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SYSTEMATIC REVIEW
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The efficacy of exercise prescription in patients with osteoporotic fractures: a systematic review and meta-analysis

Mingzhe Yu[1], Pei Zhou[3†], Yanjun Che[2*] and Yuan Luo[1*]

Abstract

Background Patients with osteoporotic fractures will further lose bone mineral density and the incidence of refractures will be greatly increased, which is one of the leading causes of death and disability in the elderly. Exercise prescription is effective in enhancing bone strength in patients with osteoporosis, but its effects on patients with osteoporotic fractures have not been systematically reviewed. The purpose of this study is to retrospectively analyze the effect of exercise prescription on bone mineral density in patients with osteoporotic fractures, so as to provide a basis for clinicians to provide postoperative guidance for fracture patients.

Method We searched online databases for published studies on exercise prescription for people with osteoporotic fractures up to September 2024. We included 11 randomized controlled trials that reported the effect of exercise prescription on bone mineral density in people with osteoporotic fractures, and four of these studies reported the effect of exercise prescription on the incidence of refracture in people with osteoporotic fractures. We analysed changes in bone mineral density and incidence of refractures using a fixed-effect model, and meta-regression analyses were performed for subgroups.

Results Of the 701 articles reviewed, we included 11 randomized controlled trials in the meta-analysis. A total of 1101 samples were pooled, including 357 males and 744 females. This study found that exercise prescription was effective in increasing bone mineral density in patients with osteoporotic fractures (MD: 0.07; 95%CI: 0.06 to 0.09), reducing the incidence of refracture by about 3.67 times (OR: 3.67; 95%CI: 1.74 to 7.72). Both whole-body exercise (MD: 0.09; 95% CI: 0.06 to 0.11) and local exercise of the affected limb (MD: 0.06; 95%CI: 0.04 to 0.09) can effectively improve the patient's bone mineral density, and more than 1 year of exercise may be better (MD: 0.10; 95%CI: 0.07 to 0.14).

Conclusion Reasonable exercise prescription can effectively improve bone mineral density and reduce the incidence of refracture in patients with osteoporotic fractures.

[†]Pei Zhou contributed equally to this work.

*Correspondence:
Yanjun Che
cheyanjun@njmu.edu.cn
Yuan Luo
ly8046@suda.edu.cn

Full list of author information is available at the end of the article

Keywords Osteoporotic fractures, Exercise, Bone mineral density, Refracture

Background

Osteoporosis is manifested by osteopenia, destruction of bone microstructure and decreased bone strength. Fractures can occur with little or no obvious external forces, including the vertebral body, hip, distal radius and proximal humerus, constituting an Osteoporotic fracture, a global clinical and public health problem. After fracture, bone loss accelerates due to limited mobility. While fractures damage the bone tissue, the fracture healing process will also lead to further loss of bone mass, resulting in a significantly higher probability of refracture [1]. After an osteoporotic fracture, the probability of recurrence within one to two years is approximately 20%, and the risk rate is approximately 2.7 times that of the normal population [2–3], while the probability of recurrence of vertebral fracture after six years is as high as 51.35% [4], and approximately one-third of patients die within 12 months of hip fracture [5]. Therefore, it is particularly important to explore ways to prevent further bone loss after fracture in patients with osteoporosis, to avoid the occurrence of refracture. Exercise training is considered the only strategy that can improve all modifiable fracture risk factors (bone strength, fall risk, fall impact) because of its effectiveness in increasing muscle strength, maintaining overall balance and coordination, improving overall functional performance, and increasing bone strength [6–7]. In the past, researchers tended to focus more on the impact of drugs on osteoporosis [8–11]. Now, an increasing number of studies are turning their attention to the relationship between osteoporosis patients and exercise training, but there is still a lack of convincing evidence-based studies on postoperative exercise for patients with osteoporotic fractures, and there is still controversy about whether patients with osteoporotic fractures can improve bone strength and reverse bone loss through exercise training. As an important indicator of bone strength, bone mineral density is one of the important indicators to help clinicians diagnose osteoporosis and predict the risk of osteoporotic fractures.

The aim of this systematic review and meta-analysis was to synthesize data from randomized controlled clinical trials on rehabilitation training in people with osteoporotic fractures and to quantify the effect of exercise on bone mineral density levels in people with osteoporotic fractures.

Methods

The study was registered in the PROSPERO International prospective register of systematic reviews(CRD: 42024590872), and all procedures followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines [12].

Search strategy

We conducted a comprehensive search of published randomised controlled studies in online databases without time and language restrictions. The databases searched in this study included PubMed, Web of Science, Medline, and the Chinese databases CNKI, Wanfang Med Online, and CQVIP. The search terms involved were: "osteoporotic fracture", "exercise", "sports", "bone density". The specific search strategy takes PubMed as an example(Fig. 1). In the "ARTICLE TYPE" column, select "Randomized Controlled Trial" and "Clinical Trial".

Inclusion criteria

In this study, we only took in randomized controlled trials. The participants were patients who had experienced osteoporotic fractures and had received proper treatment. There were no limits regarding where the fracture happened or how the exercise intervention was carried out, which could be either a full-body exercise or a local exercise focusing on the muscles near the fracture area.

Exclusion criteria

Trials that only looked into how exercise affected osteoporosis patients without the presence of fractures were not part of this study.

Outcome measures

The primary outcome measure was the change of bone mineral density before and after the exercise intervention, and DEXA was used as the measurement method for bone mineral density. We performed subgroup analyses according to the duration of the intervention (3 months, 6 months, 12 months), the type of intervention (whole-body exercise, partial exercise), and the fracture site (vertebral body, hip). The secondary data measure recorded was the incidence of refracture.

Data extraction and analysis

After the duplicate literature was removed by Endnote X8 literature management software, the preliminary screening was completed by 2 investigators according to the title and abstract of the article, and then the full text of the screened article was downloaded and read, and the literature was further screened according to the exclusion criteria. If the information is incomplete, try to contact the author for supplementation. In the final included literature, relevant data were extracted and cross-checked by 2 investigators. If there is a disagreement between

#1 Osteoporotic fracture [All Fields]
#2 exercise [All Fields]
#3 sports [All Fields]
#4 #2 OR #3
#5 bone density [All Fields]
#6 #1 AND #4 AND #5

("osteoporotic fractures"[MeSH Terms] OR ("osteoporotic"[All Fields] AND "fractures"[All Fields]) OR "osteoporotic fractures"[All Fields] OR ("osteoporotic"[All Fields] AND "fracture"[All Fields]) OR "osteoporotic fracture"[All Fields]) AND ("exercise"[MeSH Terms] OR "exercise"[All Fields] OR "exercises"[All Fields] OR "exercise therapy"[MeSH Terms] OR ("exercise"[All Fields] AND "therapy"[All Fields]) OR "exercise therapy"[All Fields] OR "exercising"[All Fields] OR "exercise s"[All Fields] OR "exercised"[All Fields] OR "exerciser"[All Fields] OR "exercisers"[All Fields] OR ("sport s"[All Fields] OR "sports"[MeSH Terms] OR "sports"[All Fields] OR "sport"[All Fields] OR "sporting"[All Fields])) AND ("bone density"[MeSH Terms] OR ("bone"[All Fields] AND "density"[All Fields]) OR "bone density"[All Fields])

Fig. 1 Search strategy for the effect of exercise prescription on bone mineral density in patients with osteoporotic fractures

the opinions of the 2 investigators, the 3rd investigator is requested to discuss and negotiate together and reach a unified opinion. The extracted information included: (1) descriptive statistics (first author's name, publication date, sample size); (2) Interventions and final outcomes; (3) Key information used to assess risk of bias.

Assessment of bias

We assessed the risk of bias using a modified version of the Cochrane Collaboration risk of bias tool addressing 5 criteria. Funnel plots were used to evaluate publication bias. If there was significant heterogeneity between the literatures, we analysed whether the removal of the more heterogeneous literature would affect the direction of the overall outcome by sensitivity analysis. The results of the bias assessment were cross-checked by 2 investigators.

Statistical analysis

Review Manager 5.3 software was used for data analysis and forest plotting. For dichotomous variable (risk of refracture), odds ratios (OR) and 95% confidence intervals were used as efficacy analysis statistics. For continuous variables, the mean difference (MD) and the 95% CI confidence interval were selected as efficacy statistics due to the same unit of measurement (g/cm^2). When the heterogeneity was low ($I^2 < 50\%$, $P > 0.10$), the fixed-effect model was selected, and when the heterogeneity was high ($I^2 > 50\%$, $P < 0.10$), the random-effect model was selected. If heterogeneity is too high or the cause cannot be identified, descriptive analysis will be chosen.

Results

Literature selection and characteristics

A total of 701 articles (PubMed 53, Web of Science 101, Medline 155, CNKI 158, CQVIP 153, Wanfang Med Online 81) were screened, 260 duplicate articles were deleted, 387 articles were excluded by reading titles and abstracts, 43 articles were excluded after reading the remaining 54 articles in full, and finally, 11 articles were included in the meta-analysis (Fig. 2; Table 1).

All of the 11 studies were randomized controlled studies and included a total of 1101 patients with osteoporotic fractures, including 357 males and 744 females. Six of the studies looked at patients with vertebral fractures, four studies with hip fractures, and one study included patients with vertebral fractures, hip fractures, and wrist fractures. The exercises involved include lumbar back muscle exercises, lower limb muscle function exercises, sports gymnastics, five-animal boxing, and eight trigrams boxing. Four of these studies reported on the incidence of refractures.

Data synthesis and meta-analysis

Comprehensive inclusion of 11 studies. Due to the small heterogeneity (I^2: 37%), a fixed-effect model was adopted for meta-analysis. The results showed that under the premise of effective medical intervention, patients who received regular functional exercise had a higher bone mineral density level than those who only received medical intervention without regular exercise (MD: 0.07; 95% CI: 0.06 to 0.09; I^2: 37%, 11 studies) (Fig. 3). Compared with the control group, whole-body exercises such as

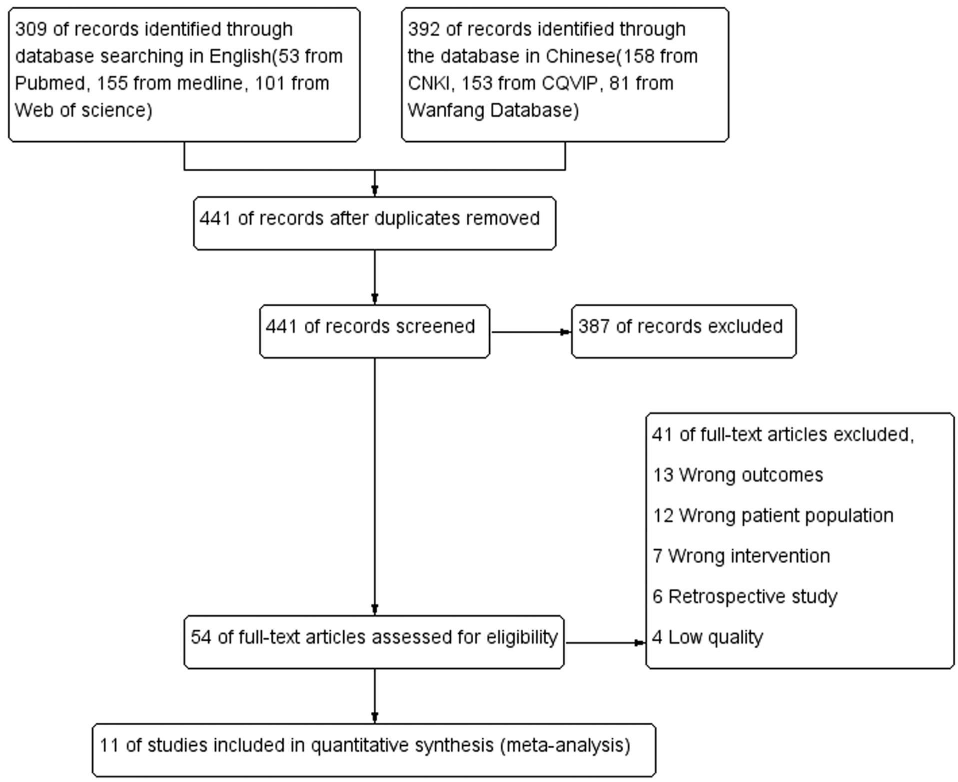

Fig. 2 Flow diagram of the systematic review of the effect of exercise prescription on bone mineral density in patients with osteoporotic fractures

Table 1 Characteristics of 11 studies included in the meta-analysis of the efficacy of exercise prescription in patients with osteoporotic fractures

Source	Disease	Observation groups		Control groups		Duration, mo	Intervention	outcomes
		Male	Female	Male	Female			
Deng et al., 2018 [13]	Vert	31	45	33	43	6	Local Movement	BMD, Refracture
Ding et al.,2020 [14]	Hp	0	57	0	56	12	Local Movement	BMD, Refracture
Huang et al.,2018 [15]	Vert	17	13	18	12	6	General Movement	BMD, Refracture
Lu et al.,2007 [16]	Hp	11	19	12	18	6	General Movement	BMD
Ma,2020 [17]	Vert	12	38	11	39	6	General Movement	BMD
Pan et al.,2023 [18]	Vert	35	25	33	27	6	General Movement	BMD, Refracture
Pei et al.,2023 [19]	Vert	0	49	0	49	6	Local Movement	BMD
Wang et al.,2012 [20]	Vert, Hp, Wrt	24	40	25	35	12	Local Movement	BMD
Wang et al.,2020 [21]	Vert	10	20	12	18	0.75	Local Movement	BMD
Yu et al.,2023 [22]	Hp	0	47	0	47	3	Local Movement	BMD
Zhu et al.,2023 [23]	Hp	37	23	36	24	3	Local Movement	BMD

"Vert"means vertebaral fracture; "Hp"means hip fracture; "Wrt" means wrist fracture. "BMD" means bone mineral density

gymnastic exercises (MD: 0.09; 95% CI: 0.06 to 0.11; I^2: 32%, 4 studies) may be more conducive to the improvement of postoperative bone mineral density in patients with osteoporotic fractures than functional exercises targeting local muscles (MD: 0.06; 95% CI: 0.04 to 0.09; I^2: 43%, 7 studies) (Fig. 4). After regular and effective exercise, vertebral fracture patients can increase their bone mineral density by an average of 0.06 g/cm2 (MD: 0.06; 95% CI: 0.03 to 0.09; I^2: 43%, 6 studies), while hip fracture patients can increase their bone mineral density by an average of 0.08 g/cm2 (MD: 0.08; 95% CI: 0.05 to 0.11; I^2: 37.5%, 4 studies). (Fig. 5) In terms of duration, long-term exercise for more than one year can result in more significant improvements in bone mineral density levels (MD: 0.10; 95% CI: 0.07 to 0.14; I^2: 0%, 2 studies) (Fig. 6). Three studies applied traditional Chinese fitness exercises such as five-animal boxing and eight trigrams boxing to the postoperative rehabilitation exercise of patients with osteoporotic fractures. Compared with the control group, the average bone mineral density

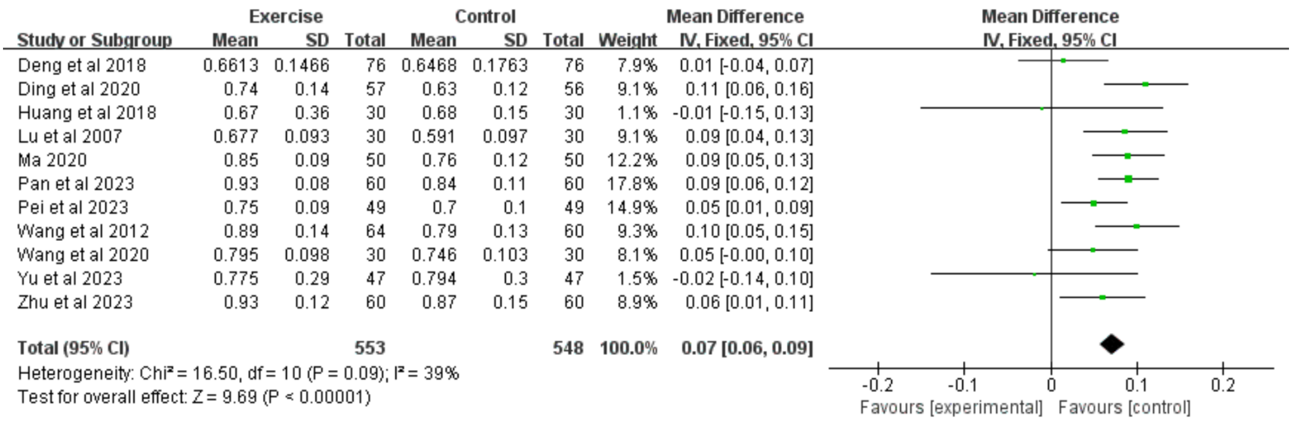

Fig. 3 The effect of exercise prescription on bone mineral density in patients with osteoporotic fractures

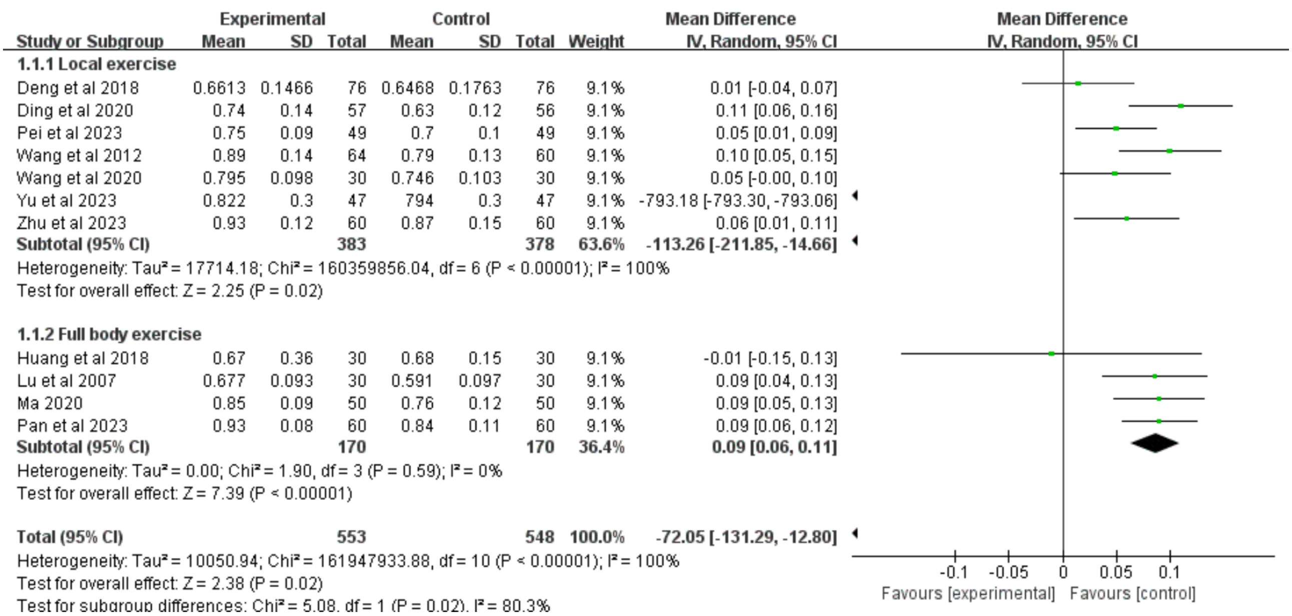

Fig. 4 Subgroup analysis to evaluate the effects of whole-body and local exercise on bone density in patients with osteoporotic fractures

of patients increased by 0.09 g/cm2 (MD: 0.09; 95% CI: 0.06 to 0.11; I^2: 0%, 3 studies), while modern exercise forms such as progressive resistance exercise, lumbar back muscle exercise, and lower limb functional exercise increased the average bone mineral density of patients by 0.07 g/cm2 (MD: 0.07; 95% CI: 0.05 to 0.08; I^2: 38%, 8 studies), but there was no statistical difference between the two (Fig. 7). Four studies reported the impact of exercise on the risk of refracture in patients with osteoporotic fractures. Patients who did not exercise had a 3.67 times higher incidence of refracture within three years after fracture than those who exercised regularly (OR: 3.67; 95% CI: 1.74 to 7.72; I2: 25%, 4 studies) (Fig. 8).

Risk of bias and validity test

The "risk of bias assessment" tool in the Cochrane Evaluation Manual was used (Fig. 9). Eleven literatures had a low risk of bias. Among them, one literature had no high-risk items and was of high quality. Ten literatures had a high risk of bias in blinding. Considering that in such studies, the treatment measures of whether to exercise or not are significantly different, it is difficult to implement double-blind operations. The next risk of bias comes from the blinding of outcome detection, which may lead to detection bias. However, the test results are mainly completed by DEXA testing instruments with little human participation, which can effectively avoid the occurrence of detection bias. Generally speaking, the quality of the literatures in this study is high and trustworthy.

A funnel plot (Fig. 10) was used to preliminarily judge whether there is publication bias for all evaluated outcome indicators. As can be seen from the funnel plot, it is basically symmetrical about the zero line position, and most of the points included in the study are in the upper

Study or Subgroup	Exercise Mean	Exercise SD	Exercise Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
1.2.1 Vertebral fracture								
Deng et al 2018	0.6613	0.1466	76	0.6468	0.1763	76	11.0%	0.01 [-0.04, 0.07]
Huang et al 2018	0.67	0.36	30	0.68	0.15	30	2.0%	-0.01 [-0.15, 0.13]
Ma 2020	0.85	0.09	50	0.76	0.12	50	14.7%	0.09 [0.05, 0.13]
Pan et al 2023	0.93	0.08	60	0.84	0.11	60	18.3%	0.09 [0.06, 0.12]
Pei et al 2023	0.75	0.09	49	0.7	0.1	49	16.6%	0.05 [0.01, 0.09]
Wang et al 2020	0.795	0.098	30	0.746	103	30	0.0%	0.05 [-36.81, 36.91]
Subtotal (95% CI)			**295**			**295**	**62.5%**	**0.06 [0.03, 0.09]**
Heterogeneity: Tau² = 0.00; Chi² = 8.81, df = 5 (P = 0.12); I² = 43%								
Test for overall effect: Z = 4.04 (P < 0.0001)								
1.2.2 Hip fracture								
Ding et al 2020	0.9	0.15	57	0.79	0.13	56	10.9%	0.11 [0.06, 0.16]
Lu et al 2007	0.677	0.093	30	0.591	0.097	30	12.1%	0.09 [0.04, 0.13]
Yu et al 2023	0.822	0.3	47	0.794	0.3	47	2.6%	0.03 [-0.09, 0.15]
Zhu et al 2023	0.93	0.12	60	0.87	0.15	60	11.9%	0.06 [0.01, 0.11]
Subtotal (95% CI)			**194**			**193**	**37.5%**	**0.08 [0.05, 0.11]**
Heterogeneity: Tau² = 0.00; Chi² = 2.70, df = 3 (P = 0.44); I² = 0%								
Test for overall effect: Z = 5.75 (P < 0.00001)								
Total (95% CI)			**489**			**488**	**100.0%**	**0.07 [0.05, 0.09]**
Heterogeneity: Tau² = 0.00; Chi² = 12.31, df = 9 (P = 0.20); I² = 27%								
Test for overall effect: Z = 6.81 (P < 0.00001)								
Test for subgroup differences: Chi² = 0.94, df = 1 (P = 0.33), I² = 0%								

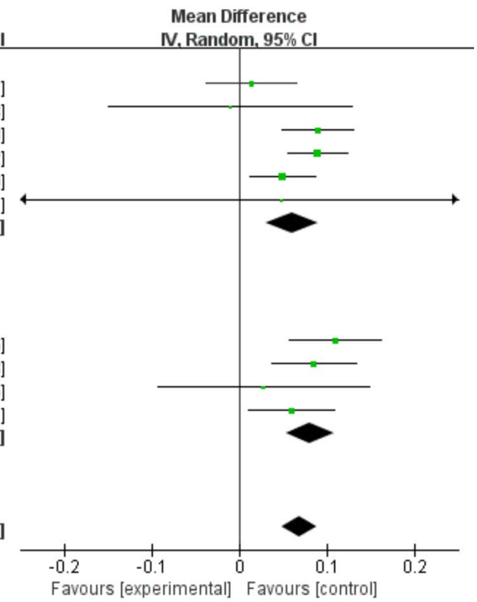

Fig. 5 Subgroup analysis to evaluate the effect of exercise on bone mineral density in patients with osteoporotic vertebral fractures and osteoporotic hip fractures

Study or Subgroup	Exercise Mean	Exercise SD	Exercise Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
1.3.1 3mon								
Yu et al 2023	0.846	0.31	47	0.824	0.31	47	2.5%	0.02 [-0.10, 0.15]
Zhu et al 2023	0.93	0.12	60	0.87	0.15	60	8.8%	0.06 [0.01, 0.11]
Subtotal (95% CI)			**107**			**107**	**11.4%**	**0.06 [0.01, 0.10]**
Heterogeneity: Tau² = 0.00; Chi² = 0.31, df = 1 (P = 0.58); I² = 0%								
Test for overall effect: Z = 2.38 (P = 0.02)								
1.3.2 6mon								
Deng et al 2018	0.6613	0.1466	76	0.6468	0.1763	76	8.4%	0.01 [-0.04, 0.07]
Ding et al 2020	0.65	0.12	57	0.63	0.11	56	9.8%	0.02 [-0.02, 0.06]
Huang et al 2018	0.67	0.36	30	0.68	0.15	30	2.1%	-0.01 [-0.15, 0.13]
Lu et al 2007	0.677	0.093	30	0.591	0.097	30	8.9%	0.09 [0.04, 0.13]
Ma 2020	0.85	0.09	50	0.76	0.12	50	10.0%	0.09 [0.05, 0.13]
Pan et al 2023	0.93	0.08	60	0.84	0.11	60	11.3%	0.09 [0.06, 0.12]
Pei et al 2023	0.75	0.09	49	0.7	0.1	49	10.7%	0.05 [0.01, 0.09]
Wang et al 2012	0.8	0.13	64	0.79	0.12	60	9.6%	0.01 [-0.03, 0.05]
Subtotal (95% CI)			**416**			**411**	**70.8%**	**0.05 [0.02, 0.08]**
Heterogeneity: Tau² = 0.00; Chi² = 18.19, df = 7 (P = 0.01); I² = 62%								
Test for overall effect: Z = 3.77 (P = 0.0002)								
1.3.3 12mon								
Ding et al 2020	0.74	0.14	57	0.63	0.12	56	8.9%	0.11 [0.06, 0.16]
Wang et al 2012	0.89	0.14	64	0.79	0.13	60	9.0%	0.10 [0.05, 0.15]
Subtotal (95% CI)			**121**			**116**	**17.9%**	**0.10 [0.07, 0.14]**
Heterogeneity: Tau² = 0.00; Chi² = 0.08, df = 1 (P = 0.77); I² = 0%								
Test for overall effect: Z = 6.09 (P < 0.00001)								
Total (95% CI)			**644**			**634**	**100.0%**	**0.06 [0.04, 0.08]**
Heterogeneity: Tau² = 0.00; Chi² = 25.72, df = 11 (P = 0.007); I² = 57%								
Test for overall effect: Z = 5.46 (P < 0.00001)								
Test for subgroup differences: Chi² = 6.51, df = 2 (P = 0.04), I² = 69.3%								

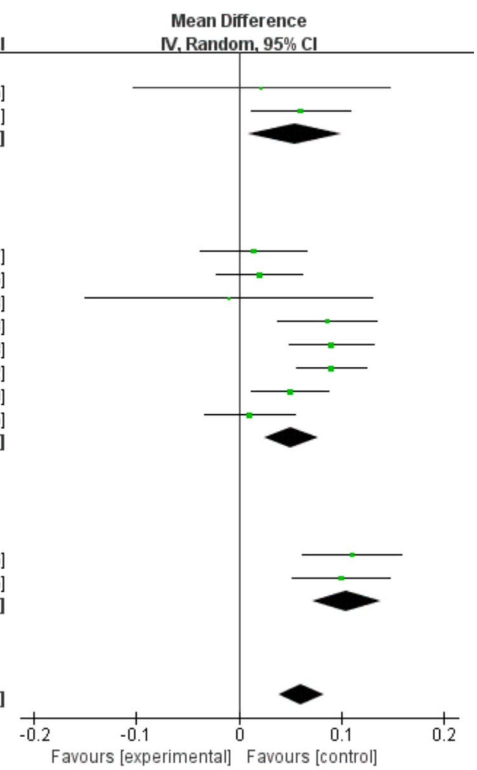

Fig. 6 Subgroup analysis evaluates the impact of different exercise time spans on bone mineral density in patients with osteoporotic fractures

part of the funnel, indicating that the precision of the study is acceptable. The scatter points are roughly symmetrically distributed on both sides of the equivalence line, suggesting that the existence of publication bias can be preliminarily excluded in this study.

Sensitivity analysis

This study conducts a sensitivity analysis aiming to determine whether the results of the meta-analysis are stable and whether they are highly sensitive to specific studies or study characteristics. The method of excluding a single

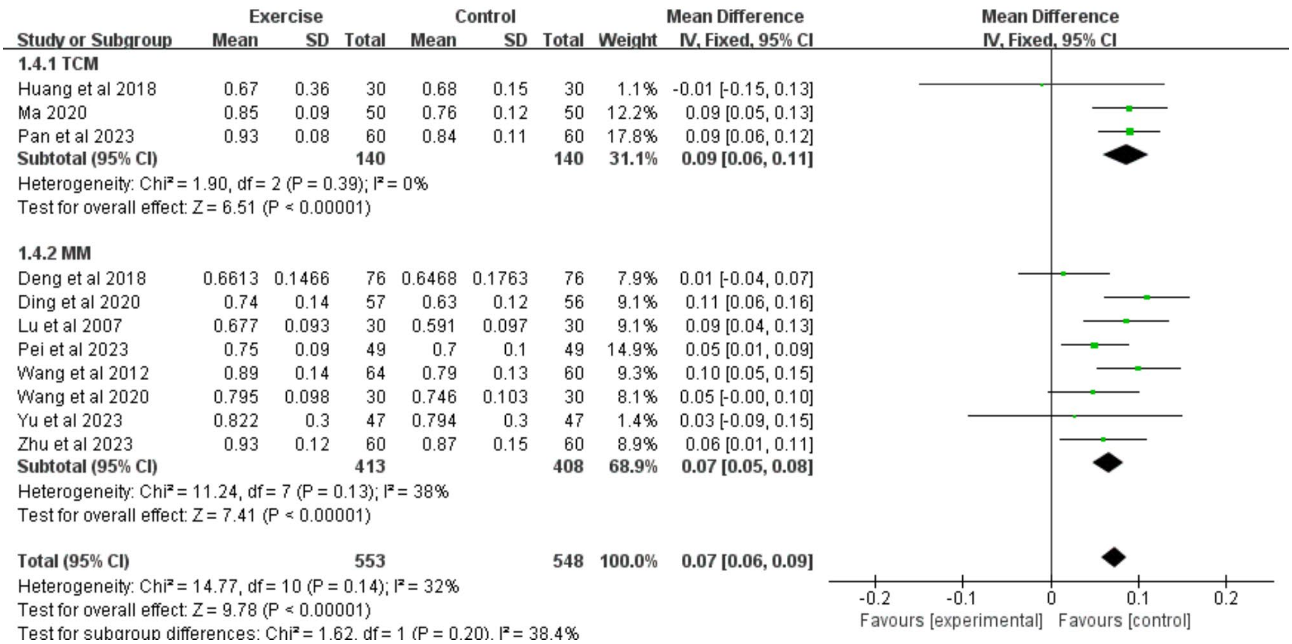

Fig. 7 Subgroup analysis evaluates the impact of traditional Chinese exercises and modern exercises on bone mineral density in patients with osteoporotic fractures

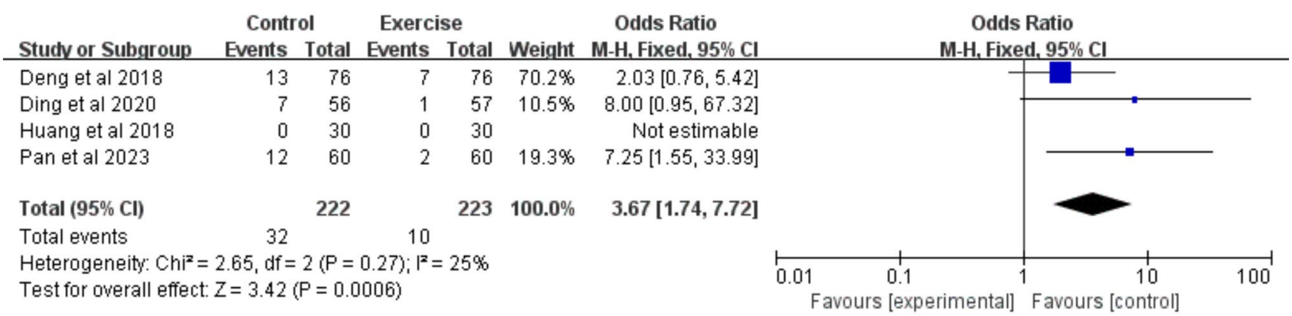

Fig. 8 The effect of exercise prescription on the incidence of recurrent fractures in patients with osteoporotic fractures

study one by one is adopted for sensitivity analysis. After excluding one study each time, the combined effect size is recalculated. It is found that excluding any one study does not significantly change the overall combined effect size, indicating that the results of this meta-analysis are relatively robust.

Discussion

This study shows that regular exercise and functional training are helpful for improving the bone mineral density [24] level of patients with osteoporotic fractures. These forms of exercise can effectively improve bone quality, avoid bone quality loss after fractures, and reduce the incidence of refractures. However, osteoporotic fractures often limit the activity ability of patients, resulting in further loss of bone quality. Previous studies have focused on the impact of exercise on patients with osteoporosis [25]. This study targets the patient population with osteoporotic fractures. Studying and analyzing the impact of exercise on the bone mineral density level of patients with osteoporotic fractures has certain innovation and can also provide certain theoretical support for formulating postoperative rehabilitation training strategies for patients with osteoporotic fractures in the future.

In this study, different types of intervention methods were categorised and subgroup analysis was conducted. We first analyzed the impact of local exercise and whole-body exercise on bone mineral density. The results showed that both are helpful for increasing bone mineral density. Some studies have shown that the magnitude of bone load force increases with the increase of exercise intensity [26]. Moderate to high-intensity exercise training can effectively enhance bone load force and bone mineral density. However, the exercise plan should not only include weight-bearing endurance and resistance activities aimed at maintaining bone mass but also activities aimed at improving balance and preventing falls. Local functional exercise can enhance the strength

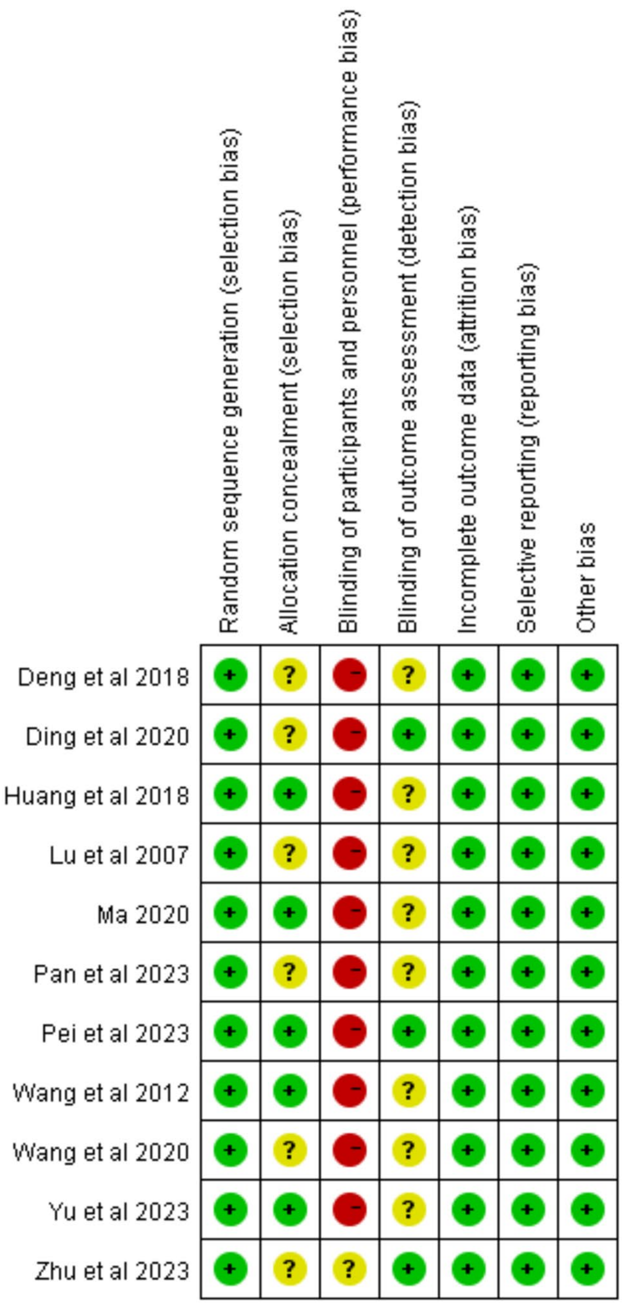

Fig. 9 The "risk of bias assessment" tool in the Cochrane Evaluation Manual

of local bones in a targeted manner and help the rapid increase of local bone load force. But whole-body exercise is more helpful in improving body balance and preventing falls and improving the overall exercise state of patients. Therefore, when formulating a training plan, we need to comprehensively consider the patient's own characteristics and formulate an exercise prescription suitable for the patient. From the results, compared with patients with spinal fractures, exercise therapy is more helpful in improving bone mineral density for patients with hip fractures. This may be because the stress on the hip during exercise is generally greater than that on the spine. This indicates that when we formulate an exercise prescription, the intensity of exercise and the load force of bones are important factors that we need to consider. Existing experiments have proved that there is a "threshold" for mechanical stimulation of cell responses. Only when the mechanical stimulation is greater than this threshold can the cells change. Exceeding the upper limit will lead to completely different or even negative responses [27]. Subsequently, when we conducted a pooled analysis of the bone mineral density of patients with different intervention periods, we found that the bone mineral density of patients who exercised regularly for more than one year (MD: 0.1 g/cm^2) had a greater improvement compared to patients who exercised for 3 months (MD: 0.06 g/cm^2) and 6 months (MD: 0.05 g/cm^2). This suggests that long-term regular exercise is helpful for improving the bone mineral density of fracture patients. Cultivating good and long-term exercise habits can help improve bone quality. A part of the researchers look for exercise therapy programs in traditional Chinese fitness methods, such as the Five Animal Exercises and Baduanjin. In this study, we conducted subgroup analysis on the intervention plans of traditional Chinese martial arts and modern common exercise modes and found that both can effectively improve bone quality. This also provides a new idea for the diversity of exercise prescriptions. Traditional Chinese fitness methods can be used as a systemic aerobic exercise, which can effectively restore the body's coordination ability after fractures, improve balance, strengthen the body, and improve the quality of life. It provides a new direction for the application of traditional Chinese medicine in the treatment of osteoporotic fractures.

This study found that after an osteoporotic fracture occurs, providing exercise training can effectively reduce the incidence of refractures after fractures. The results of a large-sample 10-year retrospective study in Australia showed that 38.2% of osteoporotic fracture patients required readmission for treatment due to refractures [28]. Among the 11 research reports included in our study, four reports statistically analyzed the incidence of refractures after osteoporotic fractures. After pooled analysis, it was found that after a fracture, timely and systematically providing exercise therapy intervention reduced the incidence of refractures after three years by 3.67 times compared to patients who did not receive exercise therapy. This may be related to multiple factors such as the increase in bone mineral density after patients receive exercise therapy and the reduction in fall risk due to the improvement of physical coordination ability.

One of the advantages of our study is the comprehensive data collection strategy, which provides a high sample size and relatively high research credibility. Secondly,

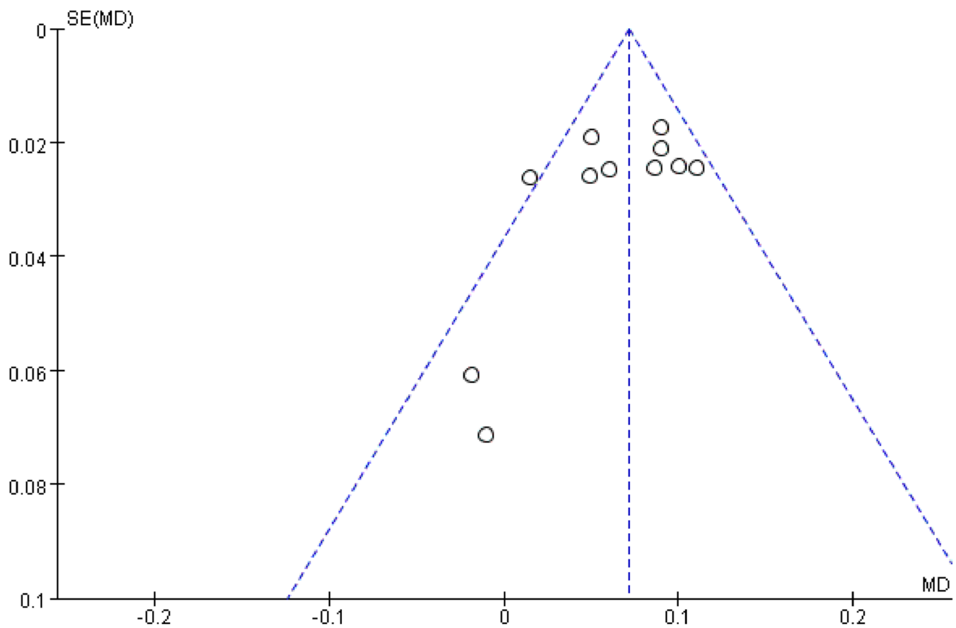

Fig. 10 Publication bias testing of different outcome measures

the literature we included are all randomized controlled trials, which can effectively reduce selection bias and improve the reliability of evidence. Thirdly, adopting the Cochrane method to reduce bias and combining risk factors and outcome sensitivity analysis enhances the validity and reliability of the study. Fourthly, setting the observation population as patients with osteoporotic fractures and studying the impact of postoperative exercise on their bone mineral density provides good theoretical support for the health management plan of patients with osteoporotic fractures after receiving medical treatment. Fifthly, we also conducted subgroup analysis to determine the impact of different intervention exercise programs and different intervention durations on bone mineral density, providing a direction for subsequent research on postoperative health management of patients with osteoporotic fractures.

This study also has some limitations. Firstly, there are differences in the treatment plans for osteoporotic fractures. In this study, there is no strict limitation on the treatment methods for fractures. For example, percutaneous kyphoplasty (PKP) or pedicle screw internal fixation technology are both methods for treating fractures, but they may have different degrees of impact on the subsequent exercise of patients. There are also certain differences in measurement results and the determination of efficacy criteria, which may cause certain biases to the outcome indicators. Secondly, the included studies were all conducted in China. No high-quality randomized controlled trial studies on patients with osteoporotic fractures conducted in other countries were found. The possibility of nationality and geographical biases cannot be excluded. Thirdly, there is a lack of long-term follow-up research data. The longest follow-up period is one year. The research results can only prove that exercise training is helpful in improving bone mineral density in the medium and long term, and further research is still needed in terms of long-term efficacy. Fourthly, the included studies have methodological flaws. Due to the significant differences in intervention methods, the implementation of blinding cannot be achieved. The literature quality is insufficient, and there is a greater possibility of potential implementation biases, which may ultimately affect the reliability of the research results. Fifthly, this study only used bone mineral density as the observational index for the improvement of bone quality in patients with osteoporotic fractures. In the future, we can further introduce other observational indexes such as biochemical markers of bone turnover (BTMs) [29, 30] to further evaluate the impact of exercise on the changes in bone quality of patients.

We hope this study can provide important information for clinicians and offer the highest level of evidence-based support for the postoperative bone health management of fracture patients. The harm of refracture should draw the attention of every orthopedic doctor, rehabilitation doctor and fracture patient. At present, a systematic post-fracture exercise rehabilitation strategy has not yet been formed. Therefore, we still need further research to form an effective consensus on post-fracture exercise rehabilitation, with the aim of minimizing the incidence of refractures after fractures and enhancing the bone health of fracture patients.

In conclusion, regular and appropriate exercise can effectively improve the bone mineral density of patients with osteoporotic fractures and reduce the incidence of refractures. In the rehabilitation process of patients with osteoporotic fractures, we should focus on exercise's positive impact on fracture healing and enhance the significance of sports rehabilitation.

Support and competing interests

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Author contributions
M.Y. and P.Z. wrote the main manuscript text, screened articles, extracted data from literature independently and prepared figures together.Y.L. and Y.C. audited and merged the extracted literature data. When there were discrepancies, they discussed and negotiated to jointly determine the final result. They formulated the research plan and audited the scientific nature of the research process.All authors reviewed the manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
Ethics approval was obtained from the Ethics Committee, Suzhou Municipal Hospital (approval number: K-2024-125-K01).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Orthopedics, The First People's Hospital of Taicang, Taicang Affiliated Hospital of Soochow University, Suzhou, Jiangsu 215400, China
[2]Orthopedics and Sports Medicine Center, The Affiliated Suzhou Hospital of Nanjing Medical University, Suzhou, Jiangsu 215008, China
[3]Department of Traditional Chinese Medicine, Community Health Service Center of Science-Education New Town, Taicang, Suzhou, Jiangsu 215400, China

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