck and Norling [39]	1	1	0	0	1	3	1	2	1	0	1	0	11
Brentano et al. [37]	1	0	0	1	0	2	0	2	1	1	0	1	9
Brooke-Wavel et al. [43]	1	0	0	1	0	2	0	2	1	0	1	1	9
Chuin et al. [35]	1	0	0	1	0	1	0	2	1	1	0	1	8
Englund et al. [38]	1	0	0	1	0	3	0	2	1	0	1	1	10
Korpelainen et al. [41]	1	1	1	1	1	2	1	2	1	0	0	1	12
Lau et al. [45]	1	1	0	1	0	3	0	2	1	0	0	0	9
Leung et al. [44]	1	1	1	1	1	2	1	2	1	0	0	0	11
Lord et al. [46]	1	0	0	1	0	3	1	2	1	0	0	0	9
Marques et al. [31]	1	1	0	1	0	1	1	2	1	0	0	1	9
Park et al. [40]	1	1	0	1	0	2	0	2	1	0	0	0	8
Pruitt et al. [32]	1	0	0	0	0	2	0	2	1	1	1	0	8
Rhodes et al. [33]	1	0	0	1	0	2	0	2	1	1	1	1	10
Santin-Medeiros et al. [36]	1	1	0	1	0	2	0	2	1	1	1	1	11
Verschueren et al. [34]	1	1	0	1	1	2	0	2	1	1	0	0	10
Von Stengel et al. [42]	1	1	1	1	1	2	1	2	1	0	0	1	12

Key: total out of 15 points. Legend: #three points possible—one point if adherence > 85%, one point if adverse events reported, one point if exercise attendance is reported. *Two points possible—one point if primary outcome is reported, one point if all other outcomes reported. TESTEX, Tool for the assessment of Study quality and reporting in Exercise. 0 awarded if no mention was made of this criteria or if it was unclear whether criteria were meet

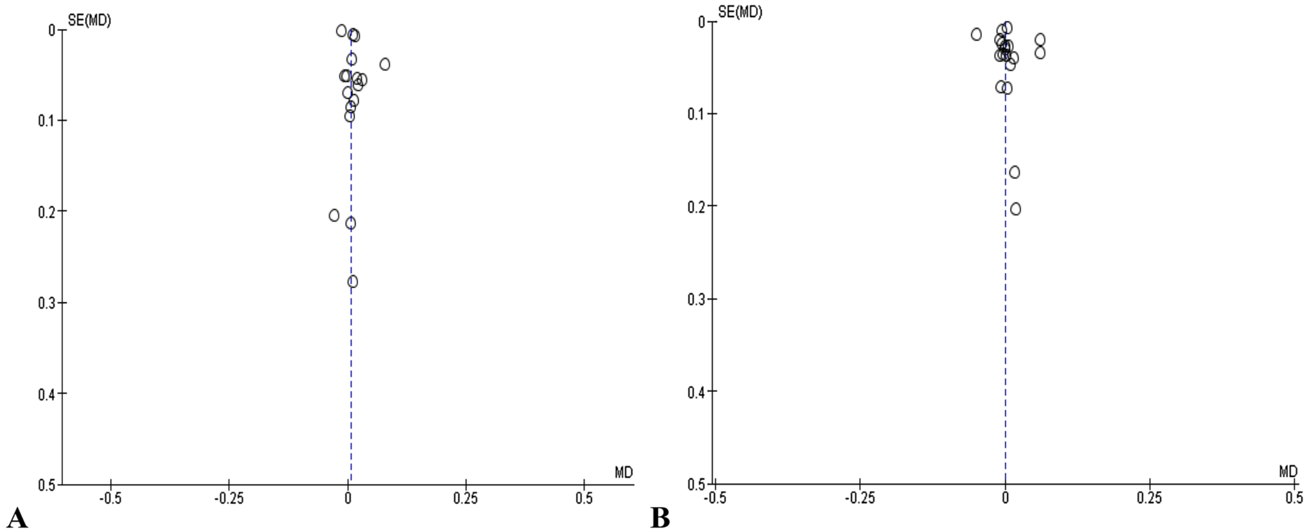


Fig. 4 Egger plot assessment of publication bias for analysis of **a** lumbar spine BMD and **b** femoral neck BMD

but not the femoral neck. Yet, aerobic exercise training significantly reduced BMD in the lumbar spine.

Regarding lumbar spine and femoral neck BMD change according to the overall analysis in older participants, our findings differ with the findings of Marques et al. (2012), who found that exercise of mixed loading impact is associated with significant increments in lumbar spine and femoral neck BMD in older adults [47]. In addition, Zhao et al. (2017) reported that combined exercise interventions positively affected the lumbar spine, femoral neck, total hip, and total body BMD compared with the control group [22] that differs from our findings. Our subgroup analysis also failed to indicate a positive effect of combined exercise intervention at the lumbar spine in PMW aged > 60 years. However, both mentioned meta-analyses, the positive change in BMD of the lumbar spine and total femur or femoral neck were studied following only one or two modes of exercise training. According to the findings of Zhao et al. lumbar spine BMD of PMW aged ≥ 60 years was still sensitive to exercise, which designated that other factors other than mechanical stimulus might contribute the beneficial effects, such as exercise-related increase of calcium absorption [48]. Yet, it should be careful to elucidate the findings because subgroup analysis only included a small number of studies.

From clinical research, it is predicted that 60–80 percent of bone mass variation through a lifetime is related to genetics [49]. Under Wolff's law, nevertheless, both mechanical stimuli and quantity of skeletal loading are considered as an active osteogenic promoter [5, 50]. Resistance or impact-loaded exercise training utilizing tensions generated from muscular contraction to stimulate bone cells with strain stress, compression force, and shear stress [51] were used. It should be emphasized that bone formation takes place only when the impact stimulus of physical activity exceeds a certain mechanical strain threshold that is above the accustomed normal daily levels [52].

Land-based running/jogging/walking, as well as step aerobic and cycling exercise involves moderate- to high-impact musculoskeletal loading activity on the lower extremities. Participants developed high muscle strength in lower body, and exhibited gain in BMD in total femur and femoral neck [53]. The land-based resistance training involves high-impact musculoskeletal loading activity on the upper and lower body as well as torso region in a gravitational environment. However, Ryan et al. (1998) reported that 16 weeks of resistance training resulted in no change in BMD in the lumbar spine and femoral neck, and improvement in arm and leg muscular strength in healthy PMW [54]. Liang et al. (2011) reported that 52 weeks of moderate intensity strength training did not induce changes in BMD of the lumbar spine and femoral neck in healthy PMW. But, there was a significant increase in leg muscle strength [55]. Other longitudinal research studies investigating the impact of resistance training on bone mass have shown that PMW's BMD can be enhanced [56–58]. It should be noted that both types of land-based training activities might not be suitable for older frail PMW and individuals with osteoporotic fractures. Nevertheless, for the older PMW, enhancing BMD and muscular force expansion also promulgates motor consonance advancement, dynamic balance and postural stabilization, allowing physical autonomy and promoting quality of life [59].

Regarding WBV, the mechanism by which vibration improves BMD is still unclear. WBV exercise has been prescribed for inducing BMD and bone strength [60] and appears to be a safe and effective training modality for maintaining or enhancing bone metabolism in varying populations [61]. Furthermore, WBV training has been used for preventing bone loss in astronauts [34, 42, 60]. Judex and Rubin (2010) proposed a plausible mechanism by which WBV training can induce anabolic or anti-catabolic responses in bone tissue, and that is the direct transmissibility of vibratory signals to bone cells, resulting in osteogenic responses [62]. Rubin (2004) who examined WBV training, observed a significant difference in BMD change between the placebo and the experimental group. At the femoral neck, the placebo group experienced a loss of 2.1% BMD after 1 year, those subjects completed the WBV training with the top compliance (upper quartile) after 1 year showed a 3.3% gain at the same BMD site ($p = 0.009$), as compared to the mean experimental group gain of 2.7% ($p = 0.02$). Rubin concluded that WBV training may have a very positive outcome for maintaining and enhancing BMD in PMW [63]. Due to its non-invasive, non-pharmacological nature of intervention, the WBV modality may be an optimal approach of osteoporosis treatment for certain specific populations including PMW [64].

Strengths and Limitations in the Systematic Review and Meta-analysis

To our understanding, this is the first systematic review and meta-analysis to investigate the effectiveness of different modes of exercise training on lumbar spine and femoral neck BMD in healthy older PMW. The strength of the present study is that we pooled all included studies in our analysis and compared the effectiveness of different modes of exercise training on BMD in lumbar spine and femoral neck. Our results show that according to the modes of exercise training, lumbar spine BMD only responded positively to WBV training in older PMW.

Our meta-analysis has some limitations that should be considered. First, the outcome of our meta-analysis is BMD change; however, it has the inherent limitations for bone strength analysis. The bone mineral content and structural adaptation due to exercise training can enhance mechanical load and bone bending strength [65–67]. It has been reported that only approximately 60–70 percent of bone strength adaptation can be explained by BMD [68], and other characteristics of the quality of bones, such as microarchitecture, are not included. Hence, in PMW, BMD estimation may not be a perfect indicator of osteogenic response to exercise training. In addition, some trials only included a smaller study population, which tended to weaken the quality of individual study and then posed a threat to risk of bias of our meta-analysis. Finally, concerning the data collection, we computed the mean differences between pre- and postintervention. Notwithstanding, in situations where actual p values within or between groups or 95% CI were unavailable, default p values were applied, and this may have influenced our results. As life expectancy is rising and the number of elderly individuals becoming more sedentary, the development of osteoporotic fracture prevention and treatment regimens is imperative. However, the difficult task of conducting human exercise trials to investigate the impact of exercise training on BMD or osteoporotic fractures as a primary or secondary study endpoint is to deal with an enormous sample size [69] that could provide definite proof that exercise training can positively achieve the ultimate goals of overall fractures prevention in older PMW [70, 71].

Conclusion

The overall conclusion of the present review and meta-analysis was that different modes of exercise training were unable to show improvement or maintenance of BMD in the lumbar spine and femoral neck in older PMW. However, subgroup analysis showed only WBV training that improves the lumbar spine BMD in older PMW, but not other types of exercise training.

Funding This study was not funded by any financial support.

Compliance with Ethical Standards

Conflict of interest Gholam Rasul Mohammad Rahimi, Neil A. Smart, Michael T.C. Liang, Nahid Bijeh, Alsaeedi L. Albanaqi, Mehrdad Fathi, Arghavan Niyazi, Nasser Mohammad Rahimi declares that they have no conflict of interest.

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