

Effects of resistance training on osteosarcopenia in community-dwelling postmenopausal Korean women: Randomised controlled ERTO-K trial

Byung Chan Lee^a, Kyung Il Kim^b, Juhyun Lee^b, Kang Hee Cho^{b,c}, Changwon Moon^{b,c,*}

^a Department of Physical Medicine and Rehabilitation, College of Medicine, Chung-Ang University, Seoul, Republic of Korea

^b Department of Rehabilitation Medicine, Chungnam National University College of Medicine, Daejeon, Republic of Korea

^c Department of Biomedical Institute, Chungnam National University, Daejeon, Republic of Korea

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ABSTRACT

Objective: We evaluated the efficacy of a 6-month progressive resistance exercise in postmenopausal women with osteosarcopenia.

Study design: Thirty-four community-dwelling postmenopausal women with osteosarcopenia were randomly assigned to either a resistance exercise group (RE; $n = 17$) or a home exercise group (HE; $n = 17$). Both groups received home exercise brochures and nutritional supplementation. The RE group additionally participated in supervised resistance training sessions twice weekly.

Main outcome measures: The primary outcome was the change in the skeletal muscle index (SMI) and bone mineral density (BMD). The secondary outcomes included changes in handgrip strength (HGS) and physical performance.

Results: Seventeen and sixteen participants in the RE and HE groups, respectively, completed the intervention. The RE group showed significantly greater SMI improvement at the 12-week follow-up ($0.310 \pm 0.343 \text{ kg/m}^2$ vs. $0.011 \pm 0.423 \text{ kg/m}^2$ in HE). However, there was no significant difference between groups at the 24-week follow-up. The other primary outcome, BMD, did not show any statistically significant differences either within or between groups. While both groups showed significant improvement in HGS and physical performance over time, the RE group had significantly higher HGS at the 6-week and 18-week follow-ups.

Conclusions: A 6-month program of progressive resistance exercise combined with nutritional support improved muscle mass and strength in postmenopausal women with osteosarcopenia. Although the HE group showed less improvement at earlier time points, their muscle strength and physical performance were comparable to those of the RE group by the end of the intervention.

1. Introduction

With the increasing proportion of older adults in the global population, the importance of ageing-related geriatric syndromes is increasing. Sarcopenia is a common geriatric disease that is characterised by reduced muscle quantity, strength, and physical performance (Baek et al., 2023). Despite variations attributable to different diagnostic criteria, the prevalence of sarcopenia ranges from 10 % to 27 % among adults aged 60 and older worldwide (Petermann-Rocha et al., 2022).

Recently, a relatively new term ‘osteosarcopenia’ denotes the co-occurrence of osteopenia or osteoporosis with sarcopenia. The risk factors of osteosarcopenia include female sex, older age, low body mass index (BMI), inadequate nutritional status, and a sedentary lifestyle (Blomqvist et al., 2024; Huang et al., 2023; Lee et al., 2023). Osteosarcopenia confers higher risks of falls, fragile fractures, functional disability, and mortality as compared to that in the healthy population or patients with either sarcopenia or osteoporosis (Lee et al., 2024a; Paulin et al., 2024; Rosas-Carrasco et al., 2024).

Abbreviations: BBT, Berg Balance Test; BMD, bone mineral density; BMI, body mass index; CTX, C-terminal telopeptide; DXA, dual-energy X-ray absorptiometry; FRAX, Fracture Risk assessment; HE, home exercise; HGS, hand grip strength; MCID, minimal clinically important difference; MNA-SF, Mini Nutritional Assessment-Short Form; MQI, Muscle Quality Index; nRM, non-repetition maximum; RE, resistance exercise; RM, repetition maximum; SMI, skeletal muscle index; SPPB, Short Physical Performance Battery.

* Corresponding author at: Department of Rehabilitation Medicine, Chungnam National University College of Medicine, 266 Munhwa-ro, Jung-gu, Daejeon 35015, Republic of Korea.

E-mail address: mcw0171@cnuh.co.kr (C. Moon).

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Therefore, in ageing societies, the proper identification and management of osteosarcopenia are important to prevent the expected complications. In patients with osteosarcopenia, the standard approach includes not only medical management but also non-pharmacological treatments, such as proper dietary management and resistance exercise (Kirk et al., 2021; Papadopoulou et al., 2021). However, only a few randomised controlled trials have specifically investigated osteosarcopenia (Banitalebi et al., 2021; Lee et al., 2021; Lichtenberg et al., 2019).

Among the aforementioned studies, Lichtenberg et al. focused on men with osteosarcopenia, while Banitalebi et al. and Lee et al. included women with osteosarcopenic obesity. Considering that low BMI is a known risk factor for osteosarcopenia, further research targeting women with osteosarcopenia in general is warranted.

Therefore, in this study, we aimed to evaluate the clinical efficacy of a 6-month progressive resistance exercise and nutritional support program compared to a control group in postmenopausal women with osteosarcopenia.

2. Materials and methods

2.1. Study design

This double-arm, assessor-blinded, 1:1 randomised controlled study compared the effects of progressive resistance training in postmenopausal female participants with osteosarcopenia. This study was approved by the institutional review board of our Hospital (CNUH 2022–12-026). All participants provided written informed consent. The clinical trial was registered with the Clinical Research Information Service of the Republic of Korea (KCT0008291). We followed the 2010 Consolidated Standards of Reporting Trials (CONSORT) statement guidelines.

2.2. Participants

Participants were recruited between March 2023 and November

2023. The inclusion criteria were as follows: 1) age 65–90 years of postmenopausal women, 2) diagnosed with sarcopenia according to the criteria of the Asian Working Group of Sarcopenia (Chen et al., 2020), and 3) diagnosed with osteopenia or osteoporosis. The exclusion criteria included: 1) secondary osteoporosis, 2) regular use of medications that may impact bone and muscle mass or quality for more than a month, 3) history of a diagnosis of diabetes mellitus, thyroid, parathyroid, or Paget's disease of the bone, 4) current cancer that requires treatment, 5) the presence of foreign hardware, implants, or devices that could influence the results of dual-energy X-ray absorptiometry (DXA), 6) Stage ≥ 3 chronic renal disease ($\text{GFR} < 60 \text{ mL/min/1.73 m}^2$), 7) alcoholism, 8) history of spine, hip, or radius fragile fractures, 9) inability to comprehend or follow the study protocol, and 10) refusal to participate.

Participants who met the eligibility criteria were screened and provided informed consent to participate in the study. After providing informed consent, the participants were randomly assigned to two groups (1:1 allocation) by randomisation with a block size of four. The two groups (Fig. 1) comprised a resistance exercise group (RE) and a home exercise group (HE).

2.3. Interventions

All the participants received interventions according to allocated groups. The RE group underwent resistance exercise training at our rehabilitation centre twice a week for 24 weeks. Resistance exercises were performed on circuit resistance training machines (Fig. 2; Milon Industries GmbH, Emersacker, Germany). During the 24-week resistance-training period, three phases of progressive exercise were applied to determine the exercise intensity (Fig. 3).

In phase 1 (1–8 weeks after allocation), participants assigned to the RE group selected a weight that they could lift within the allotted repetition range of 8–15, and the self-determined weight was lifted 8–15 times (non-repetition maximum [nRM]: maximal effort minus 1–3 repetitions) in one or two sets during Phase 1. Participants were requested to increase the intensity of the resistance exercises until a self-

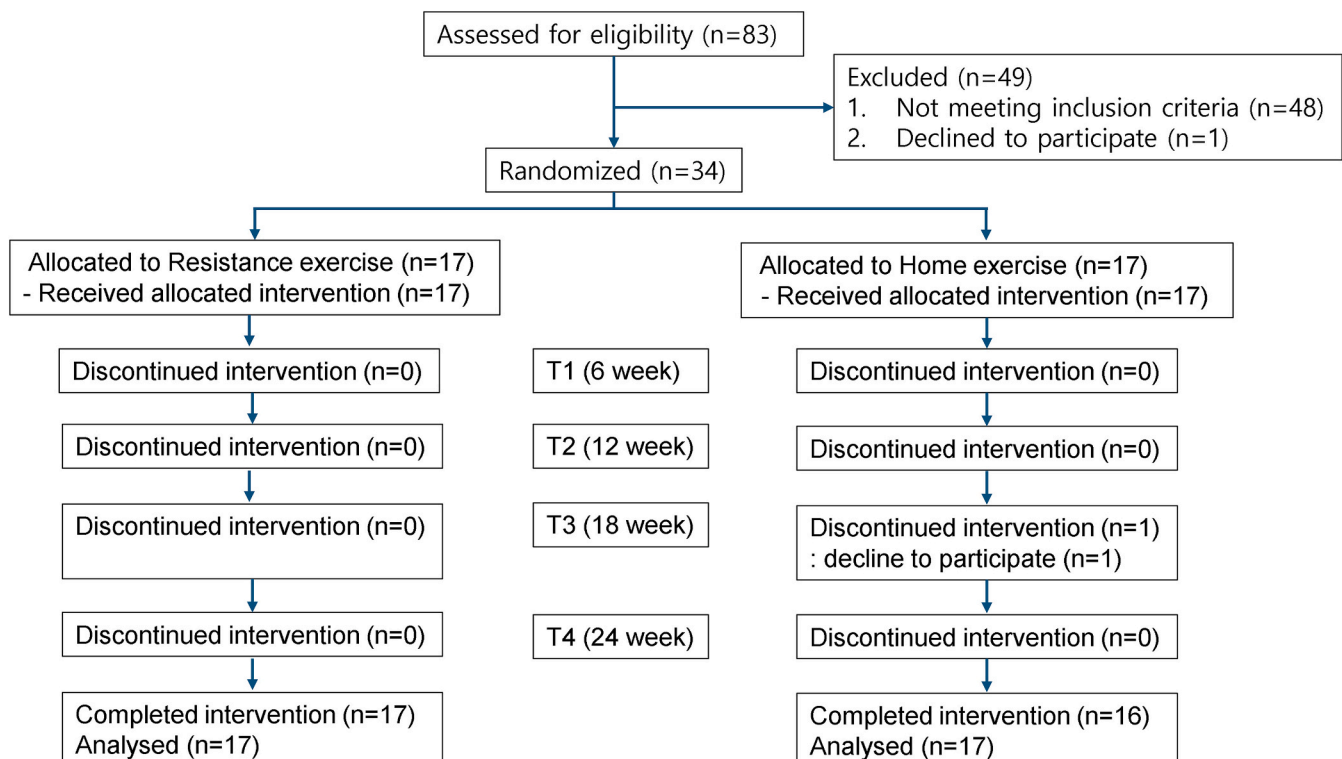


Fig. 1. Flowchart of participant selection and disposition.



Fig. 2. A: circuit resistance training machines (Milon Industries GmbH, Emersacker, Germany) consisted with eight strengthening exercises (4 for the lower extremities: leg press, leg abductor, leg flexor, leg extension; 3 for the upper extremities: chest press, row, dips; and 1 for core muscle exercise: back extension). B, C: Participant in the study performing resistance exercises.

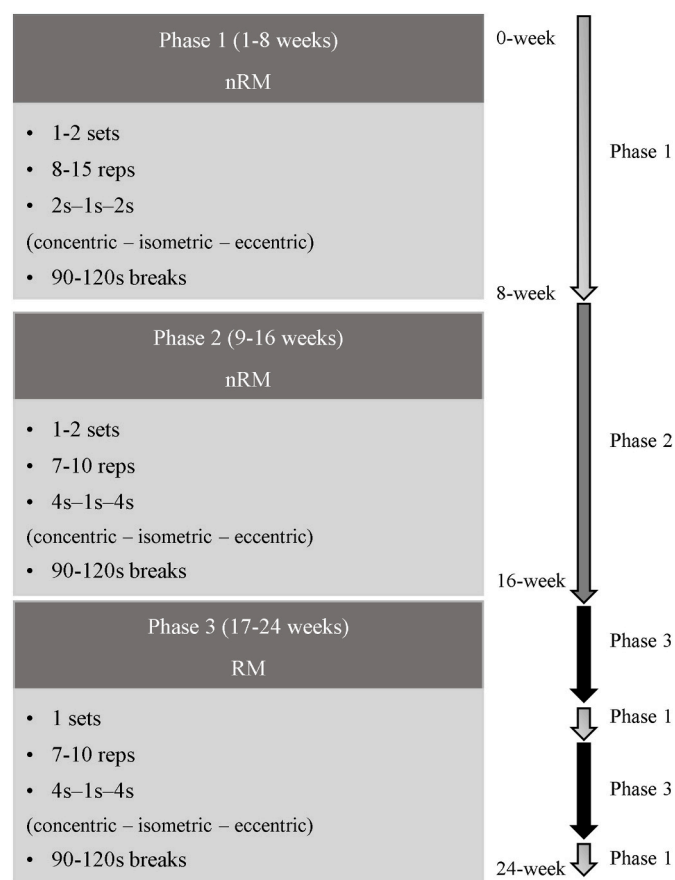


Fig. 3. Protocol for exercise intervention, Reps, Repetitions; nRM, Non-repetition Maximum; RM, Repetition Maximum.

determined weight of 7–10 feasible repetitions was reached during Phase 2 (9–16 weeks following allocation); nRM (maximum effort minus 1) was applied. Participants proceeded to Phase 3 after 16 weeks of exercise training, wherein they completed as many repetitions as they could (repetition maximum [RM]) and increased the lifting of the self-determined weight to seven and ten repetitions. Periodisation, which included 3 weeks of Phase 3 and 1 week of Phase 1, was used. The detailed exercise protocols have been published previously (Lee et al., 2024b). During the exercise period, a trained physiotherapist monitored whether the participants performed the exercises appropriately and safely. In cases where side effects, such as falls, injuries, or pain, the physiotherapist reported them to the study coordinator.

All participants in the RE and HE groups were provided home exercise brochures (Supplementary material). All participants were encouraged to perform exercises at home. During the intervention period, all participants in both groups received nutritional support consisting of two packs of protein complex powder (Selex core-protein; Maeil Dairies, Seoul, Republic of Korea). Each pack contained 20 g of protein, 800 IU of vitamin D, and 300 mg of calcium.

2.4. Outcome measurement

After obtaining informed consent, data on baseline demographics were collected by interviews from participants. We evaluated the nutritional status of the participants using a 24-h recall method to collect data on total calorie intake and the proportion of protein. The Mini Nutritional Assessment-Short Form (MNA-SF) survey was administered at the initial visit, with scores ranging from 0 to 14 wherein lower scores indicating malnutrition (Kaiser and others, 2009). The Fracture Risk assessment (FRAX) score was measured in both groups at the initial assessment. At the initial visit, blood samples were collected to quantify the levels of albumin, serum vitamin D, C-terminal telopeptide (CTX), and creatinine.

The primary outcome of the trial was the change from the initial assessment to that after 24 weeks of intervention in the skeletal muscle index (SMI) and BMD measured by DXA (Hologic, Marlborough, Massachusetts, USA). The SMI was calculated by dividing the appendicular skeletal muscle mass (kg) by the square of the height (m). BMD measurements were performed at three sites: the lumbar spine (L1–L4), femoral neck, and total hip. The diagnosis of osteoporosis was based on the lowest T-score among these three sites, in accordance with the WHO criteria (Kanis, 2000). DXA measurements were repeated at T0 (0 week), T2 (12 weeks), and T4 (24 weeks).

The muscle strength of the participants was assessed using hand-grip strength (HGS) measured in kilograms. The measurement was taken three times on the dominant hand, and the highest value was recorded. A handheld dynamometer (Jamar; Hoggan Scientific, Salt Lake City, Utah, USA) was used.

Physical performance was measured using the Short Physical Performance Battery (SPPB) and Berg Balance Test (BBT). The SPPB consists of three tasks: static standing balance, 4-m walking speed at a usual pace, and a 5-time chair rise test. The SPPB results were recorded as numerical ratings (range 0–12), with higher scores indicating better performance (Guralnik et al., 1994). To measure the balance of the participants, the BBT consisting of 14 tasks, with each item rated from 0 to 4, was used, and a lower score indicated lower function. The Muscle Quality Index (MQI) was also measured. The MQI was calculated based on the time taken to complete the sit-to-stand test, leg length, and body mass (kg) using the following formula: $MQI = ((\text{leg length (m)} - 0.4) \times \text{body mass (kg)} \times \text{gravity (9.8 m/s}^2) \times 10) / \text{sit-to-stand time (s)}$ (Takai

et al., 2009). The sit-to-stand test time was recorded as the time required to complete 10 repetitions of standing up and sitting down on a standard chair, starting from the sitting position. The MQI reflects the functional changes caused by resistance exercise in the geriatric population and its reliability has been validated (Takai et al., 2009). Muscle strength and physical performance were measured at T0 (0 week), T1 (6 weeks), T2 (12 weeks), T3 (18 weeks), and T4 (24 weeks).

A single physiotherapist assessed the patient outcomes. The assessors were blinded to the allocation of results. Owing to the nature of the trial, the participants were not blinded. The side effects were monitored during each session.

2.5. Sample-size estimation

The sample size for this study was estimated based on changes in SMI from before to after the intervention. A previous study by Lichtenberg et al. reported changes in SMI after 28 weeks of resistance exercise and protein supplementation in men with osteosarcopenia. The SMI changes were 0.30 ± 0.22 in the intervention group and -0.03 ± 0.21 in the control group (Lichtenberg et al., 2019). The estimated sample size, calculated using a two-tailed *t*-test with a 95 % power (1-β), a type-I alpha error of 0.05, and an effect size of $d = 1.53$, was 13 participants per group. To account for a 25 % dropout rate, at least 17 participants were included in each group.

2.6. Statistical analysis

Participant demographics were summarized using descriptive statistics. All analyses were performed based on the intention-to-treat principle. The normality of continuous variables was assessed using the Shapiro–Wilk test. Depending on the distribution, either an independent *t*-test or the Mann–Whitney *U* test was used to compare baseline characteristics. Categorical variables were analyzed using the chi-square test or Fisher's exact test, as appropriate.

Changes in SMI were calculated by subtracting baseline values from DXA measurements obtained at 12 and 24 weeks, and group comparisons were conducted using independent *t*-tests. Repeated-measures ANOVA was used to assess longitudinal changes in BMD, HGS, SPPB, 5-time chair rise test, 4-m gait speed, BBT, and MQI. When a statistically significant group-by-time interaction was observed, post hoc pairwise comparisons were performed with Bonferroni correction.

Missing data were imputed using the last observation carried forward method. All statistical analyses were conducted using IBM SPSS Statistics (version 23.0; IBM Corp., Armonk, NY, USA). A two-sided *p*-value <0.05 was considered statistically significant, and 95 % confidence intervals were reported where applicable.

3. Results

3.1. Participants' characteristics

A total of 34 participants were enrolled. During the intervention, one participant in the HE group discontinued participation after T2 because of the decision to withdraw. Seventeen and sixteen participants in the RE and HE groups, respectively, completed the intervention (Fig. 1).

Table 1 presents the baseline demographics and participant evaluations. The mean age was 75.8 ± 5.6 years in the RE group and 76.5 ± 5.0 years in the HE group. There were no statistically significant differences between the two groups in baseline demographics or evaluations, including FRAX score, MNA-SF, SMI, and BMD (Table 1). The use of osteoporosis-related medications at baseline included bisphosphonate in 1 participant (5.9 %), denosumab in 2 participants (11.8 %), and romosozumab in 1 participant (5.9 %) in the RE group, and bisphosphonate in 1 participant (5.9 %) and denosumab in 2 participants (11.8 %) in the HE group. No significant differences were observed between the groups (Table 1).

Table 1
Baseline characteristics of participants.

Basal demographics	RE Group (S.D.)	HE Group (S.D.)	<i>p</i> -value
Age (yrs)	75.8 (5.6)	76.5 (5.0)	0.823
Weight (kg)	47.2 (4.5)	47.2 (4.4)	0.985
Height (m)	1.51 (0.04)	1.51 (0.04)	0.921
BMI (kg/m ²)	20.85 (2.06)	20.83 (2.04)	0.972
FRAX; major fracture (%)	10.44 (3.97)	11.49 (5.23)	0.683*
FRAX; hip fracture (%)	4.31 (3.96)	3.75 (2.08)	0.524
MNA Short form	12.00 (1.06)	11.24 (2.17)	0.200
Total Calories	1359.41 (379.10)	1265.88 (333.80)	0.557*
Protein (%)	15.20 (3.27)	16.19 (3.61)	0.409
SMI	5.12 (0.37)	5.28 (0.37)	0.218
Lumbar T-score	-1.68 (1.00)	-2.02 (0.96)	0.319
Femoral neck T-score	-2.15 (0.68)	-2.19 (0.83)	0.893
Total hip T-score	-1.48 (0.59)	-1.43 (0.91)	0.860
Osteoporosis (n, %)	10 (58.8 %)	8 (47.1 %)	0.492
Bisphosphonate (n, %)	1 (5.9 %)	1 (5.9 %)	1.000†
Denosumab (n, %)	2 (11.9 %)	2 (11.8 %)	1.000†
Romsozumab (n, %)	1 (5.9 %)	0 (0.0 %)	1.000†
Albumin (g/dl)	4.30 (0.29)	4.19 (0.33)	0.300
25-OH-Vit D (ng/ml)	38.49 (18.32)	40.92 (14.71)	0.673
Serum Creatinine	0.66 (0.11)	0.66 (0.01)	0.987
CTX	0.249 (0.163)	0.263 (0.203)	0.786*

Abbreviations: RE, Resistance exercise; HE, Home exercise; BMI, Body Mass Index; FRAX, Fracture Risk Assessment; MNA, Mini Nutritional Assessment; SMI, skeletal muscle index; BMD, bone mineral densit; CTX, C-terminal telopeptide.

* Mann-Whitney U test.

† Fisher's exact test.

3.2. Results of the DXA

Changes in SMI were significantly different between the groups at T2. The RE group showed a significantly greater increase in SMI than the HE group (0.310 ± 0.343 kg/m² in the RE group vs. 0.011 ± 0.423 kg/m² in the HE group, *p* = 0.030). However, at T4, these significant differences were diminished (0.121 ± 0.316 kg/m² in the RE group vs. -0.024 ± 0.258 kg/m² in the HE group, *p* = 0.153) (Table 2). No significant changes were observed within or between the groups for BMD of the lumbar spine, femoral neck, or total hip (Table 3).

3.3. Muscle strength, physical performances, and MQI of the participants

HGS showed significant changes over time within and between the groups. Post-hoc analysis with Bonferroni correction revealed a significantly higher HGS in the RE group than in the HE group at T2 and T3. Both SPPB and BBT scores showed significant improvements over time within the groups; however, there was no significant time-by-group interaction for either measure. The time to complete the 5-time chair raise test significantly decreased across trials in both groups. Additionally, the 4-m gait velocity increased over time, albeit without significant time × group interactions. MQI scores showed significant improvements over time within the groups; however, there was no significant time-by-group interaction for either measure (Table 4, Fig. 4).

3.4. Side effects

Four adverse events were observed during the intervention. In the

Table 2
Changes in the SMI during and end of the intervention compared to baseline.

	Group	Changes of SMI (SD)	<i>p</i> values
12 weeks-basal	RE	0.310 (0.343)	0.030
	HE	0.011 (0.423)	
24 weeks-basal	RE	0.121 (0.316)	0.153
	HE	-0.024 (0.258)	

Abbreviations: SMI, Skeletal Muscle Index; RE, Resistance exercise group; HE, Home exercise group.

Table 3
Bone mineral density of lumbar spine, femoral neck, and total hip.

		T0; basal (SD)	T2; 12 weeks (SD)	T4; 24 weeks (SD)		F	p values
Lumbar spine	RE	0.801 (0.099)	0.803 (0.115)	0.802 (0.099)	Time	0.040	0.961
	HE	0.773 (0.110)	0.779 (0.093)	0.781 (0.102)	Time*Group	0.315	0.731
Femoral neck	RE	0.573 (0.071)	0.581 (0.067)	0.578 (0.070)	Time	2.061	0.136
	HE	0.568 (0.089)	0.583 (0.077)	0.584 (0.080)	Time*Group	0.445	0.643
Total hip	RE	0.681 (0.068)	0.700 (0.079)	0.682 (0.090)	Time	0.750	0.477
	HE	0.687 (0.105)	0.676 (0.087)	0.674 (0.072)	Time*Group	1.612	0.207
Body fat percent (%)	RE	29.64 (4.49)	28.24 (4.36)	29.39 (4.08)	Time	0.592	0.530
	HE	27.69 (5.88)	28.41 (5.95)	28.18 (5.45)	Time*Group	2.925	0.070

Abbreviations: RE, Resistance exercise group; HE, Home exercise group.

Table 4
Muscle strength and physical performance in both groups during the interventional period.

Value (SD)		T0; basal	T1; 6 weeks	T2; 12 weeks	T3; 18 weeks	T4; 24 weeks		F	p values
Grip Strength (Kg)	RE	17.62 (2.74)	21.35 (3.31)	22.04 (2.54)*	23.18 (2.34)*	22.28 (2.49)	Time	44.42	<0.001
	HE	17.17 (2.79)	19.12 (3.31)	19.31 (3.14)	20.25 (2.82)	20.71 (3.25)	Time*Group	3.70	0.007
SPPB	RE	11.12 (1.41)	11.88 (0.33)	12.00 (0.00)	12.00 (0.00)	11.94 (0.24)	Time	11.00	<0.001
	HE	11.06 (1.34)	11.47 (1.12)	11.65 (1.06)	11.77 (0.97)	11.77 (0.97)	Time*Group	0.49	0.574
5-time chair raise (s)	RE	10.77 (3.20)	8.77 (1.95)	7.55 (1.23)	7.34 (2.07)	7.82 (2.01)	Time	23.62	<0.001
	HE	11.54 (2.76)	9.80 (2.76)	8.95 (2.48)	8.77 (2.70)	8.23 (2.29)	Time*Group	0.61	0.601
Gait Velocity (m/s)	RE	1.06 (0.20)	1.23 (0.24)	1.31 (0.27)	1.42 (0.26)	1.46 (0.17)	Time	30.08	<0.001
	HE	1.04 (0.24)	1.15 (0.22)	1.21 (0.23)	1.32 (0.30)	1.36 (0.32)	Time*Group	0.42	0.736
BBT	RE	55.65 (0.79)	55.29 (1.26)	55.71 (0.99)	55.94 (0.24)	56.00 (0.00)	Time	3.674	0.024
	HE	54.24 (3.77)	55.29 (2.17)	55.00 (2.37)	55.29 (2.20)	55.29 (2.20)	Time*Group	2.798	0.060
MQI†	RE	66.66 (18.93)	77.70 (18.42)	86.01 (18.97)	96.00 (29.95)	89.21 (27.05)	Time	14.74	<0.001
	HE	65.15 (21.97)	71.63 (20.38)	78.80 (22.82)	81.90 (26.49)	84.10 (24.40)	Time*Group	0.877	0.449

Abbreviations: SPPB, Short physical performance battery; BBT, Berg balance test; MQI, Muscle Quality Index; RE, Resistance exercise group; HE, Home exercise group.

* p value <0.05, after Bonferroni correction compared with the home exercise group.

† MQI = ((leg length (m) - 0.4) × body mass (kg) × gravity (9.8 m/s²) × 10) / sit-to-stand time (s).

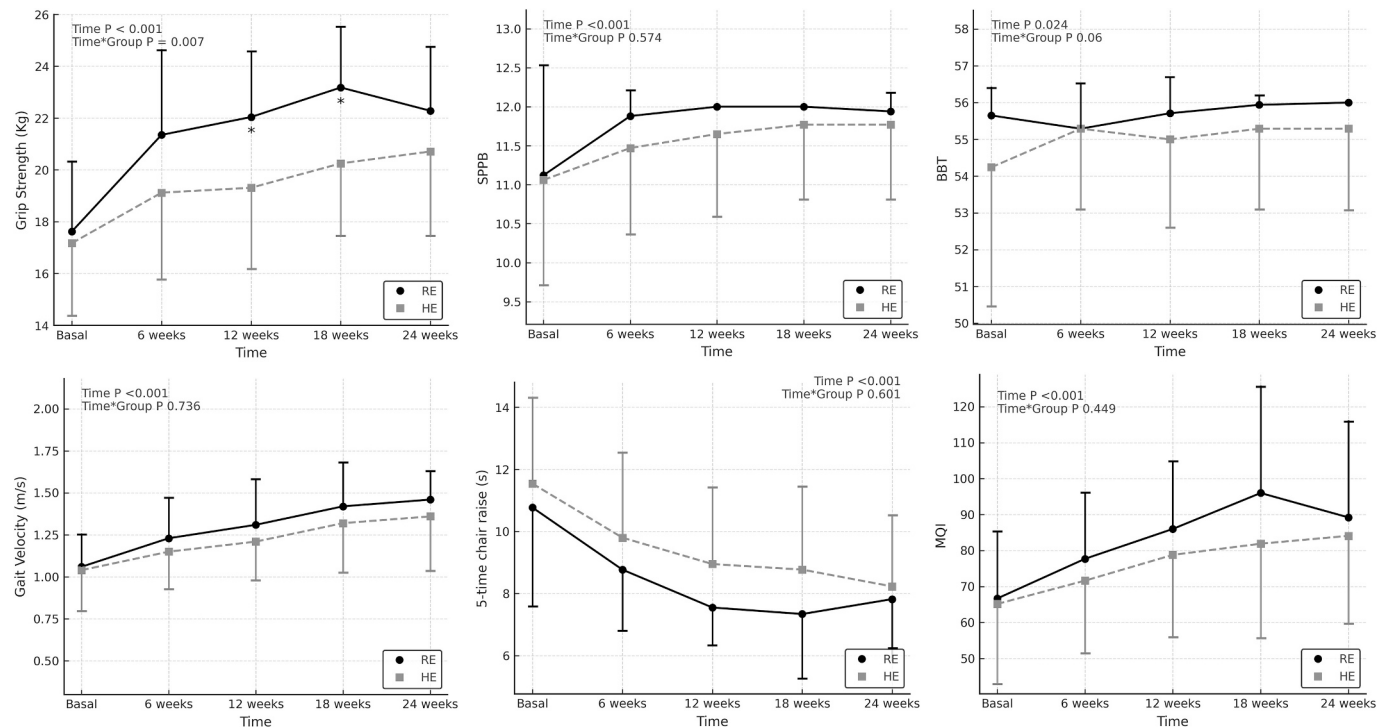


Fig. 4. Changes of HGS, SPPB, BBT, gait velocity, 5-time chair raise time and MQI throughout the intervention in both groups. Asterisk indicates the statistically significant changes between exercise and control group ($p < 0.05$), HGS, hand grip strength; SPPB, short physical performance battery; MQI, Muscle Quality index; RE, Resistance exercise group; HE, Home exercise group.

intervention group, one participant reported knee pain. In the control group, there was one case of knee pain, one case of a fall, and one case of constipation attributed to protein intake during the observation period.

None of these cases were identified as having serious side effects, and no withdrawals from the intervention due to adverse events were observed.

4. Discussion

In this trial of postmenopausal women with osteosarcopenia, resistance exercise significantly increased SMI compared with home exercise up to the 12-weeks mark. However, by the 24-weeks mark, the intergroup differences became nonsignificant. No statistically significant differences in BMD were observed within or between the groups. In terms of muscle strength and physical performances, significant improvements were observed across all measures in both group. Notably, HGS showed a statistically significant increase in the RE group compared to the HE group at the T2 and T3.

Osteosarcopenia is not uncommon, with a reported prevalence ranging from 7 % to 19.2 % (Lee et al., 2023; Park et al., 2021). Osteopenia/osteoporosis and sarcopenia may co-occur because they share the same progenitor cells, are mechanically connected, and share paracrine and endocrine signals (Chen et al., 2016). Therefore, the treatment of osteoporosis and sarcopenia should not be determined solely based on each condition individually but should incorporate a common treatment approach for osteosarcopenia.

The Franconian Osteopenia and Sarcopenia Trial (FrOST) study reported that improved SMI and HGS could be achieved by 28 weeks of progressive resistance exercise with protein supplementation in men with osteosarcopenia (Lichtenberg et al., 2019). Banitalebi et al. reported the effect of 12 weeks elastic band resistance training in 63 elderly women with osteosarcopenic obesity improved the osteosarcopenia Z-score, 30-s chair stand test, and HGS in an experimental group (Banitalebi et al., 2020). However, the lack of generalisability of this study confined to women with osteosarcopenic obesity could be an issue, as osteosarcopenia in women is associated with a low BMI (Blomqvist et al., 2024).

In sarcopenia, there is evidence that a resistance exercise could increase lean mass, HGS, and physical performance (Ferreira et al., 2023; Lu et al., 2021). Regarding osteoporosis, weight-bearing and resistance exercises are recommended to increase bone formation and halt osteoporosis progression (Watson et al., 2018). Nutritional support in the population with osteosarcopenia recommend supplementation of protein (1.2–1.5 g/kg/day), vitamin D (800 IU/day) and calcium (1000–1200 mg/day) (Kirk et al., 2021). Therefore, resistance exercise with nutritional support containing protein, vitamin D, and calcium was recommended for managing osteosarcopenia. In our study, postmenopausal women with osteosarcopenia had a significant increase in SMI at the T2 significantly, however, this statistical significance was lost at the T4. The reason for this phenomenon is unclear, but one possible explanation may lie in the change in training principles between phase 2 and phase 3. Specifically, the exercise protocol shifted from a non-repetition maximum (nRM) approach to a repetition maximum (RM) approach, involving an increase in load and a reduction in the number of sets. Although participants were instructed to increase the load to the extent possible and were encouraged by supervising therapists, the actual weight increments may not have reached the intended intensity. Additionally, the reduced number of sets may have decreased the overall training volume, potentially impacting the observed outcomes.

Previous research postulated that exercise has positive effects on BMD (Mohebbi et al., 2023). However, in our study, despite 24 weeks of progressive resistance exercise, no significant changes in BMD were observed. Nevertheless, this does not necessarily imply that resistance exercise with nutritional support is ineffective at improving BMD in patients with osteosarcopenia. Instead, it may reflect the influence of supervised versus non-supervised exercises, as the control group performed home exercises. Previous meta-analyses have demonstrated the non-superiority of the effects of supervised versus non-supervised exercise on BMD (Mohebbi et al., 2023). Therefore, the lack of changes in BMD in both groups could be considered consistent with the results of previously published studies.

This clinical trial confirmed that both the RE and HE groups showed improvements in HGS and physical performance. Despite conducting

two additional progressive resistance exercise sessions in the RE group, no statistically significant differences between the groups were observed in physical performance. However, a significant increase in HGS was observed in the RE group compared to the HE group at T2 and T3. The minimal clinically important difference (MCID) for HGS has been previously reported to be approximately 2.5 kg (Bobos et al., 2020). Therefore, the changes observed in both groups met the MCID criteria for the HGS. Similarly, gait speed also showed changes exceeding the MCID (0.1 m/s) before and after the intervention in both groups (Bohannon and Glenney, 2014). In addition, the overall physical function assessed using the SPPB, BBT, and MQI showed improvements in both groups, without no significant intergroup differences. This suggests that, assuming compliance is ensured, home exercises combined with nutritional supplementation alone may lead to functional improvement in patients with osteosarcopenia. This finding could be an important consideration for future research.

A limitation of this study is its relatively small sample size, with only 17 participants per group. This raises concerns regarding the statistical power and generalisability of the findings. Future studies should consider conducting large-scale prospective randomised trials to confirm these results. Moreover, the participants in this study were relatively healthy osteosarcopenic patients who were recruited locally, which limits the generalisability of the findings to a broader population. Additionally, although the inclusion criteria targeted individuals aged 65 to 90 years, the oldest participant enrolled was 85 years old, and no participants were included in the 85–90 age range. Therefore, the findings of this study may not be fully applicable to the very elderly population (aged 85 and above). Another limitation of this study is the inability to objectively assess compliance with the home exercise program. Although participants were regularly encouraged to perform home exercises through phone follow-ups and reported exercise two to three times per week, no formal exercise logs were collected, and compliance was based solely on self-report. It remains uncertain whether similar outcomes would be observed in patients with other comorbidities, such as hospital patients, individuals with depression, or those with other health conditions. Therefore, the applicability of these results in diverse clinical settings requires further investigation.

5. Conclusion

In postmenopausal women with osteosarcopenia, 24 weeks of progressive resistance exercise combined with home exercise and nutrition can lead to improvements in muscle mass and strength. Additionally, home exercise with nutrition alone can result in similar improvements in physical performance. Furthermore, both exercise regimens were performed safely. Therefore, progressive resistance exercise could constitute an initial exercise strategy, followed by home exercise with nutritional supplementation as maintenance treatment for osteosarcopenia.

CRediT authorship contribution statement

Byung Chan Lee: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Kyung Il Kim:** Investigation, Data curation. **Juhyun Lee:** Investigation, Data curation. **Kang Hee Cho:** Writing – review & editing, Supervision. **Changwon Moon:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization.

Clinical trial registration

This clinical trial was registered with the Clinical Research Information Service of the Republic of Korea, KCT0008291, registered on 16 March 2023 with the date of first enrolment on 20 March 2023 <https://cris.nih.go.kr/cris/search/detailSearch.do/23638>.

Consent for publication

Not applicable.

Ethics statement

The ethical validity of the trial was assessed and approved by the Institutional Review Board of Chungnam National University Hospital (CNUH-2022-12-026). All participants provided written informed consent before enrollment and agreed to participate in the study. The trial was conducted in accordance with the ethical principles of the Declaration of Helsinki.

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Declaration of competing interest

Authors have no conflict of interest to declare.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.exger.2025.112869>.

Data availability

The datasets used and/or analyzed in the current study are available from the corresponding author upon reasonable request.

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