Original Article

Position Statement: Exercise Guidelines for Osteoporosis Management and Fall Prevention in Osteoporosis Patients

Seongryu Bae[1,*], Seungyong Lee[2,*], Hyuntae Park[3], Yongin Ju[4], Seok-Ki Min[5], Jinkyung Cho[5], Hyojin Kim[6], Yong-Chan Ha[7], Yumie Rhee[8], Young-Pyo Kim[9], Changsun Kim[6]

[1]Department of Health Care and Science, Dong-A University, Busan;
[2]Department of Physical Education, Incheon National University, Incheon;
[3]Department of Health Sciences, Graduate School, Dong-A University, Busan, Korea
[4]Department of Health and Sports Science, Kawasaki University of Medical Welfare, Kawasaki, Japan
[5]Department of Sport Science, Korea Institute of Sport Science, Seoul;
[6]Department of Physical Education, Dongduk Women's University, Seoul;
[7]Department of Orthopaedic Surgery, Seoul Bumin Hospital, Seoul;
[8]Department of Internal Medicine, Severance Hospital, Endocrine Research Institute, Yonsei University College of Medicine, Seoul;
[9]Department of Kinesiology, College of Natural Science, Jeju National University, Jeju, Korea

Corresponding author

Changsun Kim
Department of Physical Education, Dongduk Women's University, 60 Hwarang-ro 13-gil, Seongbuk-gu, Seoul 02748, Korea
Tel: +82-2-940-4507
Fax: +82-2-940-4502
E-mail: chang@dongduk.ac.kr

*Seongryu Bae and Seungyong Lee contributed equally to this work and should be considered first authors.

KSBMR
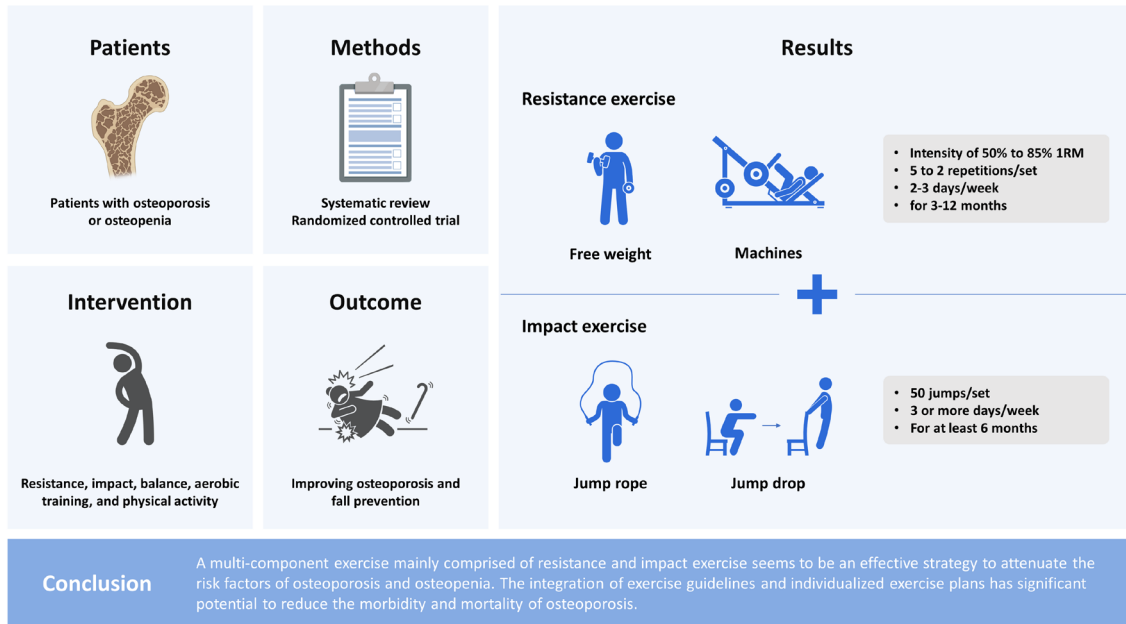Korean Society for Bone and Mineral Research

Background: The effectiveness of exercise for improving osteoporosis and fall prevention in patients diagnosed with osteoporosis or osteopenia has not been fully summarized. The Korean Society for Bone and Mineral Research and the Korean Society of Exercise Physiology has developed exercise guidelines for patients with osteoporosis or osteopenia and provide evidence-based recommendations. **Methods:** A systematic review identified randomized controlled trials (RCT) assessing the effect of resistance, impact, balance, aerobic training, and physical activity in osteoporosis and osteopenia on bone quality, physical performance, quality of life, and fall prevention. PubMed, Embase, KoreaMed, and RISS were searched from January 2000 to August 2022. Ten key questions were established to review the evidence and formulate recommendations. **Results:** The 50 RCTs reported that even with osteoporosis and osteopenia, resistance and impact training consistently maximized bone strength, improved body strength and balance, and eventually reduced fall incidences. Resistance exercise combining 3 to 10 types of free weight and mechanical exercise of major muscle groups performed with an intensity of 50% to 85% 1-repetition maximum, 5 to 12 repetitions/set, 2 to 3 days/week, for 3 to 12 months is recommended. Impact exercises such as jumping chin-ups with drop landings and jump rope performed 50 jumps/session for at least 6 months with 3 or more days/week are recommended. **Conclusions:** A multi-component exercise mainly comprised of resistance and impact exercise seems to be an effective strategy to attenuate the risk factors of osteoporosis and osteopenia. The integration of exercise guidelines and individualized exercise plans has significant potential to reduce the morbidity and mortality of osteoporosis.

Key Words: Accidental falls · Bone density · Exercise · Osteoporosis

INTRODUCTION

Osteoporosis is a common systemic disease characterized by reduced bone mass

Graphical Abstract

Patients

Patients with osteoporosis or osteopenia

Methods

Systematic review
Randomized controlled trial

Intervention

Resistance, impact, balance, aerobic training, and physical activity

Outcome

Improving osteoporosis and fall prevention

Results

Resistance exercise

Free weight   Machines

- Intensity of 50% to 85% 1RM
- 5 to 2 repetitions/set
- 2-3 days/week
- for 3-12 months

Impact exercise

Jump rope   Jump drop

- 50 jumps/set
- 3 or more days/week
- For at least 6 months

Conclusion A multi-component exercise mainly comprised of resistance and impact exercise seems to be an effective strategy to attenuate the risk factors of osteoporosis and osteopenia. The integration of exercise guidelines and individualized exercise plans has significant potential to reduce the morbidity and mortality of osteoporosis.

and deterioration of bone microarchitecture, leading to increased bone fragility and the risk of fractures.[1] Fractures in individuals with low bone mass are commonly caused by falls,[2] which can lead to pain, decreased mobility, and a reduction in both physical and social functional capacity.[3,4] In particular, following hip and vertebral fractures, common in osteoporosis patients, increase the risk of subsequent fractures and mortality.[5-7] Although pharmacological options for improving osteoporosis and fracture prevention are available, non-pharmacological approaches, such as exercise, are required to attenuate bone loss and the risk of falls for a better quality of life and to reduce the healthcare burden.

Several studies and guidelines suggested that regular exercise can effectively preserve or augment bone mineral density (BMD), which is known to reduce the risk of osteoporosis and fall-related fractures.[8,9] In addition, osteogenesis occurs via mechanical stimuli [10] such as the impact on the bone surface or contraction of surrounding muscles.[11] Mechanical stimuli by resistance training, weight-bearing or impact exercises, and balance training are known for their favorable exercise modes to enhance bone health and augment muscle mass and strength, which improves posture balance and stability and reduces the risk

of falls over time for older individuals.[10-14] However, a lack of evidence exists regarding the benefits versus harmfulness or no effects of prescribing those exercises to postmenopausal women,[14] individuals with osteoporosis,[15] or people at moderate to high risk of fractures. Despite clinical practice guidelines for osteoporosis patients recommending exercise as a positive tool to prevent fractures, the efficacy of exercise may vary by type of exercise, study population, or outcomes of interest. In turn, although exercise has been proposed as a potential strategy to manage osteoporosis, there is no consensus on the most promising types of exercise for improving bone mass.

The American College of Sports Medicine (ACSM) has published guidelines for physical activity (PA) and bone health and recommended that healthy adults must perform a jumping exercise, weight-bearing aerobic exercises for at least 3 to 5 days per week, and resistance exercise at moderate to high intensity for 30 to 60 min per day for 2 to 3 days per week to maintain bone health.[16] Although the influence of exercise on bone metabolisms is relatively well-understood, and previous guidelines recommend engagement in exercise for the management of osteoporosis, the effectiveness of exercise for improving osteoporosis and fall prevention in patients diagnosed with osteoporo-

sis or osteopenia has not been summarized. Specifically, uncertainty still exists on whether increasing exercise intensity and volume in osteoporosis patients would improve bone strength and fall prevention, and prominently, which types of exercise intervention or degrees of exercise intensity are most beneficial. In the past, exercise recommendations for individuals with a high risk of osteoporosis were generated by studies with age-matched healthy participants.[17] To date, an increasing number of randomized controlled trials (RCTs) examined the impact of various types of exercise on the subject focusing on osteoporosis patients in the past decade. Integrating the data into evidence-based recommendations is needed both to prevent fracture incidences and rehospitalization due to worsening osteoporosis and to offer orthopedic providers a guideline to help patients navigate the correct information regarding exercise for patients with osteoporosis. Therefore, the Korean Society for Bone and Mineral Research (KSBMR) and the Korean Society of Exercise Physiology (KSEP) exercise guideline seeks to provide evidence-based recommendations to improve bone health and fall prevention in patients with osteoporosis or osteopenia.

METHODS

The guidelines were developed to provide a more systematic approach to exercise for the management of osteoporosis and fall prevention in osteoporosis patients. The KSBMR and KSEP have collaboratively formed a development committee (exercise committee) aimed at establishing exercise guidelines for the management of osteoporosis and fall prevention. The committee is an expert in mul-

tidisciplinary fields and multi-institutional, which consists of exercise physiologists, on-site exercise specialists, physicians, and orthopedic surgeons. Members of the committee were required to contribute to development of guidelines, provide critical reviews, and finalize the exercise guidelines recommendations in consideration of the evidence-based on the pre-selected key questions (KQs) to define the effects of exercise for the final selection of exercise methods. The literature was chosen using a systematic review as described below.

1. Framework for guideline development

The guideline development process consisted of 3 phases: planning, development, and announcing (finalization). [18,19] Briefly, a total of 12 individual steps were applied. The first phase consisted of (1) theme selection; (2) organizing the development committee; (3) review of previously published guidelines; (4) development plan establishment; and (5) the KQs selections. The second phase of the development phase consisted of (6) evidence retrieval; (7) evaluation; and (8) synthesis; (9) formulating recommendations and establishing the recommendations grade; and (10) committee's consensus attaining. Lastly, phase 3, consisted of (11) external review; and (12) publication.

2. Selection of KQs

The committee established the KQs by reviewing the position statement published in USA,[16] Canada,[9] and Australia.[20] Furthermore, the Physical Activity Guidelines for Americans (2nd edition) published by US Centers for Disease Control and Prevention,[21] and numerous position statements in the United Kingdom,[22] Europe,[23]

Table 1. Key questions for determining exercise guidelines to improve osteoporosis and prevention of fall

KQs	
KQ1	Is resistance training an effective strategy for improving osteoporosis and fall prevention?
KQ2	What type of resistance training is effective for improving osteoporosis and fall prevention?
KQ3	Are impact exercises effective for improving osteoporosis and fall prevention?
KQ4	How can impact exercises be effectively applied to improve osteoporosis and fall prevention?
KQ5	Are balance exercises an effective strategy for improving osteoporosis and fall prevention?
KQ6	What is the effective way of applying balance exercises to improve osteoporosis and fall prevention?
KQ7	Are weight-bearing aerobic exercises effective for improving osteoporosis and fall prevention?
KQ8	How can weight-bearing aerobic exercises be effectively applied to improve osteoporosis and fall prevention?
KQ9	Is physical activity effective for improving osteoporosis and fall prevention?
KQ10	What is the effective way of applying physical activities to improve osteoporosis and fall prevention?

KQs, key questions.

and USA [24] were referenced. Based on reviewing other position statements, the committee initially nominated the 13 most pertinent KQs, which account for the domestic situation and clinical significance, and finally listed 10 KQs (Table 1). The exercise method in the KQ included general exercise prescription factors, including frequency, intensity, time, and type (FITT).

3. Literature search

To answer the KQs, an extensive literature search was conducted by using a systematic review of evidence identified through online databases such as the PubMed of the US National Library of Medicine, Embase of Elsevier, KoreaMed of the Korean Association of Medical Journal Editors, and RISS of the Korea Education and Research Information Service. Only data from RCTs published from January 1st, 2000, through August 1st, 2022, were considered. The keywords for the literature search were described in the Supplementary Appendix 1. In the review stage, the committee used the Participants, Intervention, Comparison, Outcomes, Time, Setting, and Study Design (PICOTS-SD) framework to determine the scope of inclusion in the literature for the use of systematic review methods (Supplementary Table 1).[25] Among a million outcomes, duplicate studies

were excluded using the program EndNote (Clarivate Analytics, Philadelphia, PA, USA) and firstly yielded 712,968 relevant articles without duplicates. The initially selected articles were further reduced down to 274 of the most relevant papers, of which 50 were finally selected, excluding non-osteoporotic and osteopenic patients (121 cases), non-evidence based (19 cases), duplication (37 cases), and others (47 cases) (Fig. 1). The finally chosen papers were experimental papers with randomized-controlled trials study design with clear PICOTS-SD, which allowed to provide the evidence-based recommendation about KQs selected by the committee.

4. Quality appraisal (Risk of bias)

The RCTs finally included in the review were further assessed for their quality using the Cochrane Collaboration's tool by measuring the risk of bias from the 2 independent reviewers.[25] Any conflicts were discussed between review authors and then confirmed and finalized. The quality items were the following: (1) potential randomization process bias; (2) deviations from intended interventions bias; (3) missing outcome data bias; (4) outcome measurement bias; and (5) selecting the reported result bias.[25] The review authors rated each entry as "low risk," "high risk," or "unclear
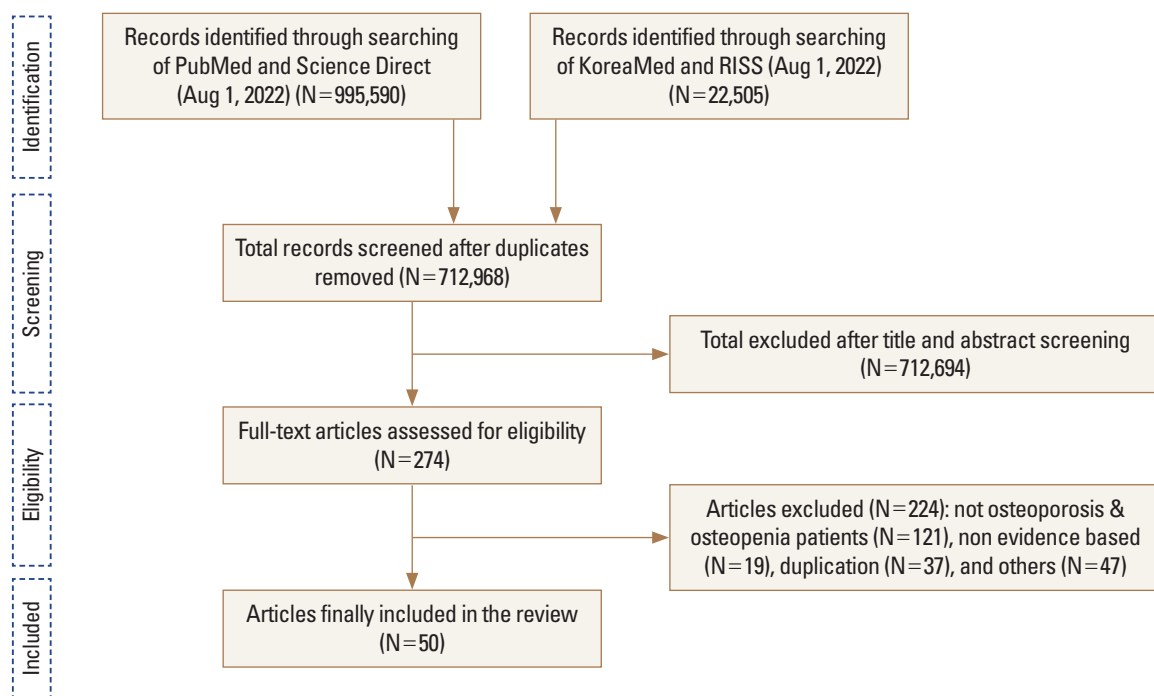

Fig. 1. Flowchart of the systematic literature searching, screening, and selection process for the development of exercise guideline.

risk." Supplementary Figures 1 and 2 show the results of the risk of bias assessment for each study according to the domain. Overall, the general risk of bias was low to moderate in the included studies.

5. Procedures for conclusive selection and formulation of guidelines

Following the review of the evidence from the conclusively selected works of literature, the committee reviewed the capability to apply the guideline for each KQ by summarizing the contents of the selected evidence as a response to the KQ. The comments from the committee members were subsequently collected and completed the recommendation. Based on the applicability review, ratings for the type of evidence, the strength of evidence, and the grade of recommendations were provided. The rate of evidence was categorized into 4 levels (Supplementary Table 2), and the recommendation grade was established according to the committee's consensus with the principle of 80% or more (Supplementary Table 3).

RESULTS

1. KQ1. Is resistance training an effective strategy for improving osteoporosis and fall prevention?

Resistance training has been recognized as an effective method to improve bone health by avoiding decreases in BMD over time for individuals with osteoporosis or osteopenia (Table 2). Liu-Ambrose et al. [26] reported significantly increased cortical bone density at the radial shaft among 75- to 85-year-old women with diagnosed osteoporosis or osteopenia who performed 6 months of resistance training. Mosti et al. [27] also showed that 3 months of squat exercise using a machine in postmenopausal women with osteoporosis or osteopenia significantly increased bone mineral content (BMC) at the lumbar spine and femoral neck by approximately 2.9% to 4.9%. Furthermore, de Matos et al. [28] evaluated the effects of resistance training using machines and free weights on BMD of postmenopausal women with osteoporosis or osteopenia, thereby non-exercising women exhibited a significant percentage decrease

Table 2. Randomized controlled trial of resistance training in age-associated osteoporosis or osteopenia

References	Year	Participants	Groups	Exercise details (FITT)	Main findings
de Matos et al. [28]	2009	Postmenopausal women with osteoporosis or osteopenia (N=59)	A: intervention/ B: control	For 12 months, 2 times/wk, 2 sets (1st set of 5–10 repetitions; 2nd set of 10–18 repetitions), weight exercises using either machines or free weights	A: lumbar spine BMD ↔[c]/B: lumbar spine BMD ↓[b]
Mosti et al. [27]	2013	Postmenopausal women with osteoporosis or osteopenia (N=16)	A: intervention/ B: control	For 12 weeks, 3 times/wk, 6 sets (2 sets of 8–12 repetitions at 50% 1RM and 4 sets of 3–5 repetitions at 85–90% 1RM), squat exercise machine	A: lumbar spine (2.9%) and femoral neck BMC (4.9%) ↑[a]
Liu-Ambrose et al. [26]	2004	Postmenopausal women with osteoporosis or osteopenia (N=104)	A: resistance/ B: agility/ C: stretching	All groups: For 6 months, 50 min/day, 2 times/wk / A: initially set at 50–60% 1RM at 2 weeks, with 2 sets of 10–15 repetitions, progressing to 75–85% 1RM with 6–8 repetitions (2 sets) by 4 weeks, pressurized air system and free weights / B: ball games, relay races, dance movement, and obstacle courses / C: stretching exercise, deep breathing and relaxation techniques, general posture education	A: cortical bone density ↑[a] (vs. B, C) / B: cortical bone density ↑[a] (vs. C)/ all groups: other bone outcome (by DXA or pQCT) ↔[c]
Borba-Pinheiro et el. [35]	2016	Postmenopausal women with low BMD T-score <-1.0 (N=52)	A: resistance training 3 times/wk/ B: resistance training 2 times/wk	For 13 months, 60 min, 2 sets per exercise 10 repetitions at 60–90%, leg press at 45°, knee extension, plantar flexion, squats, hip adduction, glutes (machine for glutes), elbow flexion, elbow extension, and shoulder adduction	A: lumbar spine L2–4 (0.07%), neck of femur (0.12%), trochanter (0.09%), total femur (0.12%), total BMD (0.10%) ↑[a]

[a] ↑=significantly increased or higher.
[b] ↓=significantly decreased or lower.
[c] ↔=no significant difference (pre/post or vs. control).
BMD, bone mineral density; FITT, frequency, intensity, time, and type; 1RM, 1-repetition maximum; BMC, bone mineral content; DXA, dual energy X-ray absorptiometry; pQCT, peripheral quantitative computed tomography.

in BMD at the lumbar spine, while lumbar spine BMD maintained in the group of 12 months of weight training intervention. Similar findings were observed in older men with osteoporosis or osteopenia utilizing high-intensity resistance training.[29,30] Based on the results of the studies outlined in Table 2, resistance training might be protective against further reductions in bone mass and plays a beneficial role in reducing osteoporosis-related fracture risk among those already diagnosed with osteoporosis or osteopenia.

2. KQ2. What type of resistance training is effective for improving osteoporosis and fall prevention?

To attain the maximal benefits of resistance training in individuals with osteoporosis or osteopenia, careful manipulation of training variables, such as intensity, volume, and frequency, is required.[31] Traditional resistance training recommendations suggest an intensity of below 60% 1-repetition maximum (1RM) in older healthy adults to improve muscular function.[32] However, as shown in Table 2 in the articles with osteoporosis patients, participants initially performed 2 sets of 10 to 12 repetitions at 50% 1RM as a warm-up and gradually progressed to 85% of 1RM at 5 to 8 repetitions based on the patient's condition.[26,27, 29,31,33] Concerning resistance training intensity, the ma-

jority of studies indicate that exercises generating high-intensity loading forces (70%–90% 1RM) are more effective for increasing BMD among postmenopausal women.[12] The number of training sessions in a given period can also determine the training benefits and recovery from acute exercise, especially in the older population.[34] For instance, Borba-Pinheiro et al. [35] reported that resistance exercise 3 times a week among postmenopausal women with low BMD showed better results for all BMD variables than twice a week when exercise type, intensity, and time were identical. Therefore, 3 times a week is recommended as a time-efficient resistance training strategy to prevent age-related bone loss and falls. However, resistance training frequency should be considered in conjunction with training volume, as training volume can determine the recovery required after vigorous training.[34]

3. KQ3. Are impact exercises effective for improving osteoporosis and fall prevention?

Several studies suggested that mechanical loading induced by exercise training has a positive effect on the skeleton by generating an optimal stimulus.[36] Although few studies confirmed the effect of impact exercise alone in osteoporosis patients, several studies have reported the effect of improving BMD, fall risk, and functional fitness in

Table 3. Randomized controlled trial studies of impact exercise in age-associated osteoporosis or osteopenia

References	Year	Participants	Groups	Exercise details (FITT)	Main findings
Basat et al. [37]	2013	Women with osteopenia (N=42)	A: high-impact exercise/ B: strengthening exercise/ C: control	Total 6 months, 3 times/wk/ A: 30-40 min/session, 1 set/10 repetition for 5 strengthening exercise/ B: 10 min/session, jump rope 10 jumps/day to 50 jumps/day	A: BMD at the lumbar spine and femoral neck (P=0.013) ↑[a], serum OC ↑[a], NTx ↓[b], HRQoL ↑[a]/ B: HRQoL ↑[a]
Kistler-Fischbacher et al. [44]	2021	Women with osteoporosis or osteopenia (N=115)	A: exercise+medicine/ B: low-intensity, pilates-based training+ medicine/ C: low-intensity, pilates-based training	Total 8 months, 2 times/wk, 40-min exercise: 5 sets of 5 repetitions, >80% to 85% 1RM, 3 free-weight resistance training exercises (deadlift, back squat, overhead press), 1 high-impact exercise (jump drop), and two balance exercises	A: BMD (lumbar spine) ↑[a], functional performance ↑[a], fracture risk factor ↓[b]
Hettchen et al. [38]	2021	Women with osteopenia or osteoporosis (N=54)	A: high-impact weight-bearing, high-intensity, velocity resistance exercise/ B: low-intensity exercise	A: total 8 months, 3 times/wk/ B: total 8 months, 1 time/wk	A: BMD (lumbar spine) ↑[a], lean body mass ↑[a], hip/leg extension strength and power ↑[a]
Multanen et al. [43]	2017	Women with osteoporosis (N=80)	A: 1) aerobic and 2) step-aerobic jumping exercise programs/ B: control	Total 12 months, 3 times/wk, 55 min/session	A: femoral neck strength ↑[a]

[a]↑=significantly increased or higher.
[b]↓=significantly decreased or lower.
FITT, frequency, intensity, time, and type; 1RM, 1-repetition maximum; BMD, bone mineral density; OC, osteocalcin; NTx, N-terminal telopeptide of collagen type I; HRQoL, health-related quality of life.

osteoporosis through impact exercise combined with resistance training (Table 3). For example, a study by Basat et al. [37] showed that 6-month high-impact exercise training significantly increased BMD due to increased bone formation marker and decreased bone resorption marker compared to the strengthening exercise and control groups in postmenopausal women with osteopenia. Impact exercise training combined with resistance training for 8-month increased BMD, functional performance, and muscle strength, but BMD didn't change when the duration was less than 8-month.[31,33,38-41] Additionally, 12-month aerobic plus impact exercise intervention showed higher femoral neck strength and BMC than a group with usual activities.[42,43] Therefore, the aggregated data suggest that impact exercise training can be an effective method to prevent bone loss in older women.

4. KQ4. How can impact exercises be effectively applied to improve osteoporosis and fall prevention?

Although impact exercise training has been understood as an effective way to improve BMD and fracture risk in women with osteoporosis, an accurate FITT for impact exercise has not been presented. As shown in Table 3, the intervention with impact exercise, especially jumping exercises such as jump rope, jump drop, and jumping chin-ups with drop landing, were applied to women with osteopenia or osteo-

porosis with a duration varying from 6- to 12- months. Most studies suggest that performing impact exercise at least 2 to 3 times a week improves BMD. The intervention consisting of only impact exercise training for 6 months was sufficient to change BMD, while longer than eight months was required when impact exercise training combined with resistance or aerobic exercise to generate similar outcomes. Given the totality of the previous outcomes, impact exercise training with suitable exercise duration is a powerful exercise regimen to improve bone health in patients with osteoporosis.[33,37,38,42-44]

5. KQ5. Are balance exercises an effective strategy for improving osteoporosis and fall prevention?

In individuals with osteoporosis or osteopenia, strategies to prevent falls and fall-related fractures are even more essential than in healthy individuals. As stated above section, older women with osteoporosis show decreased balance and muscle strength, which causes a higher risk of falling, and further increased fracture risks compared to age-matched individuals.[7] Several reports have suggested the effects of balance exercises on osteoporosis and fall prevention (Table 4). For example, the balance training for 12 months improved functional balance and decreased the number of fall incidences in patients with osteoporosis.[45,46] A relatively short period (5.5 or 12 weeks) of combined exer-

Table 4. Randomized controlled trial of balance training in age-associated osteoporosis or osteopenia

References	Year	Participants	Groups	Exercise details (FITT)	Main findings
Madureira et al. [45]	2010	Osteoporosis (N=66)	A: intervention/ B: control	A: 48 weeks, 60 min/day for once a week, balance training/ B: instructions to prevent falls	Falls in A ↓, functional balance in A ↑, quality of life in A ↑
Mikó et al. [46]	2017	Osteoporosis (N=100)	A: intervention/ B: control	48 weeks, 30 min/day for 2 time a week, balance training	Number of falls in A ↓, Berg Balance Scale in A ↑, time up and go test in A ↑, balance tests using stabilometer in A ↑
Smulders et al. [47]	2010	Osteoporosis (N=96)	A: intervention/ B: control	5.5 weeks, 15-90 min/day for once a week, obstacle course, walking exercises, weight-bearing exercises, correction of gait abnormalities, and training in fall techniques	Fall rate in A 39% ↓, balance confidence in A 13.9% ↑, lower back BMD in A ↑, hip BMD in A ↑, activity level ↔, quality of life ↔
Liu-Ambrose et al. [48]	2004	Osteopenia (N=98)	A: resistance/ B: agility/ C: control	A: 25 weeks, 50 min/day for 2 time a week, 50–60% of 1RM with a work range of 2 sets of 10–15 repetitions and progressed to 75–85% of 1RM at a work range of 6–8 repetitions (2 sets) by week 4, resistance training / B: 24 weeks, 50 min/day for 2 time a week, agility training	Fall risk in A (57.3%) and B (47.5%) ↓, postural stability in A (30.6%) and B (29.2%) ↑

a) ↑ =significantly increased or higher.
b) ↓ =significantly decreased or lower.
c) ↔ =no significant difference (pre/post or vs. control).
FITT, frequency, intensity, time, and type; 1RM, 1-repetition maximum; BMD, bone mineral density.

cise, including weight-bearing and walking exercise, has shown decreased fall rates in patients with osteoporosis after the intervention.[47] In older women with osteopenia, resistance exercise and agility training for 50 min per day, 2 days a week for 24 to 25 weeks, reduced the risk of falling.[48] Overall, RCTs confirmed that the improved postural balance following exercise training could reduce the risk of fractures by enhancing postural stability and diminishing the risk of falls in older women with osteoporosis. [49-51] Therefore, both balance training sole and combined exercise that includes balance training are associated with a significantly reduced frequency of falls in osteoporotic patients.

6. KQ6. What is the effective way of applying balance exercises to improve osteoporosis and fall prevention?

As shown in Table 4, the intervention in osteoporotic patients with balance training for 30 to 60 min per day at least 1 to 2 days per week for 48 weeks resulted in a reduced risk of falls and functional balance.[45,46] Balance training should progressively proceed from easy to demanding exercise as the physiological strength of training increases over time. Combined exercise programs, including weight-bearing exercise, walking exercise on an obstacle course, and correction of gait abnormalities with 15 to 90 min per day, once a week for 5.5 weeks, have shown decreased fall rates and increased BMD.[47] Also, an intervention study of a 10-week

(60 min per day for 2 days a week) combined strength and balance training program reported improved static and dynamic balance.[49] The strength training and aerobic exercise program for 24 weeks with 60 min per day, 3 times a week improved postural sway and walking ability.[51] However, the effects of balance training on the risk of falls should be carefully interpreted since the effectiveness of this intervention has been demonstrated when it is combined with other types of exercise, such as strength, weight-bearing, and aerobic exercise.

7. KQ7. Are weight-bearing aerobic exercises effective for improving osteoporosis and fall prevention?

Weight-bearing aerobic exercise refers to a form of aerobic exercise performed mainly using the lower extremities while moving bones and muscles against one's weight gravity. A representative form of weight-bearing aerobic exercise is walking, jogging, stair climbing, dancing, volleyball, tennis, and Tai Chi.[52] Studies on osteoporosis patients also reported that an exercise program in combination with aerobic and anaerobic exercise was positive for improving BMD and bone metabolic biomarkers (Table 5).[53-56] In particular, a study by Chien et al. [53] showed the improved BMD of the femoral neck in osteoporosis patients who performed both treadmill and stepping exercises. Taken together, a walking exercise could be the most simple and self-manageable way of preventing osteoporosis fractures, at least

Table 5. Randomized controlled trial of weight-bearing aerobic exercise age-associated osteoporosis or osteopenia

References	Year	Participants	Groups	Exercise details (FITT)	Main findings
Chien et al. [53]	2000	Women with osteopenic postmenopausal (N=43)	A: exercise/ B: control	24 week/ 3 day per week. Aerobic program (treadmill walking)+stepping exercise (20-cm high bench)/ A: 30 min, main trainning VO_{2max} (70–85%)/ B: 10 min, speed of 96 beats/min	A: femoral neck BMD ↑[a]/ B: spine (L2-4) BMD ↓[b]
Roghani et al. [55]	2013	Women with osteoporosis postmenopausal (N=36)	A: exercise/ B: control	6 week/ 3 day per week. Treadmill walking. 0–2 week: 50% HRR, WV 4%. 2–4 week: 55% HRR, WV 6%. 4–6 week 60% HRR, WV 8%	EG/EG (vest): BALP ↑[a], EG/EG (vest): NTX ↓[b]
Wen et al. [56]	2017	Women with low bone mass postmenopausal (N=48)	A: exercise/ B: control	10 week/ 3 day per week. Group-based step aerobics (120–126 beats/min). HR 75–85%	CTX ↓[b] (EG=−13.1±24.4% vs. CG=11.0±51.5%)
Jee et al. [54]	2003	Women with osteoporosis (N=34)	A: exercise/ B: control	1 year/ 5 day per week. Combined aerobic exercise (cycling, treadmill walking) and weight-bearing. Aerobic exercise: VO_{2peak} (60–70%), 40–60 min. Weight-bearing: 40–60% RM, 10 reps×2 sets, 15 reps×2 sets, 12 reps×2 sets	Total BMD ↑[a]

[a]↑=significantly increased or higher.
[b]↓=significantly decreased or lower.
FITT, frequency, intensity, time, and type; VO_{2max}, maximal oxygen consumption; HRR, heart rate recovery; WV, weighted-vest; HR, heart rate; VO_{2peak}, peak oxygen uptake; RM, repetition maximum; BMD, bone mineral density; EG, exercise group; CTX, C-terminal telopeptide; CG, control group.

in terms of bone mass and BMD maintenance. However, since the effect of improving bone density may be limited only by walking exercise, it will be a more effective strategy for bone health if combined with impact exercise or resistance training.

8. KQ8. How can weight-bearing aerobic exercises be effectively applied to improve osteoporosis and fall prevention?

Most studies with weight-bearing aerobic exercise have been conducted with combined exercise, mainly treadmill walking, cycling, and resistance training. In a study by Chien et al. [53], walking exercise at moderate to the vigorous intensity combined with step exercise 3 times a week for 24 weeks caused a significant increase in femoral neck BMD. Two studies also revealed that combined exercise (cycling or treadmill walking + weight training) 5 times a week for a year increased total BMD,[54] pelvic, spine, and trunk BMD. [57] However, similar studies with relatively short duration (6-12 weeks) did not show beneficial effects in BMD, whereas the specific markers of bone formation include bone specific alkaline phosphatase, irisin, and osteocalcin were significantly increased, while the marker of bone resorption such as N-terminal telopeptide of collagen type I and C-terminal telopeptide were decreased.[55,56,58] Further-

more, weight-bearing aerobic exercise with weighted vests, even for 6 weeks, was effective in improving bone metabolic markers.[55] We also recommend outdoor exercise at a moderate intensity of the rate of perceived exertion (RPE) 11 to 14 or 40% to 60% of the maximum heart rate for 30 min a day, at least 3 times a week.

9. KQ9. Are PA effective for improving osteoporosis and fall prevention?

It has long been known that various PA including Tai Chi, dance, and yoga help bone regeneration, development, and positively associated with higher BMD. Some studies have reported the effects of fracture prevention through PA (Table 6). Multiple types of PA with vitamin D supplementation in osteoporosis patients have shown improved physical performance, including standing balance, 4 m walking, and grip strength after 6 month and 12 months.[59] Also, lumbar vertebral BMD was significantly increased, while the risk of fall was reduced at 12 months.[59] A mind-body PA for 9 months showed increased femoral neck BMD and upregulated serum bone formation marker osteocalcin. Moreover, self-reported physical quality was improved, while there was no change in overall balance.[60] Postmenopausal women with regular PA for 1 year showed increased proximal femur BMD and physical performance.[61] Taekwon-

Table 6. Randomized controlled trial studies of physical activity studies in age-associated osteoporosis or osteopenia

References	Year	Participants	Groups	Exercise details (FITT)	Main findings
Feng et al. [59]	2021	420 aged male and female with diagnosed osteoporosis	A: dynamic flamingo/ B: Tai Chi/ C: walking	A: 1 min/day for 3 days/wk/ B: 10 min/day/ C: 30 min/day for 12 months	Physical performance ↑[a], lumbar spine BMD ↑[a], risk of fall ↓[b] with PAs
Wayne et al. [60]	2012	86 postmenopausal women with diagnosed osteopenia	A: Tai Chi/ B: control	9 month of program, 1 class/wk for 1 hr followed by practice 3 times/wk for 30 min	FN BMD ↑[a] A>B, OC ↑[a] A>B, physical quality ↑[a] A>B, no change in balance
Young et al. [61]	2007	45 healthy postmenopausal women	A: line dance only/ B: line dance with loaded squats/ C: line dance with loaded squats and foot stamp	A: 1 class/wk for 45 min/ B: A+loaded squats for 2 sets of 8 reps/day, 5 times/wk/ C: B+foot stamp for twice/day, 5 times/wk for a 12 months	PF BMD ↑[a] C>B>A, the number of squats ↑[a] C>B>A
Jung et al. [62]	2017	16 osteosarcopenic obesity	A: Taekwondo training with music and resistance training/ B: none	16 wk/3 day per week. Taekwondo training with music, kicking, punching, blocking, stepping and resistance training. Taekwondo training: 20 min, 40–60% HRR, RPE 11–14. Resistance training: 20 min, 12–15 reps, 3 sets, Thera-band, RPE 11–14	Lumbar BMD ↑[a]

[a]↑=significantly increased or higher.
[b]↓=significantly decreased or lower.
FITT, frequency, intensity, time, and type; HRR, heart rate recovery; RPE, rate of perceived exertion; PAs, physical activities; BMD, bone mineral density; FN, femoral neck; OC, osteocalcin; PF, proximal femur.

do training with music and resistance training was effective in improving lumbar BMD.[62] Therefore, it is plausible that regular PA presents indirect evidence that bone density reduction due to aging or osteopenia can be alleviated and fracture can be prevented.

10. KQ10. What is the effective way of applying PA to improve osteoporosis and fall prevention?

An important question that remains to be further identified is which type of PA positively regulate bone metabolism, BMD, and further prevent risk of fall. In age-associated osteoporosis and osteopenia, various types of PA have been explored including Tai Chi, engaging social activity, line dancing with a combination of foot stamping activity, and Taekwondo training with kicking, stepping.[59-62] The importance of these types of PA in the BMD and fall-related fracture in osteoporosis or osteopenia were described where regular PA at least 6 months at least maintain bone mass and BMD, and additional loading and strain confer the larger positive effects on BMD and physical strength. It is shown that any PA can maintain or increase bone density to some extent, but the anabolic activity of the bone appears to be activated when additional loads or even a little more force are applied in addition to the basic activity.[63] Therefore, our aggregate review suggest that regular PA would be the effective method to maintain BMD and prevent fall-related fracture in patients with osteoporosis and osteopenia, but it could be strengthened particularly in concert with an extra resistance and light impact that may reduce musculoskeletal deficits.

DISCUSSION

The primary goal of establishing the exercise guideline is to provide evidence-based recommendations to improve BMD and fall prevention in patients diagnosed or undergoing treatment with osteoporosis or osteopenia. Most importantly, this guideline is the first to demonstrate specifically the methods and effects of various exercises on the osteoporosis care trajectory in Korea. The guideline showed the effects of exercise based on the criteria of evidence level and the grade of recommendation by selecting effective exercise methods. Table 7 summarized the finalized exercise guideline based on FITT for improving osteoporosis and fall prevention in individuals diagnosed with osteoporosis or osteopenia.

This guideline recommends that resistance training and impact exercise appear to be more effective for improving bone mass and preventing the risk of falls, with the highest level of evidence and grade of recommendations. The committee's review of the evidence suggests that a resistance training program is effective for older adults who are diagnosed with osteoporosis or osteopenia when they performed at least 2 or 3 times a week, with one set of 5 to 12 repetitions by a combination of free- and machine-weight including 3 to 10 exercise in major muscle groups at 50% to 85% 1RM for 3 to 12 months (Evidence level: I / Grade of recommendation: A). However, in clinical practice, a careful evaluation must precede the exercise prescription in patients with osteoporosis and older adults, thus, it is indispensable to identify the individualized type, intensity, and duration of a proposed exercise program. In general, the ACSM guidelines recommend that older adults perform re-

Table 7. Exercise guidelines based on frequency, intensity, time, and type for improving osteoporosis and fall prevention

Modality	Frequency	Intensity	Time	Type	Evidence	Grade
Resistance training	$\geq$2–3 days · week^{-1}: 5–12 repetition · set^{-1}	$\geq$50% 1RM (intensity starts at 50% 1RM and progresses to 85% 1RM)	2–5 set · region^{-1}	Resistance exercise by combination of free weights and machines, including $\geq$3 major muscles	I	A
Impact exercise	$\geq$2-3 days · week^{-1}	-	10-50 jumps/session	Jump drop, jumping chin-ups with drop landings and jump rope, etc. $\geq$6 months	I	A
Balance training	$\geq$1-3 days · week^{-1}	-	$\geq$15 min/day	Dynamic and static balance	II	B
Weight-bearing aerobic exercise	$\geq$3 days · week^{-1}	RPE 11–14, 40–60% HRR, 3–6 METs	$\geq$20 min · day^{-1}	Weight-bearing aerobic exercise by walking, cycling, stepping, climbing, climbing the stair, etc.	II	B
Physical activity	$\geq$2-5 days · week^{-1}	-	10–60 min · day^{-1}	Tai Chi, dynamic flamingo exercise, line dance, foot stamps, etc. $\geq$6 months	II	B

1RM, 1-repetition maximum; RPE, rate of perceived exertion; HRR, heart rate recovery; METs, metabolic equivalent of tasks.

sistance training on at least 2 non-consecutive days each week, with one set of 10 to 15 repetitions for 8 to 10 exercises involving all the major muscle groups at 50% to 60% of the 1RM. In addition, very deconditioned older adults, such as osteoporotic patients, could start resistance training with a "very light" to "light" intensity (40%–50% 1RM) to increase strength, power, and balance.[32] Resistance training is an exercise that improves muscular strength and endurance by contracting a specific muscle or muscle group against external resistance, including free weights, weight machines, and bodyweight exercises such as push-ups or squats. The ACSM now recognizes that resistance training also has a positive effect on bone health across the age spectrum.[32] Moreover, the majority of evidence indicates that resistance training has positive impacts on bone mass in those already diagnosed with osteoporosis or osteopenia by markedly inhibiting aging-associated bone loss, or rather achieving dramatic increases in bone mass.[26-31,33] Likewise, the preponderance of evidence suggests that resistance training may reduce the risk of fracture not only by improving bone parameters but also by preventing falls in older adults. Therefore, resistance training that induces high levels of mechanical strain by making muscles work against a weight or force is expected to prevent age-related bone loss and falls in those already diagnosed with osteoporosis or osteopenia, and it should be recommended for those populations.[48]

The guideline also recommended the impact exercise for at least 6 months with 3 or more days per week, and start at ten jumps and progressing to 50 jumps per session (I/A). For example, Australian guidelines recommended that impact exercise with 50 jumps per set for 3 to 5 sets and 10 to 20 repetitions with 1 to 2 min rest between sets for 4 to 7 days per week would improve bone health.[20] They recommended high-intensity (>4 times body weight) impact exercise for those without osteoporosis but 2 to 4 times body weight for those at moderate risk of osteoporosis. According to a recent consensus from the UK Expert Exercise Steering Group (EESG), moderate- to high-intensity impact exercise including jumping, hopping, running, and Scottish dance or Zumba with a minimum of 50 impacts per session while avoiding landing from a height.[64] Likewise, our guideline recommended that individuals with osteoporosis should undertake resistance training and impact exercise to maximize bone strength. In practice, all

muscle groups, including the back muscles, should be targeted to improve bone strength in the spine. Also, the patients with osteoporotic conditions are required to start with low-intensity exercises ensuring good technique and a maximum of 8 to 12 lifts to build up to 3 sets for each exercise.[63] Furthermore, the combination of progressive resistance and impact exercise best promotes bone strength based on evidence similar to the other national guidance. [63]

Our guidelines also proposed an intermediate level of evidence and less strong recommendations for weight-bearing aerobic exercise, PA, and balance training in individuals with osteoporosis. Balance training should include several exercise stimuli, including dynamic and static balance with gradual increases in the intensity, such as tandem foot standing, multi-directional weight lifts, heel-toe walking, line walking, standing on one leg for at least 6 months with 1 to 3 or more day per week for more than 15 min per day (II /B). Although less strongly recommended, weight-bearing aerobic exercise more than 3 times per week, with 20 or more min per day (II /B), could be more welcoming for many people than resistance exercise since it does not necessarily require special facilities or equipment. The ACSM suggests that carrying out simple weight-bearing endurance activities, such as stair climbing, jogging, and tennis, which include motion with sufficient gravitational or mechanical load and possibly in combination with other types of exercise during adulthood, are recommended for bone health.[32] Our guideline recommended that the patients with osteoporosis perform the weight-bearing exercise intensity at least in RPE of 11 to 14 on the Borg scale, an alternative method for prescribing exercise intensity, or 40% to 60% of heart rate reserve or 3 to 6 metabolic equivalents to generate positive outcomes. Moreover, the proper frequency, intensity, and time are dependent on the type of PA (Tai chi, dynamic flamingo, line dance, foot stamps, etc.), but PA at least 2 to 5 days a week, 10 to 60 min a day for more than 6 months is recommended (II/B). The SIOM-MS guides recommend performing a minimum of PA, such as walking, for 30 min every day, despite the lack of available evidence.[65] PA such as Tai Chi and dance may be of benefit to individuals with low bone density because of their positive effect on fall risk and postural control, suggesting that in combination with its modest effects of BMD, PA is a potentially valuable intervention for prevention of

falls and fall-related fractures in postmenopausal osteopenic women.[60,61] The consensus was that PA that improve balance and muscle strength, including Tai Chi, dance, and yoga could be conducted, at least twice a week in line with PA guidance.[64]

Although the effect of exercise on BMD is modest, a meta-analysis concluded that improvement in the lumbar spine and femoral neck BMD with exercise reduces the risk of osteoporotic fractures by approximately 10%.[66] Additionally, since about 95% of hip fractures are caused by falls, fall prevention by improving postural balance may be more important than the effect of exercise on BMD in terms of fracture. As impaired balance was a significant contributor to falls in the older generation,[67] the enhanced postural balance could reduce the risk of fractures by improving postural stability and mobility and diminishing the risk of falls. [68] Balance training was revealed to effectively prevent falls and improve the quality of life in the older adults.[45, 69] The most effective fall-prevention exercise programs have yet to be clarified, but programs targeting strength and balance appear particularly effective.[65] Strength and balance training is recommended that is individualized, supervised by an exercise professional, and conducted for 3 hr per week over at least 4 months, in line with previous evidence.[70] A combination of balance exercises and other weight-bearing exercises may also be necessary to prevent age-related bone loss and falls in older individuals with low bone mass. This guideline recommended strength and balance training to reduce fall incidence and enhance physical function based on evidence. Previous studies found that a short duration of resistance and balance training improved strength, balance function, and fear of falling, which may reduce fall risk and increase confidence to remain active. [71] However, considering that older people have been diagnosed with osteoporosis or osteopenia, it is also effective to apply an additional load on light PA to eliminate the possibility of fractures accompanied by exercise in terms of safety. For this reason, several studies have recently published alternatives that have similar effects of exercise, such as whole-body vibration (WBV). In general, WBV in multiple settings showed increased lumbar spinal and femoral BMD and improved bone remodeling activities in the osteoporosis and osteopenia population.[40,72,73] However, it is complex to define WBV as a PA that can replace exercise.

The schematic image of the exercise guidelines to improve osteoporosis and prevention of fall is shown in Figure 2.

The key recommendations in this guideline are that individuals with osteoporosis or osteopenia should undertake resistance and impact exercise to maximize bone strength. It is recommended that resistance training should be performed 2 or 3 times a week, with one set of 5 to 12 repetitions by a combination of free weights and machines, including 3 to 10 exercises in major muscle groups at 50% to 85% 1RM for 3 to 12 months. Impact exercise is recommended to include jump drop, jumping chin-ups with drop landings, and jump rope with 50 jumps per session for at least 6 months, with 3 or more days per week. Moreover, weight-bearing aerobic exercise, balance training, and habitual PA
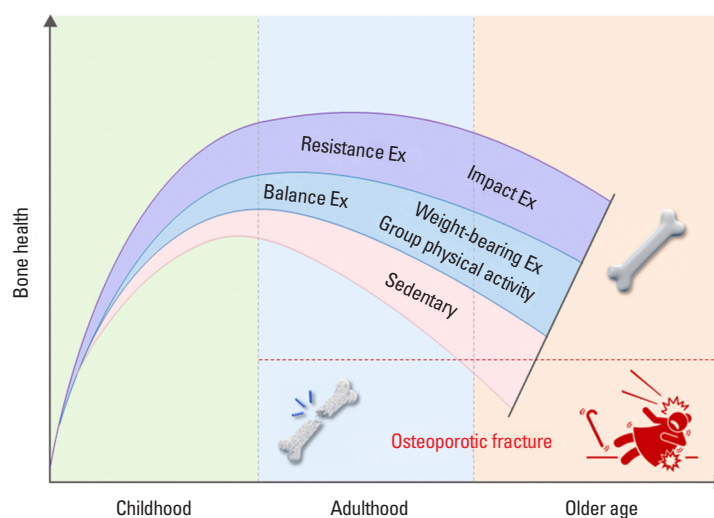

Fig. 2. Exercise guidelines to improve osteoporosis and prevention of fall for individuals with osteoporosis or osteopenia.

prevent further bone loss, maintain or improve BMD and reduce the risk of falls in the individual with osteoporosis and osteopenia. While it is evident that resistance and impact exercise or combinations of those 2 exercise programs influence both BMD and fracture prevention, it is believed that exercise prescriptions must fully consider the individual's health status and characteristics.

DECLARATIONS

Ethics approval and consent to participate
Not applicable.

Conflict of interest
No potential conflict of interest relevant to this article was reported.

ORCID
Seongryu Bae   *https://orcid.org/0000-0001-8185-1015*
Seungyong Lee   *https://orcid.org/0000-0002-5397-6889*
Hyuntae Park   *https://orcid.org/0000-0002-1976-0005*
Yongin Ju   *https://orcid.org/0000-0001-8653-7623*
Seok-Ki Min   *https://orcid.org/0000-0003-3134-9689*
Jinkyung Cho   *https://orcid.org/0000-0002-4500-3622*
Hyojin Kim   *https://orcid.org/0000-0001-9676-6462*
Yong-Chan Ha   *https://orcid.org/0000-0002-6249-0581*
Yumie Rhee   *https://orcid.org/0000-0003-4227-5638*
Young-Pyo Kim   *https://orcid.org/0000-0001-6662-1393*
Changsun Kim   *https://orcid.org/0000-0003-4317-3609*

REFERENCES

1. Eschard JP. Nursing care. Diagnosis and treatment of osteoporosis in the elderly. Soins Gerontol 2001;31:17-21.
2. Tromp AM, Pluijm SM, Smit JH, et al. Fall-risk screening test: a prospective study on predictors for falls in community-dwelling elderly. J Clin Epidemiol 2001;54:837-44. https://doi.org/10.1016/s0895-4356(01)00349-3.
3. Bliuc D, Nguyen ND, Milch VE, et al. Mortality risk associated with low-trauma osteoporotic fracture and subsequent fracture in men and women. JAMA 2009;301:513-21. https://doi.org/10.1001/jama.2009.50.
4. Klop C, Welsing PM, Cooper C, et al. Mortality in British hip fracture patients, 2000-2010: A population-based retrospective cohort study. Bone 2014;66:171-7. https://doi.org/10.1016/j.bone.2014.06.011.
5. Cauley JA, Thompson DE, Ensrud KC, et al. Risk of mortality following clinical fractures. Osteoporos Int 2000;11:556-61. https://doi.org/10.1007/s001980070075.
6. Lindsay R, Silverman SL, Cooper C, et al. Risk of new vertebral fracture in the year following a fracture. JAMA 2001;285:320-3. https://doi.org/10.1001/jama.285.3.320.
7. Liu-Ambrose T, Eng JJ, Khan KM, et al. Older women with osteoporosis have increased postural sway and weaker quadriceps strength than counterparts with normal bone mass: overlooked determinants of fracture risk? J Gerontol A Biol Sci Med Sci 2003;58:M862-6. https://doi.org/10.1093/gerona/58.9.m862.
8. Bonaiuti D, Shea B, Iovine R, et al. Exercise for preventing and treating osteoporosis in postmenopausal women. Cochrane Database Syst Rev 2002;3:CD000333. https://doi.org/10.1002/14651858.Cd000333.
9. Giangregorio LM, Papaioannou A, Macintyre NJ, et al. Too fit to fracture: Exercise recommendations for individuals with osteoporosis or osteoporotic vertebral fracture. Osteoporos Int 2014;25:821-35. https://doi.org/10.1007/s00198-013-2523-2.
10. Turner CH, Robling AG. Exercises for improving bone strength. Br J Sports Med 2005;39:188-9. https://doi.org/10.1136/bjsm.2004.016923.
11. Kohrt WM, Barry DW, Schwartz RS. Muscle forces or gravity: What predominates mechanical loading on bone? Med Sci Sports Exerc 2009;41:2050-5. https://doi.org/10.1249/MSS.0b013e3181a8c717.
12. Martyn-St James M, Carroll S. Effects of different impact exercise modalities on bone mineral density in premenopausal women: a meta-analysis. J Bone Miner Metab 2010;28:251-67. https://doi.org/10.1007/s00774-009-0139-6.
13. Vuori I, Heinonen A, Sievänen H, et al. Effects of unilateral strength training and detraining on bone mineral density and content in young women: a study of mechanical loading and deloading on human bones. Calcif Tissue Int 1994;55:59-67. https://doi.org/10.1007/bf00310170.
14. Zhao R, Zhao M, Xu Z. The effects of differing resistance training modes on the preservation of bone mineral density in postmenopausal women: a meta-analysis. Osteoporos Int 2015;26:1605-18. https://doi.org/10.1007/s00198-015-3034-0.
15. Nowalk MP, Prendergast JM, Bayles CM, et al. A randomized trial of exercise programs among older individuals

living in two long-term care facilities: the FallsFREE program. J Am Geriatr Soc 2001;49:859-65. https://doi.org/10.1046/j.1532-5415.2001.49174.x.

16. Kohrt WM, Bloomfield SA, Little KD, et al. American College of Sports Medicine Position Stand: Physical activity and bone health. Med Sci Sports Exerc 2004;36:1985-96. https://doi.org/10.1249/01.mss.0000142662.21767.58.

17. Bonaiuti D, Arioli G, Diana G, et al. SIMFER Rehabilitation treatment guidelines in postmenopausal and senile osteoporosis. Eura Medicophys 2005;41:315-37.

18. Kim SY, Park JE, Seo HJ, et al. NECA's guidance for undertaking systematic review and meta-analyses for intervention. Seoul, KR: National Evidence-based Healthcare Collaborating Agency; 2011.

19. Min SK, Oh T, Kim SH, et al. Position statement: Exercise guidelines to increase peak bone mass in adolescents. J Bone Metab 2019;26:225-39. https://doi.org/10.11005/jbm.2019.26.4.225.

20. Beck BR, Daly RM, Singh MA, et al. Exercise and Sports Science Australia (ESSA) position statement on exercise prescription for the prevention and management of osteoporosis. J Sci Med Sport 2017;20:438-45. https://doi.org/10.1016/j.jsams.2016.10.001.

21. U. S. Department of Health and Human Services. Physical activity guidelines for Americans. Washington, DC: U.S. Department of Health and Human Services; 2018.

22. Compston J, Cooper A, Cooper C, et al. UK clinical guideline for the prevention and treatment of osteoporosis. Arch Osteoporos 2017;12:43. https://doi.org/10.1007/s11657-017-0324-5.

23. Kanis JA, Cooper C, Rizzoli R, et al. European guidance for the diagnosis and management of osteoporosis in postmenopausal women. Osteoporos Int 2019;30:3-44. https://doi.org/10.1007/s00198-018-4704-5.

24. Camacho PM, Petak SM, Binkley N, et al. American Association of Clinical Endocrinologists/American College of Endocrinology Clinical Practice Guidelines for the diagnosis and treatment of postmenopausal osteoporosis-2020 update executive summary. Endocr Pract 2020;26:564-70. https://doi.org/10.4158/gl-2020-0524.

25. Higgins JPT, Thomas J, Chandler J, et al., editors. Cochrane handbook for systematic reviews of interventions. Version 6.1. London, UK: The Cochrane Collaboration; 2019.

26. Liu-Ambrose TY, Khan KM, Eng JJ, et al. Both resistance and agility training increase cortical bone density in 75- to 85-year-old women with low bone mass: a 6-month randomized controlled trial. J Clin Densitom 2004;7:390-8. https://doi.org/10.1385/jcd:7:4:390.

27. Mosti MP, Kaehler N, Stunes AK, et al. Maximal strength training in postmenopausal women with osteoporosis or osteopenia. J Strength Cond Res 2013;27:2879-86. https://doi.org/10.1519/JSC.0b013e318280d4e2.

28. de Matos O, Lopes da Silva DJ, Martinez de Oliveira J, et al. Effect of specific exercise training on bone mineral density in women with postmenopausal osteopenia or osteoporosis. Gynecol Endocrinol 2009;25:616-20. https://doi.org/10.1080/09513590903015593.

29. Harding AT, Weeks BK, Lambert C, et al. Effects of supervised high-intensity resistance and impact training or machine-based isometric training on regional bone geometry and strength in middle-aged and older men with low bone mass: The LIFTMOR-M semi-randomised controlled trial. Bone 2020;136:115362. https://doi.org/10.1016/j.bone.2020.115362.

30. Kemmler W, Kohl M, Fröhlich M, et al. Effects of high-intensity resistance training on osteopenia and sarcopenia parameters in older men with osteosarcopenia-one-year results of the randomized controlled franconian osteopenia and sarcopenia trial (FrOST). J Bone Miner Res 2020;35:1634-44. https://doi.org/10.1002/jbmr.4027.

31. Kistler-Fischbacher M, Yong JS, Weeks BK, et al. High-intensity exercise and geometric indices of hip bone strength in postmenopausal women on or off bone medication: The MEDEX-OP randomised controlled trial. Calcif Tissue Int 2022;111:256-66. https://doi.org/10.1007/s00223-022-00991-z.

32. Garber CE, Blissmer B, Deschenes MR, et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. Med Sci Sports Exerc 2011;43:1334-59. https://doi.org/10.1249/MSS.0b013e318213fefb.

33. Watson S, Weeks B, Weis L, et al. High-intensity resistance and impact training improves bone mineral density and physical function in postmenopausal women with osteopenia and osteoporosis: The LIFTMOR randomized controlled trial. J Bone Miner Res 2019;34:572. https://doi.org/10.1002/jbmr.3659.

34. Murlasits Z, Reed J, Wells K. Effect of resistance training

frequency on physiological adaptations in older adults. J Exerc Sci Fit 2012;10:28-32. https://doi.org/10.1016/j.jesf.2012.04.006.

35. Borba-Pinheiro CJ, Dantas EH, Vale RG, et al. Resistance training programs on bone related variables and functional independence of postmenopausal women in pharmacological treatment: a randomized controlled trial. Arch Gerontol Geriatr 2016;65:36-44. https://doi.org/10.1016/j.archger.2016.02.010.

36. Shaw JM, Witzke KA. Exercise for skeletal health and osteoporosis prevention. In: Roitman JL, editor. ACSM's resource manual for guidelines for exercise testing and prescription. Baltimore, MD: Williams and Wilkins; 1998. p.288-93.

37. Basat H, Esmaeilzadeh S, Eskiyurt N. The effects of strengthening and high-impact exercises on bone metabolism and quality of life in postmenopausal women: a randomized controlled trial. J Back Musculoskelet Rehabil 2013;26:427-35. https://doi.org/10.3233/bmr-130402.

38. Hettchen M, von Stengel S, Kohl M, et al. Changes in menopausal risk factors in early postmenopausal osteopenic women after 13 months of high-intensity exercise: The randomized controlled ACTLIFE-RCT. Clin Interv Aging 2021;16:83-96. https://doi.org/10.2147/cia.S283177.

39. Moreira LD, Fronza FC, Dos Santos RN, et al. The benefits of a high-intensity aquatic exercise program (HydrOS) for bone metabolism and bone mass of postmenopausal women. J Bone Miner Metab 2014;32:411-9. https://doi.org/10.1007/s00774-013-0509-y.

40. Sen EI, Esmaeilzadeh S, Eskiyurt N. Effects of whole-body vibration and high impact exercises on the bone metabolism and functional mobility in postmenopausal women. J Bone Miner Metab 2020;38:392-404. https://doi.org/10.1007/s00774-019-01072-2.

41. Watson SL, Weeks BK, Weis LJ, et al. High-intensity exercise did not cause vertebral fractures and improves thoracic kyphosis in postmenopausal women with low to very low bone mass: the LIFTMOR trial. Osteoporos Int 2019;30:957-64. https://doi.org/10.1007/s00198-018-04829-z.

42. Multanen J, Nieminen MT, Häkkinen A, et al. Effects of high-impact training on bone and articular cartilage: 12-month randomized controlled quantitative MRI study. J Bone Miner Res 2014;29:192-201. https://doi.org/10.1002/jbmr.2015.

43. Multanen J, Rantalainen T, Kautiainen H, et al. Effect of progressive high-impact exercise on femoral neck struc-

tural strength in postmenopausal women with mild knee osteoarthritis: a 12-month RCT. Osteoporos Int 2017;28:1323-33. https://doi.org/10.1007/s00198-016-3875-1.

44. Kistler-Fischbacher M, Yong JS, Weeks BK, et al. A comparison of bone-targeted exercise with and without antiresorptive bone medication to reduce indices of fracture risk in postmenopausal women with low bone mass: The MEDEX-OP randomized controlled trial. J Bone Miner Res 2021;36:1680-93. https://doi.org/10.1002/jbmr.4334.

45. Madureira MM, Bonfá E, Takayama L, et al. A 12-month randomized controlled trial of balance training in elderly women with osteoporosis: improvement of quality of life. Maturitas 2010;66:206-11. https://doi.org/10.1016/j.maturitas.2010.03.009.

46. Mikó I, Szerb I, Szerb A, et al. Effectiveness of balance training programme in reducing the frequency of falling in established osteoporotic women: a randomized controlled trial. Clin Rehabil 2017;31:217-24. https://doi.org/10.1177/0269215516628616.

47. Smulders E, Weerdesteyn V, Groen BE, et al. Efficacy of a short multidisciplinary falls prevention program for elderly persons with osteoporosis and a fall history: a randomized controlled trial. Arch Phys Med Rehabil 2010;91:1705-11. https://doi.org/10.1016/j.apmr.2010.08.004.

48. Liu-Ambrose T, Khan KM, Eng JJ, et al. Resistance and agility training reduce fall risk in women aged 75 to 85 with low bone mass: a 6-month randomized, controlled trial. J Am Geriatr Soc 2004;52:657-65. https://doi.org/10.1111/j.1532-5415.2004.52200.x.

49. Carter ND, Khan KM, Petit MA, et al. Results of a 10 week community based strength and balance training programme to reduce fall risk factors: a randomised controlled trial in 65-75 year old women with osteoporosis. Br J Sports Med 2001;35:348-51. https://doi.org/10.1136/bjsm.35.5.348.

50. Evstigneeva L, Lesnyak O, Bultink IE, et al. Effect of twelve-month physical exercise program on patients with osteoporotic vertebral fractures: a randomized, controlled trial. Osteoporos Int 2016;27:2515-24. https://doi.org/10.1007/s00198-016-3560-4.

51. Papaioannou A, Adachi JD, Winegard K, et al. Efficacy of home-based exercise for improving quality of life among elderly women with symptomatic osteoporosis-related vertebral fractures. Osteoporos Int 2003;14:677-82. https://doi.org/10.1007/s00198-003-1423-2.

52. Benedetti MG, Furlini G, Zati A, et al. The effectiveness of physical exercise on bone density in osteoporotic patients. Biomed Res Int 2018;2018:4840531. https://doi.org/10.1155/2018/4840531.

53. Chien MY, Wu YT, Hsu AT, et al. Efficacy of a 24-week aerobic exercise program for osteopenic postmenopausal women. Calcif Tissue Int 2000;67:443-8. https://doi.org/10.1007/s002230001180.

54. Jee YS, Yoon KJ, Byeun JJ, et al. The effects of exercise on bone mineral density and relating variables of elderly women with osteoporosis during taking the alendronate. J Sport Leis Stud 2003;19:1455-66.

55. Roghani T, Torkaman G, Movasseghe S, et al. Effects of short-term aerobic exercise with and without external loading on bone metabolism and balance in postmenopausal women with osteoporosis. Rheumatol Int 2013;33:291-8. https://doi.org/10.1007/s00296-012-2388-2.

56. Wen HJ, Huang TH, Li TL, et al. Effects of short-term step aerobics exercise on bone metabolism and functional fitness in postmenopausal women with low bone mass. Osteoporos Int 2017;28:539-47. https://doi.org/10.1007/s00198-016-3759-4.

57. Choi PB. Long-term combined exercise has effect on regional bone mineral density and cardiovascular disease risk factors of the elderly with osteoporosis. J Korean Gerontol Soc 2011;31:355-69.

58. Kim C, Lee JW. Effects of combined exercise using walking and band resistance exercising on irisin, osteocalcin and bone mineral density in elderly women with osteopenia. J Korean Assoc Phys Educ Sport Girls Women 2019;33:169-84. https://doi.org/10.16915/jkapesgw.2019.6.33.2.169.

59. Feng F, Shi G, Chen H, et al. Comprehensive interventions including vitamin D effectively reduce the risk of falls in elderly osteoporotic patients. Orthop Surg 2021;13:1262-8. https://doi.org/10.1111/os.13009.

60. Wayne PM, Kiel DP, Buring JE, et al. Impact of Tai Chi exercise on multiple fracture-related risk factors in post-menopausal osteopenic women: a pilot pragmatic, randomized trial. BMC Complement Altern Med 2012;12:7. https://doi.org/10.1186/1472-6882-12-7.

61. Young CM, Weeks BK, Beck BR. Simple, novel physical activity maintains proximal femur bone mineral density, and improves muscle strength and balance in sedentary, postmenopausal Caucasian women. Osteoporos Int 2007;18:1379-87. https://doi.org/10.1007/s00198-007-0400-6.

62. Jung SW, Seo MW, Kim SW, et al. Effects of 16 weeks combined training on irisin, adipokines and bone metabolism markers expression and functional fitness and muscle function in elderly women with osteosarcopenic obesity. Korea J Sports Sci 2017;26:937-54. https://doi.org/10.35159/kjss.2017.10.26.5.937.

63. Nakamura K, Saito T, Kobayashi R, et al. Physical activity modifies the effect of calcium supplements on bone loss in perimenopausal and postmenopausal women: subgroup analysis of a randomized controlled trial. Arch Osteoporos 2019;14:17. https://doi.org/10.1007/s11657-019-0575-4.

64. Brooke-Wavell K, Skelton DA, Barker KL, et al. Strong, steady and straight: UK consensus statement on physical activity and exercise for osteoporosis. Br J Sports Med 2022;56:837-46. https://doi.org/10.1136/bjsports-2021-104634.

65. Sherrington C, Whitney JC, Lord SR, et al. Effective exercise for the prevention of falls: a systematic review and meta-analysis. J Am Geriatr Soc 2008;56:2234-43. https://doi.org/10.1111/j.1532-5415.2008.02014.x.

66. Kelley GA, Kelley KS, Kohrt WM. Effects of ground and joint reaction force exercise on lumbar spine and femoral neck bone mineral density in postmenopausal women: a meta-analysis of randomized controlled trials. BMC Musculoskelet Disord 2012;13:177. https://doi.org/10.1186/1471-2474-13-177.

67. Silsupadol P, Siu KC, Shumway-Cook A, et al. Training of balance under single- and dual-task conditions in older adults with balance impairment. Phys Ther 2006;86:269-81.

68. Karlsson MK, Nordqvist A, Karlsson C. Physical activity, muscle function, falls and fractures. Food Nutr Res 2008;52:1-7. https://doi.org/10.3402/fnr.v52i0.1920.

69. Rogers ME, Fernandez JE, Bohlken RM. Training to reduce postural sway and increase functional reach in the elderly. J Occup Rehabil 2001;11:291-8. https://doi.org/10.1023/a:1013300725964.

70. Sherrington C, Fairhall NJ, Wallbank GK, et al. Exercise for preventing falls in older people living in the community. Cochrane Database Syst Rev 2019;1:CD012424. https://doi.org/10.1002/14651858.CD012424.pub2.

71. Stanghelle B, Bentzen H, Giangregorio L, et al. Effects of a resistance and balance exercise programme on physical fitness, health-related quality of life and fear of falling in older women with osteoporosis and vertebral fracture: a randomized controlled trial. Osteoporos Int 2020;31:1069-

78. https://doi.org/10.1007/s00198-019-05256-4.

72. ElDeeb AM, Abdel-Aziem AA. Effect of whole-body vibration exercise on power profile and bone mineral density in postmenopausal women with osteoporosis: A randomized controlled trial. J Manipulative Physiol Ther 2020;43: 384-93. https://doi.org/10.1016/j.jmpt.2019.12.003.

73. Jepsen DB, Ryg J, Hansen S, et al. The combined effect of Parathyroid hormone (1-34) and whole-body Vibration exercise in the treatment of postmenopausal OSteoporosis (PaVOS study): a randomized controlled trial. Osteoporos Int 2019;30:1827-36. https://doi.org/10.1007/s00198-019-05029-z.

Supplementary Appendix 1. Literature search terms and Participants, Intervention, Comparison, Outcomes, Time, Setting, and Study Design (PICOTS-SD) description. The keywords for the literature search were as follows: (aerobic OR endurance OR weight-bearing OR muscle strength OR resistance OR power OR impact OR plyometric OR exercises OR physical activity OR balance OR stability OR flexibility OR jump OR walking OR running) AND (BMD OR bone metabolic markers OR fracture OR fall OR posture) AND (osteoporosis). In the review stage, the committee used the PICOTS-SD framework to determine the scope of inclusion in the literature for the use of systematic review methods (Supplementary Table 1).

Supplementary Table 1. Participants, Intervention, Comparison, Outcomes, Time, Setting, and Study Design for determining the scope of literature

Category	Research questions
Participants	The osteoporosis patients (both male and female)
Intervention	aerobic OR endurance OR weight-bearing OR muscle strength OR resistance OR power OR impact OR plyometric OR exercises OR physical activity OR balance OR stability OR flexibility OR jump OR walking OR running
Comparison	Non-exercise control, routine care, etc.
Outcomes	BMD OR bone metabolic markers OR fracture OR fall OR posture, etc.
Time	Pre- and post- test studies, etc.
Setting	Home, hospital, gym, community, etc.
Study design	RCT

BMD, bone mineral density; RCT, randomized controlled trial.

Supplementary Table 2. The level of evidence literature research

| The level	Evidence rating	Type of evidence
I	Strong	Confirmatory studies will not likely change the results presented (from at least one RCT or meta-analysis of RCT)
II	Intermediate	Confirmatory study may change the results presented by research (from at least one well-constructed non-randomized controlled study or at least one different type of quasi-experimental design study)
III	Weak	Conducting confirmatory study may change the results presented by research (from well-constructed descriptive studies without experiments or comparative studies and/or correlation studies and/or case reports)
EC	Expert consensus	Expert consensus (evidence accepted by the experts based on the clear scientific outcomes or physiology studies)

RCT, randomized controlled trial; EC, expert consensus.

Supplementary Table 3. The grade of recommendations to exercise guideline

Grade	Expression	Type of recommendations
A	Very strong	Recommended because it is sufficiently effective based on evidence (evidence levels I)
B	Strong	The evidence for effectiveness is relatively inadequate, so it is recommended that it be selectively given or given to a specific individual at the discretion of the experts (evidence levels II)
C	Not strong	Not recommended because it is insufficiently effective based on evidence (evidence levels III)
D	No recommendation	The recommendation itself is insignificant as there is no evidence for its effectiveness, and additional research is required

	D1	D2	D3	D4	D5	Overall
de Matos et al. (2009)	+	!	+	+	!	!
Mosti et al. (2013)	!	+	+	+	!	!
Liu-Ambrose et al. (2004)	+	+	+	+	!	!
Harding et al. (2020)	+	+	+	+	+	+
Kemmler et al. (2020)	+	+	+	+	+	+
Kistler-Fischbacher et al. (2022)	+	+	+	+	+	+
Watson et al. (2018)	+	+	+	+	+	+
Borba-Pinheiro et el. (2016)	!	+	+	+	!	!
Basat et al. (2013)	!	+	+	+	!	!
Watson et al. (2018)	+	+	+	+	+	+
Kistler-Fischbacher et al. (2021)	+	+	+	+	+	+
Hettchen et al. (2021)	+	+	+	+	+	+
Watson et al. (2019)	+	+	+	+	+	+
Moreira et al. (2014)	!	+	+	+	!	!
Sen et al. (2020)	!	+	+	+	!	!
Multanen et al. (2014)	+	+	+	+	+	+
Multanen et al. (2017)	+	+	+	+	+	+
Madureira et al. (2010)	+	+	+	+	+	+
Miko et al. (2017)	+	+	+	+	!	!
Smulders et al. (2010)	+	+	+	+	!	!
Evstigneeva et al. (2016)	+	+	+	+	+	+
Papaioannou et al. (2003)	+	+	+	+	!	!
Carter et al. (2001)	+	!	+	+	+	!
Liu-Ambrose et al. (2004)	+	+	+	+	!	!
Chien. et al. (2000)	!	+	+	+	+	!
Roghani et al. (2013)	!	+	+	+	+	!
Wen et al. (2017)	!	+	+	+	+	!
Jee et al. (2008)	!	+	+	+	!	!
Choi et al. (2011)	!	+	+	+	!	!
Kim et al. (2019)	!	+	+	+	+	!
Feng et al. (2021)	!	+	+	+	+	!
Wayne et al. (2012)	+	+	+	+	+	+
Young et al. (2007)	!	+	+	+	!	!
Jung et al. (2017)	!	+	+	+	!	!

+	Low risk
!	Some concerns
-	High risk

D1	Randomisation process
D2	Deviations from the intended interventions
D3	Missing outcome data
D4	Measurement of the outcome
D5	Selection of the reported result

Supplementary Fig. 1. The result of risk of bias assessment: each risk of bias item for included studies. The 21 studies used adequate methods for allocation sequence generation, and all these applied adequate methods of allocation concealment. The other 13 studies did not provide sufficient information on allocation concealment, so the risk of bias remains unclear. The risk of deviations from the intended interventions was low in 32 studies and unclear in 2 studies. The risk of bias due to missing outcome data was low in all studies. In all studies, outcome measures were appropriate, and the data were not likely to have been influenced by knowledge of the intervention received. The selection bias risk of the reported results was low in 18 studies, unclear in 15 studies, and high in 1 study.
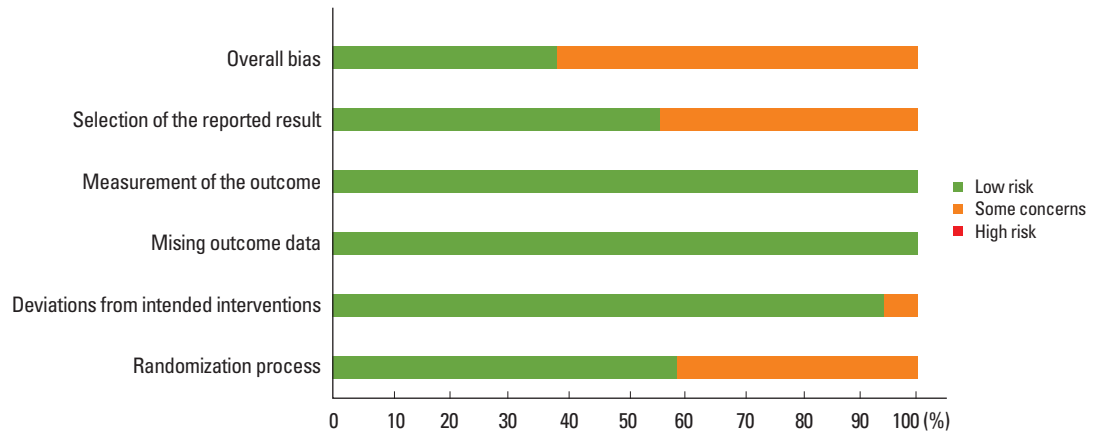
Supplementary Fig. 2. Risk of bias summary: review authors' judgments about each risk of bias item presented as percentages across all included studies. Overall, the general risk of bias was low to moderate in the included studies.