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Review Article

Exercise and Musculoskeletal Health in Men With Low Bone Mineral Density: A Systematic Review

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Osteopenia;
Osteoporosis;
Rehabilitation;
Systematic review

Abstract *Objective:* This systematic review aims to determine the effects of exercise on bone and muscle health in men with low bone density.
Data Sources: An electronic search in the following databases was performed: Medline, AMED, Embase, Scopus, and SPORTDiscus between January 1940 and September 2021.
Study Selection: Randomized or non-randomized trials involving any form of exercise in adult men with a densitometric diagnosis of osteoporosis or osteopenia and reported outcomes relating to bone or muscle health. Two independent reviewers screened 12,018 records, resulting in 13 eligible articles.
Data Extraction: One reviewer extracted data into a pre-formed table, including characteristics of the exercise intervention, population examined, and primary and secondary outcomes. Study quality was assessed by 2 independent reviewers using the Tool for assEssment of Study qualiTy and reporting in Exercise (TESTEX).
Data Synthesis: Thirteen publications, originating from 6 unique trials, were eligible for inclusion, which assessed the effect of resistance training, impact training, whole body vibration, and traditional Chinese exercises. Resistance training was the most effective: it stimulates the replacement of adipose tissue with muscle, and in some cases, improved bone density.
Conclusions: Exercise, especially resistance training, slowed down the natural progression of osteoporosis and sarcopenia in men. These benefits are reflected in enhancements to function, such as improved mobility and balance. Other exercise modalities, such as whole body vibration

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List of abbreviations: BMD, bone mineral density; CRT, chair-rise test; DXA, dual-energy x-ray absorptiometry; FrOST, Franconian Osteopenia and Sarcopenia Trial; FTSTS, 5-times-sit-to-stand; HIRIT, high intensity resistance and impact training; IAC, isometric axial compression; LBM, lean body mass; LIFTMOR-M, Lifting Intervention For Training Muscle and Osteoporosis Rehabilitation for Men; MILES, maximum bilateral hip/leg extension against an isokinetic leg press; SMI, skeletal muscle index; TESTEX, Tool for assEssment of Study qualiTy and reporting in Exercise; TUG, timed Up and Go; WBV, whole body vibration.
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and traditional Chinese exercises, generated minimal improvements to bone health, strength, and balance.

Osteoporosis leads to fragility fractures, a significant cause of disability, loss of independence, reduced quality of life, and increased mortality in older adults.[1] The prevalence of osteoporosis is higher in postmenopausal women than in men; women account for 61% of all osteoporosis fractures.[2] Despite the lower prevalence of osteoporosis and lower fracture incidence rates in men, the burden of osteoporosis and its consequences are also substantial in men. Men face 2-fold higher mortality rates after fracture than women.[3-5] The underrepresentation of men in osteoporosis research has also contributed to suboptimal screening, undertreatment, and underdiagnosis of osteoporosis in men.[6]

In postmenopausal women, exercise has been suggested as a safe, non-pharmacologic intervention to maintain bone density and prevent falls.[7,8] Because of the inherent physiological disparities between men and women, however, we cannot draw conclusions on the effectiveness of exercise in men from these studies. Post-menopausal women experience steep declines in oestrogen, contributing to significant bone loss and leading to reduced mechanosensitivity in bone.[9] Older men experience a steady decline of testosterone and oestrogen throughout life, resulting in reduced muscle mass, and in contrast to women, less pronounced declines in bone mass.[9,10] Because the mechanical loading of exercise is applied to muscle and transferred to bone, it is possible that the osteogenic response to physical training differs between sexes and is further attenuated with age.[9,11] Thus, these structural differences in age-related loss of bone and muscle tissue highlight the need for determining sex-specific exercise regimens.

As the global population ages and fracture incidence increases exponentially, it is imperative to establish non-pharmacologic therapies suitable for men with low bone density. Progressive resistance training and moderate to high-impact training have been recommended as effective modalities of exercise that can maintain or increase bone density and improve overall bone strength.[12,13] In healthy individuals, the mechanical loading and straining from dynamic exercises stimulates site-specific osteogenic responses, such that new bone tissue replaces damaged tissue.[11,14] Incremental increases in magnitude of loading, such as in progressive resistance training, ensures that this process of adaptive bone remodeling does not plateau.[12] The positive osteogenic effect of exercise has been noted in younger men, because they attain wider and longer bones at their peak and experience steady trabecular thinning with ageing, rather than loss of trabecular connectivity seen in women at the onset of mid-life.[5,15] Thus, men retain significant trabecular bone, a compartment that is capable of being remodeled with exercise. Despite the reported bone-related benefits of exercise in healthy young men, it is unclear if exercise will produce similar outcomes in older men with low bone density.

In this review, we focus on men with osteoporosis or osteopenia, and examine evidence for the effect of different forms of exercise on bone and muscle health. The primary outcome examined in this review is bone mineral density (BMD), and secondary outcomes are changes to body composition, muscle strength, and physical function.

Methods

Inclusion and exclusion criteria

Inclusion criteria for this review were as follows: (1) randomized or non-randomized trials, (2) any type of exercise as an intervention, (3) community-dwelling men aged 18 years or older with confirmed osteoporosis or osteopenia as the subjects, and (4) outcomes assessed related to physical function, muscle, or bone. All subjects in the included trials were required to have their low bone density measured and confirmed on dual-energy x-ray absorptiometry (DXA), or a clinical diagnosis of osteoporosis or osteopenia. Trials that were not fully randomized or did not have a non-exercising control group were included because withholding potentially effective forms of non-pharmacologic therapy, such as exercise, from participants with low bone density may be considered unethical. Conference papers were not included. If an article fulfilled all the aforementioned criteria but studied both men and women subjects, the results had to be separated by sex to be included.

Literature search

Searches for relevant articles published between January 1940 and September 2021 inclusive were conducted in the following electronic databases: Medline, AMED, Embase, Scopus, and SPORTDiscus. Free search terms for the target population were used in an AND-combination with search terms for exercise and for outcomes of interest (table 1). Duplicates were removed automatically by EndNote and manually by observing similarities in titles, author names, sample sizes, and date of publication.

Screening

Titles and abstracts of the articles were independently and manually screened for eligibility by 2 reviewers (K.H. and M. C.). Non-English texts were excluded. The remaining articles were obtained in full and assessed according to inclusion and exclusion criteria by the same 2 reviewers. Reasons for excluding ineligible articles were recorded (fig 1). Disagreements were resolved by a third independent reviewer (C. G.). See figure 1 for the systematic flow diagram.

Table 1 Search terms for target population, exercise and outcomes

Target Population	Exercise	Outcomes
Men	Exercise*	Bone mineral density
Male	Physical Activity	Bone mineral*
	Exercise training	BMD
AND	Physical exercise	Bone mass
	Sport*	Bone strength
Osteoporosis	Resistance training	Fracture*
Osteopenia	Aerobic training	Re-fracture
	Aerobic exercise	Fall*
	Weight-bearing exercise*	Body comp*
	Progressive resistance training	Physical function
	Strengthening exercise*	Function*
	Strength training	Functional ability
	Impact training	Balance
	Impact loading	Strength
	Running	Fitness
	Skipping	Quality of life
	Stair climbing	Mental health
	Weight training	
	Walking	
	Circuit training	

* Denotes truncated terms.

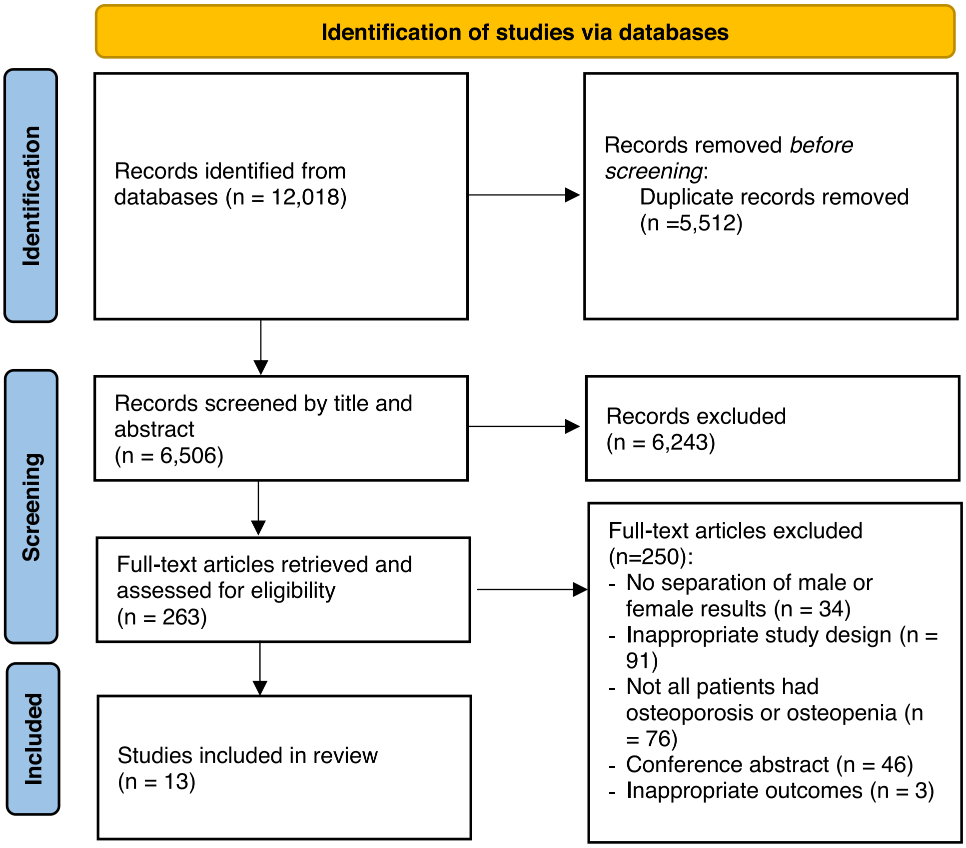

Fig 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram.

Data extraction

Data from the 13 eligible studies[17-29] were manually extracted, qualitatively synthesized, and tabulated by a single reviewer (K.H.; tables 2 and 3). The data extracted included study characteristics (sample size, duration, control groups), participant characteristics (age, osteoporosis/osteopenia diagnosis), details of the exercise intervention (frequency, exercise modality, intensity, time, supervision, adherence, adverse events), and primary and secondary outcomes relating to bone or muscle health, such as BMD, sarcopenia z scores, and tests of muscle strength and physical function. Adherence rates were defined as the percentage of patient groups attending all required training sessions and complying with prescribed exercise regimens. Outcomes from studies are presented as raw values extracted from the original publications and did not undergo conversions.

Study quality

Study quality was independently assessed by 2 reviewers (K. H. and M.C.) using the "Tool for assEssment of Study qualiTy and reporting in Exercise" (TESTEX).[16] TESTEX was specifically designed for assessing exercise intervention studies, in which blinding of subjects and trainers is not feasible and non-exercising controls may continue to exercise outside of the study. Using 12 different criteria, TESTEX allocates 5 points to study quality and 10 points to study reporting, for a maximum of 15 points. We categorized study quality according to TESTEX scores: a score <5 was considered "poor", 5-8 as "fair", 9-12 as "good", and >12 as "excellent".

Results

Study selection

A total of 12,018 articles were initially identified in the search process (fig 1). After removing duplicates, the 6506 unique articles were screened by title and abstract for relevance. The remaining 263 articles were then obtained in full and assessed for eligibility of inclusion by 2 independent reviewers. Thirteen studies, originating from 6 different trials, were selected for inclusion.[17-29] Minor differences between papers originating from the same trial included different trial lengths and different study outcomes. The characteristics and findings of the included articles were tabulated (tables 2 and 3).

Study quality

Table 4 shows the allocation of points to each study according to the TESTEX scale. Overall, the mean TESTEX score was 12.2±3.4 and the median was 14. Of the 13 studies, 7 studies were considered "excellent" quality.[18,20,23-26,28,30] Six studies were from the Franconian Osteopenia and Sarcopenia Trial (FrOST) in Germany, most of which received the maximum 15 points.[20,23-26,28] Three of the 4 studies that were of "good" quality were from the Lifting Intervention For Training Muscle and Osteoporosis rehabilitation for men (LIFTMOR-M) trial.[21,22,29] The lowest scoring study received 4 points.[17] All studies clearly reported eligibility criteria and concealed group allocation. Most studies specified the randomization method (12/13), used intention-to-treat analysis (12/13), and reported point measures and measures of variability for all reported outcomes (11/13). Common areas of weaknesses included significant differences in primary or secondary outcomes between groups at baseline (5/13), no blinding of assessors to group allocation of subjects (5/13), and lack of activity monitoring in control groups (8/13).

Participants

Participants of the included studies were community-dwelling men with a densitometric diagnosis of osteoporosis or osteopenia. There was a total of 320 participants with a mean age of 64.5 years. The lower threshold for age ranged from 45 years to 72 years for most studies (table 2); however, 1 study permitted participants as young as 25 years old.[18] Of the 13 included studies, 6 studies were from the FrOST study in Germany and 3 studies were from the Australian-based LIFTMOR-M trial. The 4 other independent studies originated from Saudi Arabia, Poland, United States of America, and Germany.[17-19,27]

Regarding bone density measurements, most studies used DXA to determine low bone density in participants when assessing for eligibility, except for Genest et al.[27] While this study did not scan all patients, it included patients who had a clinical diagnosis of low bone density, such as patients on anti-resorptive treatment or with a 10-year fracture risk probability of 20% or greater.[27] Most studies included participants with osteoporosis or osteopenia, whereas Hinton et al only included participants with osteopenia and did not state the methods used to confirm osteopenia.[18]

Exercise interventions

Eight exercise interventions were assessed: high intensity resistance and impact training (HIRIT), resistance training, machine-based isometric axial compression (IAC), jumping exercises, WBV, Tai Chi, Qi Gong, and a multi-modal regimen involving a mixture of exercises.

Frequency of exercise was most commonly twice a week for HIRIT and resistance training regimens and 3 times a week for lower intensity exercises, such as in Alayat et al, and jumping exercises, as in Hinton et al.[18,19] Intensity was reported in most studies, excluding Genest et al and Maciaszek et al.[17,27] Several trials involving resistance training, such as the LIFTMOR-M trial and Hinton et al, permitted intensity to peak at >80% of participants' 1 repetition maximum for each exercise.[18,21,22,29] The FrOST studies built up the intensity of resistance training in designated phases, as detailed in table 5.[20,23-26,28] One study specified intensity for aerobic exercises, such as treadmill walking, to be 40%-60% of the participant's maximum heart rate, but did not indicate intensity for other weight-bearing or strengthening exercises.[19] Jumping exercises in Hinton et al's study were categorized as low, moderate, and high intensity exercises, depending on the estimated ground reaction forces on jumping and the complexity of the movement.[18] The duration of exercise programs ranged from 18 weeks to 72 weeks.

Table 2 Study and participant characteristics of included publications, grouped by trial

Author and Year of Publication(s)	Trial (if Applicable)	Country	Study Design	Sample Size of Intervention and Control Groups	Participant Characteristics	Mean Age (years)
Alayat et al, 2018[19]	-	Saudi Arabia	RCT	EG: 25 CG: 25	Men >50 years with osteopenia or osteoporosis	53.8
Harding et al, 2020; Harding et al, 2020; Harding et al, 2021[21,22,29]	LIFTMOR-M trial	Australia	Semi-randomized trial with parallel-matched control group	HIRIT: 34 IAC: 33 CG: 26	Men ≥45 years with osteopenia or osteoporosis at the spine or hip	67.1
Hinton et al, 2015[18]	-	United States of America	Randomized parallel intervention trial with no control group	RT: 19 JUMP: 19	Physically active men aged 25-60 years with osteopenia	43.7
Genest et al, 2021[27]	-	Germany	Randomized parallel intervention trial with no control group	RT: 11 WBV: 13 Qi Gong: 10	Men ≥65 years with pre-existing osteoporosis at hip or spine, osteoporosis treatment or 10-year fracture risk probability ≥20%	77.0
Ghasemikaram et al, 2021; Kemmler et al, 2020; Kemmler et al, 2020, Kemmler et al, 2020; Kemmler et al, 2020; Lichtenberg et al, 2019[20,23-26,28]	FrOST	Germany	RCT	HIRIT: 21 CG: 22	Men ≥72 years with sarcopenia and osteopenia or osteoporosis at hip or spine	78.5
Maciaszek et al, 2007[17]	-	Poland	RCT	Tai Chi: 25 CG: 24	Men between 60 and 82 years with osteopenia or osteoporosis	70.1

Abbreviations: EG, exercise group; CG, control group; JUMP; jumping exercises; RCT, randomized controlled trial; RT; resistance training.

Table 3 Details of interventions and participant groups in included publications

Author and Year	Exercise Group: Intervention(s), Frequency, Duration	Control Group	Primary and/or Secondary Outcomes: BMD, Sarcopenia z Score, Lean Body Mass	Other Outcomes Assessed in Study	Key Findings
Alayat et al, 2018[19]	Exercise (aerobic, weight-bearing, flexibility, strengthening, balance) Frequency: 3 × /week Duration: 6 months	Randomized CG present and assumed usual care.	**Primary outcomes:** LS and TH BMD **LS BMD:** - **EG:** 0.99±0.08 at baseline to 1.06±0.06 at 6 months (*P*=.0003) - **CG:** 0.98±0.06 at baseline to 0.978±0.05 at 6 months (*P*=.0298) **TH BMD:** - **EG**: 0.90±0.04 at baseline to 0.93±0.04 at 6 months (*P*<.0001) - **CG:** 0.89±0.04 at baseline to 0.89±0.03 at 6 months (*P*=.0905)	N/A	- EG experienced an increase in LS and TH BMD compared with baseline - Mean differences between exercise and controls were higher at 1-year follow-up than immediately after the 24-week exercise program
Harding et al, 2020[21] (a)	HIRIT OR machine-based IAC Frequency: 2 × /week Duration: 8 months	Self-selected CG present and assumed usual care.	**Primary outcomes:** total volumetric BMD at FN and TH **FN vBMD:** - HIRIT: 0.217±0.027 at baseline to 0.220±0.034 at 8 months (*P*>.05) - IAC: 0.212±0.029 at baseline to 0.219±0.039 at 8 months (*P*>.05) - CG: 0.236±0.032 at baseline to 0.237±0.033 at 8 months (*P*>.05) **TH vBMD:** - HIRIT: 0.224±0.027 at baseline to 0.222±0.038 at 8 months (*P*>.05) - IAC: 0.215±0.028 at baseline to 0.223±0.038 at 8 months (*P*>.05) - CG: 0.240±0.031 at baseline to 0.235±0.026 at 8 months (*P*>.05)	- Bone mineral content, volume and volumetric BMD for the total, trabecular and cortical bone compartments at the FN, tibia, and distal radius - Total FN cortical thickness	- HIRIT either improved or sustained all outcomes measured compared with IAC and the controls - HIRIT and IAC both attenuate the progressive loss of bone strength at the distal tibia and radius
Harding et al, 2020[22] (a)	HIRIT OR machine-based IAC Frequency: 2 × /week Duration: 8 months.	Self-selected CG present and assumed usual care.	**Primary outcomes:** LS, TH, FN BMD **LS BMD:** - **HIRIT**: 1.072±0.154 at baseline to 1.114±0.150 at 8 months (*P*<.05) - **IAC**: 1.082±0.171 at baseline to 1.103±0.171 at 8 months (*P*<.05) - **CG**: 1.153±0.190 at baseline to 1.162±0.190 at 8 months (*P*>.05) **TH BMD:** - **HIRIT**: 0.947±0.107 at baseline to 0.958±0.111 at 8 months (*P*<.05) - **IAC**: 0.948±0.088 at baseline to 0.956±0.090 at 8 months (*P*>.05) - **CG**: 0.996±0.100 at baseline to 1.008±0.106 at 8 months (*P*>.05) **FN BMD:** - **HIRIT**: 0.781±0.083 at baseline to 0.801±0.086 at 8 months (*P*<.05) - **IAC**: 0.758±0.080 at baseline to 0.771±0.082 at 8 months (*P*>.05) - - **CG**: 0.832±0.085 at baseline to 0.844±0.092 at 8 months (*P*>.05)	- Body composition from whole-body DXA scans - Calcaneal ultrasound parameters - Functional tests: TUG, FTSTS, back and leg extensor strength	- HIRIT improves indices of body composition, physical function, and bone strength to a greater extent than IAC - IAC is inadequate for positively stimulating bone or muscle - Without any type of exercise, osteoporosis naturally progresses
Harding et al, 2021[29] (a)	HIRIT OR machine-based IAC Frequency: 2 × /week Duration: 8 months	Self-selected CG present and assumed usual care.	**Primary outcomes:** vertebral fracture incidence - **HIRIT and CG**: no new vertebral fractures - **IAC**: Progression of existing fractures and new incidental vertebral fractures	- Change in kyphosis when standing - Change in Cobb angle of kyphosis when in lateral decubitus position	- HIRIT is more well-tolerated and safer than IAC.
Hinton et al, 2015[18]	(RT 2 × /week OR JUMP 3 × /week) AND Supplemental calcium and vitamin D Duration: 12 months	No CG	**Primary outcomes:** TH and LS BMD at 6 months and 12 months **LS BMD:** - **RT**: 0.939±0.069 at baseline, 0.957±0.086 at 6 months, 0.955±0.088 at 12 months - **JUMP**: 0.919±0.056 at baseline, 0.931±0.059 at 6 months, 0.928±0.049 at 12 months	- Markers of bone formation (osteocalcin and BAP) and resorption (CTx and TRAP5b) - Pain and fatigue ratings - Potential confounders (changes in 25OHD, body weight and	- Six months RT OR JUMP improved LS BMD; however, post hoc within-group comparisons are not available. - TH BMD only improved with RT, not JUMP.

(*continued*)

Table 3 (*Continued*)

Author and Year	Exercise Group: Intervention(s), Frequency, Duration	Control Group	Primary and/or Secondary Outcomes: BMD, Sarcopenia z Score, Lean Body Mass	Other Outcomes Assessed in Study	Key Findings
			- Within-group comparisons not performed **TH BMD:** - **RT**: 0.898±0.082 at baseline, 0.905±0.087 at 6 months, 0.906±0.089 at 12 months ($P<.05$) - **JUMP**: 0.912±0.116 at baseline, 0.911±0.118 at 6 months, 0.907±0.111 at 12 months ($P>.05$)	composition, nutrient intake, and physical activity level)	
Genest et al, 2021[27]	RT: 2 × /week OR WBV: 2 × /week OR Qi Gong: 2 × /week Duration: 6 months	No CG	No primary outcomes.	- One repetition maximum force isometric measurement of trunk strength for extension and flexion on a stationary machine - Functional tests: handgrip strength, CRT, usual gait speed, TUG	- RT is superior to WBV and Qi Gong in improving trunk strength and gait speed. - The latter are feasible and safe alternatives that could be considered where RT is not suitable for patients.
Ghasemikaram et al, 2021[28] (b)	RT AND supplements (protein, cholecalciferol, calcium) Frequency: 2 × /week Duration: 16 months	Randomized CG present and assumed usual care, in addition to supplements (protein, cholecalciferol, calcium)	No primary outcomes.	- Intra-muscular adipose tissue of the thigh on MRI - Muscle tissue volume - Thigh volume - Intra fascia fat fraction - Muscle tissue fat fraction - Subcutaneous adipose tissue	- RT prevents fat infiltration of thigh muscle but does not reverse pre-existing sarcopenia.
Kemmler et al, 2020[24] (b)	RT AND Supplements (protein, cholecalciferol, and calcium) Frequency: 2 × /week Duration: 18 months	Randomized CG present and assumed usual care, in addition to supplements (protein, cholecalciferol, calcium)	**Primary outcomes:** LS and TH aBMD by DXA and Sarcopenia *z* score **LS BMD:** - **RT**: 1.054 (0.981-1.122) at baseline to 1.065 (1.048 to1.061) at 18 months - **CG**: 0.987 (0.916-1.060) at baseline to 0.986 (0.965-0.979) at 18 months - Between groups at 18 months: $P=.024$ **TH BMD:** - **RT**: 0.894 (0.856-0.932) at baseline to 0.894 (0.886-0.900) at 18 months - **CG**: 0.869 (0.826-0.911) at baseline and 0.856 (0.835-0.849) at 18 months - Between groups at 18 months: $P=.025$ **Sarcopenia z score:** - **RT**: -2.51 (-1.45 to -3.65) at baseline to -3.34 (-3.83 to -4.51) at 18 months - **CG**: -2.14 (-1.45 to -2.83) at baseline to -2.03 (-1.9 to -1.21) at 18 months - Between groups at 18 months: $P<.001$	- SMI - Functional tests: Handgrip strength, Gait velocity	- RT, in combination with supplements, markedly improved some parameters of osteosarcopenia and functional assessments of physical frailty. - Osteosarcopenia naturally progresses without exercise.

(*continued*)

Table 3 (*Continued*)

Author and Year	Exercise Group: Intervention(s), Frequency, Duration	Control Group	Primary and/or Secondary Outcomes: BMD, Sarcopenia *z* Score, Lean Body Mass	Other Outcomes Assessed in Study	Key Findings
Kemmler et al, 2020[25] (b)	RT AND Supplements (protein, cholecalciferol, and calcium) Frequency: 2 × /week Duration: 12 months	Randomized CG present and assumed usual care, in addition to supplements (protein, cholecalciferol, calcium)	**Primary outcomes:** LS BMD by QCT and TH BMD by DXA **LS BMD by QCT:** - **RT**: 176.3 (171 to 182) at baseline to 179.2 (179-185) at 12 months - **CG**: 166.7 (154-179) at baseline to 162.6 (155.3-162) at 12 months - Between groups at 12 months: P=.006 **TH BMD by DXA:** - **RT**: 0.894 (0.856-0.932) at baseline to 0.894 (0.888-0.899) at12 months - **CG**: 0.869 (0.826-0.911) at baseline to 0.859 (0.855-0.843) at 12 months - Between groups at 12 months: P=.064	- SMI by DXA - MILES	- RT, combined with supplements, improved parameters of sarcopenia, and osteoporosis. - Osteosarcopenia naturally progresses without exercise. - Using QCT prevents overestimation of BMD in patients with aortic calcifications, spine degeneration, or sclerotic lesions.
Kemmler et al, 2020[23] (b)	RT AND Supplements (protein, cholecalciferol, and calcium) Frequency: 2 × /week Duration: 18 months	Randomized CG present and assumed usual care, in addition to supplements (protein, cholecalciferol, calcium)	**Primary outcomes:** LBM by DXA **LBM by DXA:** - **RT**: 44.93 (42.81-47.06) at baseline to 46.40 (47.54-48.2) at 18 months (P<.001) - **CG**: 43.19 (40.99-45.39) at baseline to 42.93 (42.99-42.36) at 18 months (P=.11) - Between groups at 9 months: P<.001	- MILES - Total body and abdominal fat percentages	- RT, combined with supplements, improves muscle strength and body composition. - Without consistent exercise, total body fat continues to increase in men with osteosarcopenia.
Kemmler et al, 2020[26] (b)	RT AND Supplements (protein, cholecalciferol, and calcium) Frequency: 2 × /week Duration: 9 months	Randomized CG present and assumed usual care, in addition to supplements (protein, cholecalciferol, calcium)	**Primary outcomes:** LBM by DXA **LBM by DXA:** - **RT**: 44.93±4.66 at baseline to 46.19±6.16 at 9 months (P<.001) - **CG**: 43.19±4.84 at baseline to 43.00±5.76 at 9 months (P=.46) - Between groups at 9 months: P<.001	- Total and abdominal body fat percentage by DXA - MILES	- RT, combined with supplements, improved indices of sarcopenia. - Exercising beyond 9 months may produce only minor improvements to the parameters measured.
Lichtenberg et al, 2019[20] (b)	RT AND Supplements (protein, cholecalciferol, and calcium) Frequency: 2 × /week Duration: 6 months	Randomized CG present and assumed usual care, in addition to supplements (protein, cholecalciferol, calcium)	**Primary outcomes:** Sarcopenia *z* score - **RT:** -0.09±1.94 at baseline to -1.01±0.78 at 6 months (P<.001) - **CG:** -0.11±1.18 at baseline to 0.43±0.74 at 6 months (P=.012) - Between groups at 6 months: P<.001	- SMI - Functional tests: handgrip strength, Habitual gait velocity	- Short-term RT, combined with supplements, is effective in improving sarcopenia and some functional capacity.

(*continued*)

Table 3 (*Continued*)

Author and Year	Exercise Group: Intervention(s), Frequency, Duration	Control Group	Primary and/or Secondary Outcomes: BMD, Sarcopenia z Score, Lean Body Mass	Other Outcomes Assessed in Study	Key Findings
Maciaszek et al, 2007[17]	Tai Chi training Frequency: 2 × / week Duration: 18 months	Randomized CG present and assumed usual care.	No primary outcomes	- Body balance, assessed on Computer Posturographic System PE 90. - Time of completing balancing tasks - Percentage of the reaching path to the set area - Percentage of task performance - Accuracy of the task	- Long-term Tai Chi improves dynamic balance and is a safe form of exercise that requires minimal effort. - Results are difficult to compare with other included studies, which primarily assess BMD and functional status. - No assessment or exclusion of patients with disturbances in vestibular, visual, or proprioceptive ability.

NOTE. (a) indicates studies derived from the LIFTMOR-M trial.
(b) indicates studies derived from the FrOST trial.
Abbreviations: BAP, bone alkaline phosphatase; CTx, C-terminal telopeptide of type 1 collagen; JUMP, jumping exercises; LS, lumbar spine; MILES, maximum isokinetic hip/leg extensor strength; QCT, quantitative computed tomography; RT, resistance training; TH, total hip; TRAP5b, Tartrate-resistant acid phosphatase 5b; WB, whole body; 25OHD, 25-hydroxycholecalciferol.

Resistance training was the most common exercise intervention assessed: 11 of 13 studies involved some variation of resistance training.[18,20-29] The regimens involving resistance training differed between studies and have been detailed in table 5. Alayat et al used a multi-modal exercise program, which was a mixture of aerobic exercise, resistance training and impact training.[19] Several studies compared alternative exercise interventions to resistance training.[18,21,22,27,29] The LIFTMOR-M trial by Harding et al compared HIRIT with machine-based IAC, which consisted of 4 exercises: chest press, leg press, core pull, and vertical lift.[21,22,29] Hinton et al compared resistance training and impact training, the latter consisting of various jumping exercises.[18] Genest et al adopted WBV training, which involved participants standing on a side alternating vibration platform, for the purpose of improving strength in the lower extremities and core.[27] Traditional Chinese movement exercises, such as Tai Chi and Qi Gong, were assessed by Maciaszek et al and Genest et al, respectively, and involve low-impact movements with a focus on posture, balance, and breathing.[17,27] Most exercise interventions were fully supervised and predominantly performed in small groups, except for Alayat et al's multi-modal exercise program. Stair climbing and jumping exercises were supervised; however, participants performed all other exercises at home using a booklet of exercise descriptions.[19]

Adherence to intervention

All articles included reported adherence rates,[18-30] except for 1 study which had a TESTEX score of 4/15.[17] The adherence rates reported by studies reflected attendance to the training sessions and compliance with the prescribed exercise programs (table 5). Several studies required supervisors at the exercise sessions to record attendance and compliance.[18,19,21,22,27,29] The FrOST study reported 95% attendance rate, which was determined by assessing records of gym card use to access exercise sessions, and adherence rates ranging between 93% and 95% over various durations of the HIRIT program.[20,23-26,28] The LIFTMOR-M trial observed compliance rates ranging between 77% and 78%, with no significant difference between HIRIT and IAC groups.[21,22,29] Two studies reported 100% compliance rates: 1 study required self-recorded compliance for home-based exercises[19] and another study required all participants to attend replacement exercise sessions for any missed sessions.[18] Genest et al reported varying attendance rates depending on the exercise intervention: the lowest attendance rate was seen in the Qi Gong group (65.1%), and highest in the WBV group (83.2%).[27]

Control groups

Eleven of the thirteen studies had a control group in which no exercise intervention was allocated, and usual care was assumed, meaning participants were permitted to maintain any regular physical activity habits from prior to joining the study (table 3). While Hinton et al and Genest et al did not have a non-exercising control group, they did compare 2 or more exercise interventions in each study.[18,27] Participants of the LIFTMOR-M trial allocated themselves to the control group, as the authors deemed it unethical to prevent

Table 4 Assessment of study quality and reporting using the TESTEX scale

Study and Year	Journal	1. Eligibility Criteria Specified (1 pt)	2. Randomization Specified (1 pt)	3. Allocation Concealment (1 pt)	4. Groups Similar at Baseline (1 pt)	5. Blinding of Assessor (1 pt)	6. Outcome Measures Assessed in >85% of Patients* (3 pts)	7. Intention-to-treat Analysis (1 pt)	8. Between-group Statistical Comparisons Reported* (2 pts)	9. Point Measures and Measures of Variability (1 pt)	10. Activity Monitoring in Control Groups (1 pt)	11. Relative Exercise Intensity Remained Constant (1 pt)	12. Exercise Volume and Energy Expenditure (1 pt)	Overall TESTEX Score
Alayat et al (2018)[19]	Photomedicine and Laser Surgery	1	1	1	1	1	2	1	1	0	0	0	0	9
Harding et al (2020)[21] (a)	Bone	1	1	1	0	0	3	1	2	1	0	1	1	12
Harding et al (2020)[22] (a)	Journal of Bone and Mineral Research	1	1	1	0	0	3	1	2	1	0	1	1	12
Harding et al (2021)[29] (a)	Osteoporosis International	1	1	1	0	0	3	1	2	1	0	1	1	12
Hinton et al (2015)[18]	Bone	1	1	1	1	1	2	1	2	1	1	1	1	14
Kemmler et al (2020)[24] (b)	Nutrients	1	1	1	1	1	3	1	2	1	1	1	1	15
Kemmler et al (2020)[25] (b)	Journal of Bone and Mineral Research	1	1	1	1	1	3	1	2	1	1	1	1	15
Kemmler et al (2020)[26] (b)	Frontiers in Sports and Active Living	1	1	1	1	1	3	1	2	1	1	1	1	15
Genest et al (2021)[27]	Bone Reports	1	1	1	0	0	3	1	0	1	0	0	0	8
Ghasemikaram et al (2021)[28] (b)	Geroscience	1	1	1	1	1	3	1	2	1	0	1	1	14
Kemmler et al (2020)[23] (b)	Frontiers in Physiology	1	1	1	1	1	3	1	2	1	0	1	1	14
Lichtenberg et al (2019)[20] (b)	Clinical Interventions in Aging	1	1	1	1	1	3	1	2	1	1	1	1	15
Maciaszek et al (2007)[17]	The American Journal of Chinese Medicine	1	0	1	0	0	0	0	2	0	0	0	0	4

NOTE. (a) indicates studies derived from the LIFTMOR-M trial. (b) indicates studies derived from the FrOST trial.

[*] These criteria award more than 1 point. Criterion #6 awards 1 point each for reporting the following outcome measures: (1) adherence to training in >85% of patients, (2) adverse events, and (3) exercise attendance who exercise subjects who did not withdraw, for a maximum total of 3 points. Criterion #8 awards 1 point each for reporting point measures and measures of variability for (1) primary outcomes and (2) secondary outcomes.

Table 5 Training regimens and exercises involved within eligible studies, grouped by trial

Study	Intensity	Time (min; set × reps)	Type	Progression	Supervision	Adherence	Adverse Events
Alayat et al (2018)[19]	40%-60% HRmax for treadmill walking. Intensity not specified for strength exercises	20 min treadmill walking; 3 × 10 strength exercises	Multi-modal exercise program: treadmill walking, bodyweight abdominal and back strength exercises, theraband and sandbag weighted hip strength exercise, leg press, stair climbing, jumping	No	Stair climbing and jumping exercises were supervised. All other exercises were performed at home, unsupervised.	100% at 24 weeks and 85% at 1-year follow-up	Not reported
Genest et al (2021)[27]	Not reported	30 min; not reported	Resistance training: exercises not described	Not reported	Yes	71%	None
	Not reported	20 min; not reported	WBV	Not reported	Yes	83%	
	Not reported	45 min; not reported	Qi Gong	Not reported	Yes	65%	
LIFTMOR-M trial[21,22,29]	≥80%-85% 1RM for each exercise	30 min total; 5 × 5 for each exercise movement	Resistance and impact training: deadlift, squat, and overhead press, jumping chin-ups	Progressed in increments of 2.5 kg	Fully supervised in small groups	78%	Minor adverse events reported: mild musculoskeletal discomfort
		30 min; 1 × 1	IAC: chest press, leg press, core pull, vertical lift	No	Fully supervised individually	79%	5 vertebral fractures
Hinton et al (2015)[18]	Low intensity: 50% 1RM Moderate intensity: 70%-75% 1RM High intensity: 80%-90% 1RM	Time not reported; 2-3 × 10 at 50%-60% 1RM; 1 × 6-8 at 70%-75% 1RM; 1 × 3-5 at 80%-90% 1RM	Resistance training: Squats, bent-over-row, modified deadlift, military press, lunges, calf raises	Yes, intensity progressed every 2 weeks from low to moderate to high intensity on a 6-week cycle	Fully supervised	100%	None
	Jumping exercises varied in intensity, with no more than 100 jumps performed per session. Intensity was estimated by ground reaction forces associated with the jumps and by the complexity of the movement.	60-120 min; 1 × 10 of 4-12 different jumps	Impact training: squat jumps, forward hops, split-squat jumps, lateral box push-offs, bounding, bounding with rings (lateral), box drill with rings, lateral hurdle jumps, zigzag hops, single-leg lateral hops, progressive depth jumps (10-100 cm), jumping off a box.				
FrOST trial[20,23-26,28]	Dependent on training phase. Exercise program divided into 4 phases. Phase 1: Familiarization of exercises. Intensity not specified. Phase 2: RIR 1-2. Phase 3: Explosive movements introduced. Intensity not specified. Phase 4: Intensity not specified.	Time not reported; Sets × reps dependent on phase.	Resistance training: leg press, extension, curls, adduction, abduction, latissimus front pulleys, rowing, back extension, inverse fly, bench press, military press, lateral raises, butterfly with extended arms, crunches, calf raises, hip extension, pull-overs, lateral crunches.	Progression dependent on phase	Fully supervised	93%-95% (depending on duration of trial)	None
Maciaszek et al (2007)[17]	Not reported	45 min; not applicable	Five sequences of movement chosen from the simplified 24-form Tai Chi	Not reported	Fully supervised in groups	Not reported	Not reported

Abbreviations: HRMax, maximum heart rate; RIR, repetitions in reserve; 1RM, 1 repetition maximum.

randomized participants from trialing exercise as a potentially effective form of therapy for their low bone density.[21,22,29] In the FrOST study, the randomized control group assumed usual care, in addition to taking whey protein and vitamin D supplements.[20,23-26,28]

Outcomes

Bone health: bone mineral density

Six of thirteen studies assessed BMD at vertebral and hip sites. Most studies show that BMD of the lumbar spine, total hip, and whole body, measured by DXA, improved significantly in men that engaged in variations of long-term resistance training.[18,19,22] Six months of resistance training, in addition to supplemental calcium and vitamin D, improved lumbar spine, total hip, and whole-body BMD in men with osteopenia.[18] Similarly, the LIFTMOR-M trial showed that twice-weekly HIRIT over 8 months significantly improved lumbar spine BMD by 4% and total hip BMD by 3%.[22] Extending the duration of twice-weekly resistance training to 12 months and 18 months in the FrOST study continued to improve lumbar spine BMD, compared with controls and baseline.[24,25] Total hip BMD was sustained at 12 months and 18 months of resistance training, whereas it declined consistently in non-exercising controls.[24,25]

Alayat et al showed that 6 months of a mixture of training modalities (aerobic, resistance, and impact training) increased BMD by 10% at the lumbar spine and 3% at the total hip, and these changes were sustained 1 year after ceasing the exercise regimen.[19] In trials that used non-exercising control groups, BMD would remain unchanged or decrease.[19,22,24,25]

Resistance training was compared with other training modalities, such as jump exercises, known as impact training, and machine-based IAC.[18,22] Six months of resistance training or impact training improved lumbar spine BMD, and no superior exercise was identified.[18] However, total hip BMD significantly improved with resistance training only, not with jumping exercises.[18] IAC significantly improved lumbar spine BMD after 8 months, but to half the extent seen in the HIRIT group.[22] There was no significant improvement at the total hip or femoral neck with IAC.[22]

Muscle outcomes: body composition

Improvements in body composition in men with osteosarcopenia, defined as skeletal muscle index (SMI) T score $\leq$-2 SD and BMD T score $\leq$1 SD, were most prominent in the first 8-12 months of regular resistance training. At 8 and 9 months of resistance training, lean body mass (LBM) significantly increased, and the fat percentage of the total body and abdomen were reduced in men with osteosarcopenia, compared with baseline and to non-exercising controls, who exhibited worsening of these parameters.[23,26] These changes to body composition were not significantly different to results at 12 months and 18 months.[23,26]

From baseline to 16 months, intermuscular adipose tissue increased in non-exercising controls and remained unchanged in resistance training subjects.[28] Additionally, volumes of the thigh and fascia were unchanged in controls at 16 months, but fat fractions in these areas significantly increased, compared with baseline and to the resistance training group.[28]

There were significant improvements to SMI after 12 months of resistance training[24]; however, an additional 6 months of training maintained the SMI but did not lead to further improvements.[25] Rapid muscle atrophy in controls was seen early in the FrOST study: at 7 months, SMI deteriorated in non-exercising subjects, which continued at 12 months and 18 months.[20]

In the FrOST study, resistance training improved the sarcopenia *z* score significantly from baseline at 7 months, 12 months, and 18 months, whereas the non-exercising control group had a poorer *z* score at the end of the trial.[20,24,25]

Functional outcomes

In the resistance training group of the FrOST study, maximum bilateral hip/leg extension strength (MILES) against an isokinetic leg press improved after 9 months, 12 months, or 18 months of training, compared with baseline.[23,25,26] Without resistance training in controls, no substantial changes in MILES were observed.[24,25] Three studies assessed handgrip strength: handgrip strength improved with 7 months and 18 months of resistance training in men with osteosarcopenia,[20,24] but no changes were observed after 6 months of resistance training in men with osteoporosis by Genest et al.[27] The latter study did not have a non-exercising control group for comparison.

In the LIFTMOR-M trial, regular HIRIT improved mobility, dynamic balance, and strength.[22] Times to complete test of physical function, such as timed Up and Go (TUG) and 5-times-sit-to-stand (FTSTS), were reduced by 5% and 10%, respectively, and back and leg extensor strength were also augmented, compared with controls.[22] Another study observed no significant changes in outcomes for the 6-minute-walk test, TUG, static balance, and chair-rise test (CRT), after 6 months of resistance training.[27] Gait speed was shown to improve with resistance training in 2 studies.[20,27]

IAC significantly reduced the time for FTSTS test, but it did not improve back or leg extensor strength.[22] WBV was the only exercise modality assessed by Genest et al that significantly improved handgrip strength.[27] Within the same study, Qi Gong did not improve trunk or handgrip strength, balance, gait speed, or CRT results.[27] Tai Chi improved the ability to maintain dynamic balance after 18 months of intervention; however, this study did not use common tests of physical function.[17]

Adverse events

Two of 13 studies reported adverse events, notably falls, and fractures.[21,22,29]. Harding et al reported that 3 HIRIT participants, 2 IAC participants, and 2 control group participants had at least 1 fall during the 8-month trial, none of which resulted in complications, fractures, or hospital admissions.[22] Harding et al also reported vertebral fractures at baseline and 8 months, identified on lateral thoracolumbar DXA scans.[22] Within the HIRIT group, no new incidental vertebral fractures were diagnosed, and no pre-existing wedge fractures had progressed in severity. In the IAC group, 5 incidental wedge fractures were identified at 8 months, in addition to the progression of 1 pre-existing wedge fracture.[29] Eight studies reported no adverse events related to the exercise interventions,[18,20,23-28] and 2 studies did not address adverse events.[17,19]

Discussion

This systematic review is the first to assess the effects of exercise on measures of bone and muscle health in men with pre-existing low bone density. The results suggest that regular resistance and impact training of various durations can maintain or even improve BMD in men with osteopenia or osteoporosis. Resistance training is also beneficial for muscle health, as it hinders the natural progression of fatty infiltration in men with osteosarcopenia. In contrast, low impact exercise does not produce improvements in bone density and other measures of muscle health, with inconsistent improvements in tests of physical function. Studies examining alternative modalities of exercise, such as whole body vibration (WBV) and traditional Chinese exercises, were of fair or poor quality,[17,27] whereas studies assessing variations of high intensity resistance training and impact training were mostly of excellent or good quality.[19-25,27,28] As a potential non-pharmacologic therapy for osteoporosis, the safety, and accessibility of exercise prescriptions are important factors to consider alongside its efficacy.

Out of the exercise interventions assessed, twice-weekly resistance training produced the most favorable and consistent effects on BMD. Varying durations of resistance training, ranging from 6 months to 18 months, were sufficient to induce small but statistically significant positive effects on bone.[18,21,22,24,25] In men with normal bone density, resistance training has been shown to produce similarly small to moderate improvements in BMD, with mixed degrees of improvements at different sites.[31-34] The evidence supporting resistance training for improving BMD is well-established in studies involving post-menopausal women subjects. A systematic review of studies involving post-menopausal women determined that dynamic resistance training had a significant positive effect on BMD at the lumbar spine, total hip, and femoral neck; however, this effect was considered low to moderate.[35] To induce continuous bone modeling and remodeling, bone tissue must be exposed to novel and dynamic mechanical loading greater than what is normally encountered in daily living.[11,36] Resistance and impact training programs aim to generate this aberrant mechanical loading with a progressive intensity design, which is intended to allow participants to gradually adapt to the increased strain on bones and muscle. Although the natural mechanostat in bone is less sensitive to loading with age, regular physical training continues to protect against declines in BMD in older individuals. Resistance training has a relatively minor absolute effect on BMD, but it could translate into meaningful improvements to clinical outcomes in susceptible populations, such as reduced risk of falls and fractures.

This review found that the lumbar spine was more receptive to the osteogenic effect of dynamic loading during exercise and showed the greatest improvements in BMD, whereas the total hip was the most resistant of the skeletal sites assessed.[18,22,24,25] Similar site-specific changes to BMD have been reported in other studies: in pre-menopausal and post-menopausal women, high intensity resistance training, had a statistically significant, albeit moderate, positive effect on BMD at the lumbar spine, but less conclusive results at the femoral neck.[8,16,37] The disparity between osteogenic responses to exercise at vertebral and hip sites is currently not well-understood. Several factors may contribute to this finding: the skeletal site itself may be difficult to target with resistance training alone, or the different components of bone, cortical, and trabecular, may respond to exercise differently. The osteogenic effect of exercise is specific to skeletal sites that have been actively stimulated with sufficient novel mechanical loading and progressive intensity but does also require a mixture of strengthening, weight-bearing, and resistance exercises.[37-40] An understanding of the site-specific effect of exercises could enable the formulation of individualized exercise prescriptions for patients with osteoporosis or osteopenia needing to target specific skeletal sites.

Bone and muscle are known to closely interact, and declines in mass and quality of both contribute to osteoporosis and sarcopenia, which often co-exist in older patients.[41,42] Thus, it is valuable to explore concurrent changes to indices of muscle and bone health in men with low BMD after regular exercise. High intensity resistance training had a positive effect on measures of body composition in men with osteosarcopenia, such as increased LBM, reduced fat percentage, and improved SMI.[20,23-26,28] The gain in muscle may be partially attributed to the higher individualized doses of whey protein supplements provided to exercising participants compared with non-exercising controls. Despite the progressive increases in intensity in the resistance training program, improvements in body composition appeared to be limited to the early stages of exercise and may subsequently plateau as patients gradually acclimatize to regular exercise. This plateau could also indicate a physiological limit to the degree at which resistance training improves body composition in our population of interest. A study involving men and women participants with osteosarcopenia showed that a supervised resistance training regimen as short as 3 months was of sufficient duration to significantly increase LBM in exercising participants, whereas non-exercising controls experienced no changes.[43] Without regular resistance training in frail patients, muscle is consistently lost and replaced with adipose tissue.[44] Therefore, it can be said that resistance training attenuates the natural progression of fatty infiltration and muscle loss. High intensity resistance training can build and sustain muscle to replace lost fat in men with osteosarcopenia in the medium-term but does not continue to produce substantial long-term improvements. It is likely that resistance training alone would be an inadequate therapy for men with severe sarcopenia.

While the findings for functional tests after resistance training were mixed in this review, measures of physical and functional performance have been shown to improve with resistance training in older adults with sarcopenia or frailty, such as handgrip strength, lower limb strength, agility, gait speed, postural stability, and functional performance.[44] Improvements in these areas are valuable in elderly patients, where functional independence is related to physical capacity. Gait speed in particular is strongly associated with falls and fractures and is a reliable indicator of physical function when trialing interventions.[45] Resistance training may be even more beneficial for men than women: a Sweden-based randomized-controlled trial found that men participants performing resistance training had a better Short Physical Performance Battery score and reduced TUG times compared with their non-exercising counterparts, whereas women participants experienced less pronounced improvements in these outcomes.[46] Exercising, particularly resistance training, in men may be more productive than in women. Overall, the limited evidence available suggests that resistance training yields minimal yet appreciable developments in functional performance.

Alternative exercises explored in this review, such as IAC, WBV, Tai Chi, and Qi Gong, had a limited effect on bone and muscle health. Machine-based IAC was found to be insufficient in generating an osteogenic response at the major skeletal sites.[22] WBV improved handgrip strength, but this was likely due to the need for subjects to grip the available handgrips to self-stabilize while on the vibrating platforms. Self-stabilization also trains the lower extremities to maintain balance, contributing to significant improvements seen during the CRT. Low-impact and low-effort training modalities, such as Qi Gong and Tai Chi, involve slow, meditative movements and emphasize control of posture and balance. While Tai Chi generally focuses on more complex, choreographed movements than Qi Gong, the 2 practices overlap in terms of style and movement. Some studies suggest that traditional Chinese movements improve BMD in older adults; however, the evidence is poor and inconsistent.[47,48] While traditional Chinese exercises have not been proven to be beneficial for bone and muscle health, these exercises remain appealing as less physically demanding alternatives to high-intensity exercises.

Study limitations

The absence of control groups and randomization in some studies prevents us from interpreting improvements to bone and muscle health as being a direct result of exercise alone.[18,21,22,29] It was deemed unethical to request that clinical trial participants with low bone density forego exercise if randomly placed in the control group. Because of the lack of activity monitoring in some control groups, it is possible that control subjects continued to exercise unsupervised, which could significantly confound the results. Additionally, despite the included studies reporting few or no fractures, there are other factors that reduce the reliability of these results, such as a small number of participants, absence of randomization, and possibly selection bias, such as selecting patients with limited to no comorbidities that would increase frailty and susceptibility to fractures.

There was considerable heterogeneity in bone and muscle outcomes assessed and exercise regimens chosen in the included studies, rendering results difficult to compare. Naturally, numerical data from different studies and at different skeletal sites are not calculated to be directly compared. This is because focal remodeling activity in response to mechanical loading differs between skeletal sites, leading to differences in expected percentage changes.[11] An important primary outcome in osteoporosis research is fracture prevention. Because none of the included studies assessed this outcome, we are unable to comment on the effectiveness of exercise in preventing fractures. The review protocol was also not prospectively registered.

Conclusions

Exercise is a favorable non-pharmacologic intervention that is under-used in men with osteoporosis. Compared with

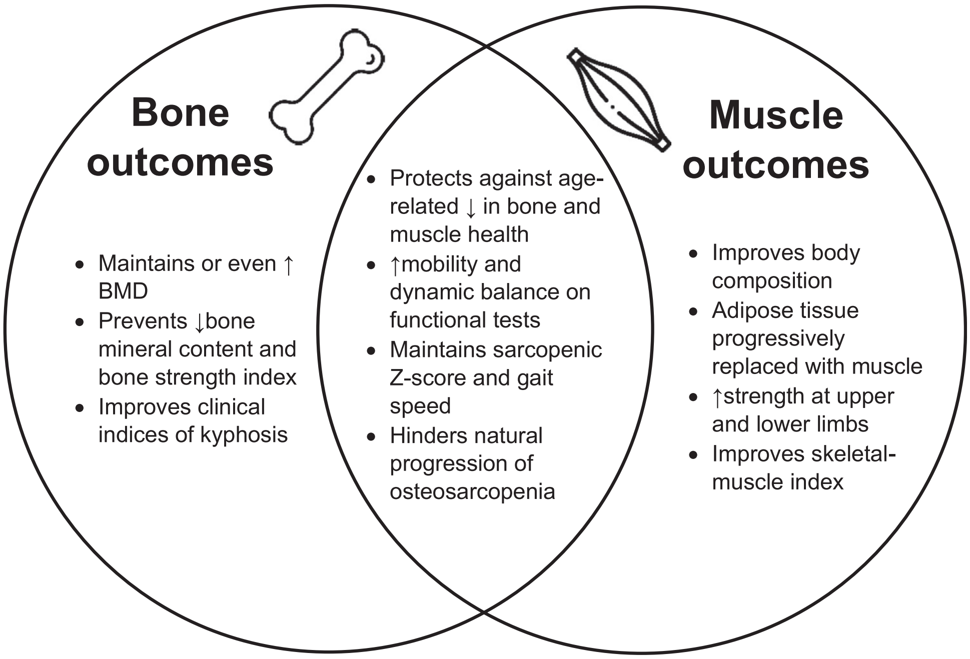

Fig 2 Summary of bone and muscle outcomes in response to exercise in men with low bone density.

women, men experience 2-fold greater mortality rates after a hip fracture. Additionally, the number of hip fractures in men is projected to increase to a greater extent than in women.[3,4] Despite this, men are frequently overlooked in osteoporosis research and are often under-treated when diagnosed with low bone density.[6]

Exercise is protective against age-related declines in bone and muscle health and slows down the progression of osteosarcopenia (fig 2). Resistance training is well-tolerated and has shown the most substantial results out of all the exercise modalities assessed in this review. It maintains or potentially increases BMD and builds muscle to replace adipose tissue, lending to enhancements in mobility, balance, and strength. Gradual acclimatization to supervised, progressive resistance training encourages compliance and limits the risk of injuries.

Alternative exercise modalities, such as WBV, IAC, Qi Gong, and Tai Chi, offer limited bone-promoting effects. WBV was only noted to improve handgrip strength and Tai Chi improved dynamic balance. Site-specific exercise regimens, such as the IAC regimen, did not improve bone density at all crucial skeletal sites. However, these exercise modalities remain viable options that are less physically demanding.

Most exercise interventions were safe and feasible, largely due to direct supervision. IAC notably resulted in new vertebral fractures in 5 subjects,[29] raising the question of its suitability and safety for men with low bone density. There are limitations in implementing exercise interventions: exercise programs should be taught and supervised by professionals, such as exercise physiologists, which can limit its accessibility and convenience for participants. Thus far, resistance or impact training without supervision has not been trialed nor recommended in men with osteoporosis. The benefits of exercise are sustained with regular sessions and modifications in line with the individual's physical capacity, over long periods of time. Therefore, individual adherence to exercise interventions is key to ensuring improvements to bone and muscle health.

Overall, exercise is an under-used yet promising therapy for preserving bone density and improving muscle function in men with low bone density. Ongoing research is needed to better understand the ideal training regimen to be prescribed in our population of interest.

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