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ORIGINAL ARTICLE

Effects of short-term aerobic exercise with and without external loading on bone metabolism and balance in postmenopausal women with osteoporosis

Tayebeh Roghani · Giti Torkaman · Shafieh Movasseghe · Mehdi Hedayati · Babak Goosheh · Noushin Bayat

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Abstract The aim of this study is to evaluate the effect of submaximal aerobic exercise with and without external loading on bone metabolism and balance in postmenopausal women with osteoporosis (OP). Thirty-six volunteer, sedentary postmenopausal women with OP were randomly divided into three groups: aerobic, weighted vest, and control. Exercise for the aerobic group consisted of 18 sessions of submaximal treadmill walking, 30 min daily, 3 times a week. The exercise program for the weighted-vest group was identical to that of the aerobic group except that the subjects wore a weighted vest (4–8 % of body weight). Body composition, bone biomarkers, bone-specific alkaline phosphatase (BALP) and N-terminal telopeptide of type 1 collagen (NTX), and balance (near tandem stand, NTS, and star-excursion, SE) were measured before and after the 6-week exercise program. Fat decreased ($p = 0.01$) and fat-free mass increased ($p = 0.005$) significantly in the weighted-vest group. BALP increased and NTX decreased significantly in both exercise groups ($p \leq 0.05$). After 6 weeks of exercise, NTS score increased in the exercise groups and decreased in the control group (aerobic: +49.68 %, weighted vest: +104.66 %, and control: −28.96 %). SE values for all directions increased significantly in the weighted-vest group. Results showed that the two exercise programs stimulate bone synthesis and decrease bone resorption in postmenopausal women with OP, but that exercise while wearing a weighted vest is better for improving balance.

Keywords Submaximal aerobic exercise · External loading · Postmenopausal women · Osteoporosis · Balance

T. Roghani · G. Torkaman (✉)
Physical Therapy Department, Faculty of Medical Sciences, Tarbiat Modares University, Ale-Ahmad Ave., 1411713116 Tehran, Islamic Republic of Iran
e-mail: torkamg@modares.ac.ir

S. Movasseghe
Department of Rheumatology, Vali-e-Asr Hospital, Theran University of Medical Sciences, Tehran, Islamic Republic of Iran

M. Hedayati
Obesity Research Center, Research Institute for Endocrine Sciences, Shahid Beheshti University of Medical Sciences, Tehran, Islamic Republic of Iran

B. Goosheh
Department of Cardiac Rehabilitation, Rofayde Hospital, University of Social Welfare and Rehabilitation Sciences, Tehran, Islamic Republic of Iran

N. Bayat
Department of Rheumatology, Baqiyatallah Hospital, Baqiyatallah University of Medical Sciences, Tehran, Islamic Republic of Iran

Introduction

Affecting about 200 million women worldwide, OP is a disease characterized by low bone mass and micro-architectural deterioration of bone tissue, which enhances bone fragility [1]. Menopause and aging are associated with low physical activity [2], and a sedentary lifestyle is particularly prevalent in postmenopausal women living in urban areas [3]. Due to the decrease in mechanical stimulation of bone, a decrease in muscle loading is associated with low muscle mass as well as decreased strength, coordination, and balance. All of these changes reduce physical fitness and quality of life [2, 3]. Aging women with osteoporosis are at a higher risk for fracture than women without OP.

The reason for the higher risk is not only low bone mass, but also decreased balance and muscle strength [4]. There is evidence that exercise can prevent some of the complications associated with menopause, such as bone loss, loss of physical fitness, and increased risk of coronary heart disease [5]. Physical exercise without the side effects of drug therapy can decrease risk factors for falling [6] and, importantly, improve balance [2, 7, 8].

High-impact and weight-bearing exercises are primarily important to increase bone mass [9, 10]. Because changes in bone mass resulting from physical activity occur slowly and may be site-specific [11], the use of biomarkers to determine changes in bone turnover changes and to clarify the mechanism of the impacts of exercise on bone has expanded. Assessment of bone-specific alkaline phosphatase (BALP) has an important role in the prevention and treatment of OP in postmenopausal women [12]. BALP is used as a bone formation marker in studies because of its high accuracy and sensitivity [13]. Study of N-terminal telopeptide of type 1 collagen (NTX) has revealed information concerning the mechanisms of action of loading on bone turnover [14]. Measurements of bone markers are an effective and noninvasive manner and are able to detect even short-term changes [13]. Several studies have reported on the impact of exercise on bone biomarkers; however, the results have been inconsistent. These inconsistencies may be because of differences in the mode, intensity and duration of exercise, subject age, and the type of biomarkers measured.

Thus, the effects of exercise on bone metabolism in postmenopausal women are not well established, especially regarding the effects of aerobic exercise [15, 16]. Some studies have shown beneficial effects of aerobic exercise for OP [9, 17, 18]. Results of a study by Adami et al. [11] showed an increase in bone formation marker levels only after short-term physical activity. Furthermore, there is evidence that a combination of aerobic and anaerobic exercise increases levels of bone formation markers [19].

Because postmenopausal women with OP are at a higher risk for falling and fractures, there is a necessity for more studies, especially to develop typical exercise regimes that are easy and safe and that have sufficient impact on the musculoskeletal system. Although high-impact and weight-bearing exercises seem to be more effective for a greater osteogenic response [9, 10], these exercise programs may be associated with injury and fracture risk in women with OP [20].

Shaw et al. [21] found that weight-bearing resistive exercises lasting for 9 months significantly increased muscle strength of the lower extremities and lateral stability in postmenopausal women. Fiqueroa et al. [22] found that exercise while wearing a weighted vest increased not only muscle strength, but also total and local lean mass. Teoman et al. [3] showed that a 6-week submaximal aerobic exercise program improved muscle strength, endurance, and balance. They concluded that a regular and controlled 6-week exercise program can improve the physical fitness level and quality of life of postmenopausal women. Gunendi et al. [23] also reported that 4 weeks of submaximal aerobic exercise improved both static and dynamic balance in postmenopausal women with OP.

Hourigan et al. [4] focused on adding external loading, such as a weighted vest for improving balance. These vests are easy for elderly individuals to wear, provide well-distributed loading on the pelvic and lumbar spine regions, and allow the applied force to be increased gradually. Therefore, they provide a safe and appropriate form of exercise for aging individuals [21]. In the present study, we investigated the effects of two types of submaximal aerobic exercise, a simple form and one with a weighted vest, on BALP, NTX, and balance in postmenopausal women with OP. We hypothesized that exercise with the weighted vest would improve bone formation and balance and decrease NTX in postmenopausal women with OP more than a simple aerobic exercise program.

Methods

Subjects and experimental design

Subjects were recruited from patients who were admitted to a rheumatology outpatient clinic, and through advertisements at medical clinics, clinics for densitometric measurements, and urban entertainment districts. A total of 100 sedentary, postmenopausal women volunteered to participate in this study. Inclusion criteria included: between 45 and 65 years of age, a body mass index (BMI) of 22–30 kg/m^2, menopause at least 6 months prior to the study, no record of regular exercise for at least 1 year, and a T-score for the hip and lumbar spine of at least −2.5 SD. The subjects were assessed by a rheumatology specialist. Any subject that had secondary OP, a history of osteoporotic fracture, diabetes, thyroid and renal diseases, a history of cardiovascular diseases, or orthopedic disorders was excluded. Subjects were also excluded if they were taking any drugs that affected bone metabolism or were receiving hormone replacement therapy. A cardiologist applied the modified Bruce test to assess the cardiovascular health of each participant. Overall, 64 women were excluded from the study.

The remaining 36 postmenopausal women with primary OP were randomly assigned into aerobic, weighted-vest, and control groups. Nine subjects were unable to complete the exercise program and withdrew from the study (4 in the aerobic group, 3 in the weighted-vest group, and 2 in the control group). The study was approved by the Ethics Committee of Tarbiat Modares University. After subjects were carefully informed about the design of the study, each subject signed a written informed consent prior to participation. Women in each group were asked not to alter their routine physical activity or dietary patterns during the course of the study.

Exercise protocol

The exercise program consisted of 18 sessions of submaximal aerobic walking exercise on a treadmill (Forma, Techno Gym, Wellness Company, Italia), 3 times a week, every other day, with each session lasting 30 min. The exercise program on the treadmill was similar for both the aerobic and weighted-vest groups and consisted of four parts: (1) 3-min warm-up, (2) 3–4 min to reach target heart rate (HRt), (3) 20-min holding of HRt, and (4) 3-min cooldown. The intensity of the exercise was increased gradually during the 6 weeks; specifically, 50 % heart rate reserve (HRR) during the first 2 weeks, 55 % HRR during the second 2 weeks, and 60 % HRR during the last 2 weeks. Heart rate, blood pressure (BP), and electrocardiogram (ECG) were monitored throughout the course of the exercise program. Exercise was stopped when BP exceeded 220/110 mmHg, the subject was unable to maintain the determined HRR, or ECG showed abnormalities.

Subjects in the weighted-vest group donned the vest before standing on the treadmill. The initial inner weight of the vest was 4 % of the individual's body weight and was gradually increased 2 % every 2 weeks based on the tolerance level of each subject. The design of the vest provided symmetrical distribution of load on the pelvic and lumbar spine regions, and weights were placed in the vest pockets so as to prevent flexor torque during exercise. The control group was requested not to change their daily physical activity or dietary patterns during the 6 weeks.

Measurements

Body composition measurements

Body weight was measured by a calibrated digital scale, and height was measured using a stadiometer. BMI was calculated as weight divided by height squared (kg/m^2). Body fat percentage was calculated by measuring subcutaneous fat at three locations (triceps, suprailium, and thigh) with calipers (Nederland b.v-Pondenral-Huidplooi-dikte-meter), and three measurements at each location were recorded. Fat-free mass was calculated by subtracting body fat percentage from total body weight using the Watson formula [24].

Blood sampling and bone marker measurements

Blood samples were taken after overnight fast and centrifuged at 2,600 g for 15 min. Blood sampling was done before and after the 6 weeks of exercise in the three groups. Serum samples were stored at −70 °C until the measurement of serum calcium (Ca), phosphorus (P), total alkaline phosphatase (tALP), BALP, and NTX levels.

Serum BALP (BSALP ELISA kit, Cusabio Biotech, Co. Ltd., Wuhan, P.R. China) and NTX (NTX ELISA kit, Cusabio Biotech, Co. Ltd.) were measured using an enzyme-linked immunosorbent assay (ELISA). The assay sensitivity of BALP and NTX was 3.12 and 0.8 %, respectively, and the intra-assay coefficient of variation (CV) of BALP and NTX was 7.2 and 7.6 %, respectively.

Balance measurement

The balance ability of all subjects was measured by near tandem stand (NTS) and star-excursion (SE) test. At the beginning of each test, a verbal and visual demonstration of the testing procedure was given to each subject by the examiner.

For the NTS, participants were asked to stand with their eyes closed in a near tandem position with their bare feet separated laterally by 2.5 cm, the heel of the front foot 2.5 cm anterior to the great toe of the back foot (Fig. 1). The time that participants were able to stand in this position before a step was taken or the eyes were opened was the score, three trials were conducted, and the best time was used as the test score.

The SE is performed with the subject standing at the center of a grid placed on the floor, with eight lines extending from the center of the grid. The eight lines positioned on the grid are labeled according to the direction of excursion relative to the stance leg: anterior (A), anterior-right (AR), right (R), posterior-right (PR), posterior

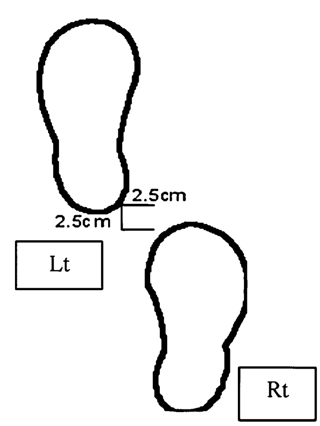

Fig. 1 The position of the feet in the near tandem stand test. *Lt* left foot and *Rt* right foot

(P), posterior-left (PL), left (L), and anterior-left (AL) (Fig. 2a). To perform the SE, each subject was asked to stand on their nondominant leg while reaching as far as possible along the appropriate vector with their dominant leg. The subject lightly touched the furthest point possible on the line with the most distal part of the reaching foot (Fig. 2b). The subject then returned to a bilateral stance while maintaining equilibrium. The examiner manually measured the distance from the center of the grid to the touch point. Three reaches in each direction were recorded. Subjects were given 15 s of rest between reaches. The mean of the three reaches was calculated for each direction.

Statistical analysis

All data were analyzed with SPSS software package (version 17.0). Kolmogorov–Smirnov test showed normal distribution of data, so we used ANOVA and Tukey's test to compare data in the three groups. Paired *t* test was used to determine the differences between data before and after 6 weeks of exercise in each group. Statistical significance was set at $p \leq 0.05$.

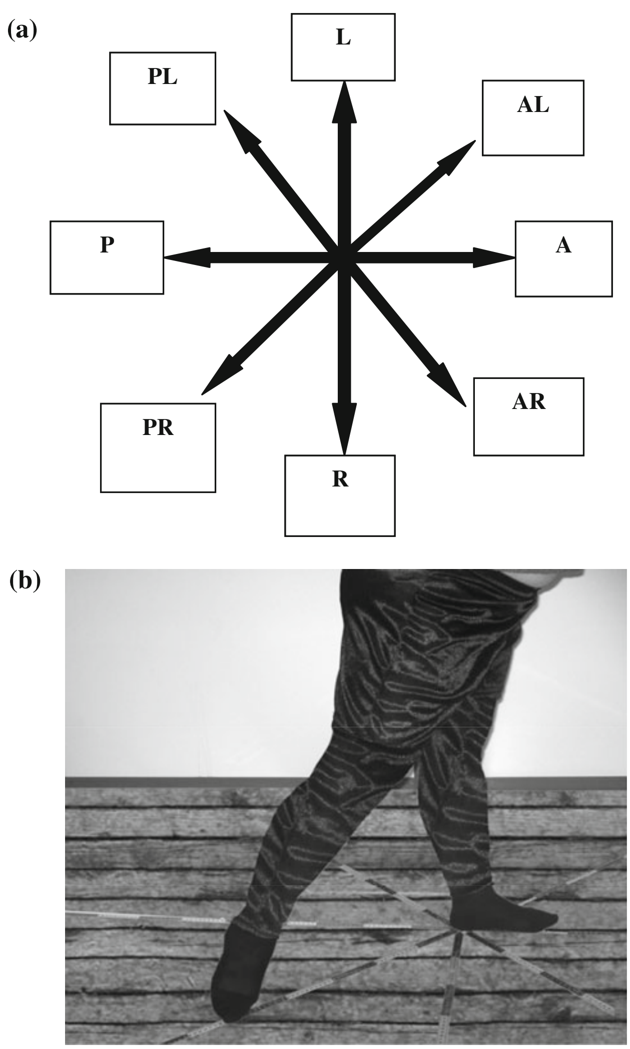

Fig. 2 Star-excursion test. **a** Star-excursion test directions; *A* anterior, *AR* anterior-right, *R* right, *PR* posterior-right, *P* posterior, *PL* posterior-left, *L* left, and *AL* anterior-left. **b** Star-excursion test method (with patient's permission)

Results

The physical characteristics of women in the three groups are shown in Table 1. No significant differences were found between baseline anthropometric measurements of the three groups. Fat mass decreased in the aerobic and the weighted-vest groups (2.39 and 8.37 %, respectively). Fat-free mass increased in the weighted-vest group (7.81 %). The changes in fat mass and fat-free mass were significant for the weighted-vest group ($p = 0.01$ and $p = 0.005$, respectively).

There were no significant differences between baseline serum measurements of the three groups except for *p* levels (Table 2).

After the 6 weeks of exercise, BALP significantly increased in the aerobic (10.25 %, $p = 0.03$) and the weighted-vest (7.31 %, $p = 0.05$) groups, but decreased approximately 1.93 % in the control group (Fig. 3a). NTX significantly decreased in the aerobic (5.99 %, $p = 0.001$) and the weighted-vest (6.34 %, $p = 0.002$) groups, but increased in the control group (0.60 %, $p = 0.60$) (Fig. 3a). The changes in bone biomarker levels were significant between each exercise group compared to the control group ($p \leq 0.05$). In the weighted-vest group, Ca was significantly increased after the exercise program, compared to that in the control group ($p \leq 0.05$). There were no significant differences in TALP and P in the three groups (Fig. 3b).

After 6 weeks of exercise, the NTS score increased in the exercise groups and decreased in the control group (aerobic: +49.68 %, weighted vest: +104.66 %, and control: −28.96 %). SE values for all directions increased significantly in the weighted-vest group, whereas the increases in SE values for three directions (AR, R, and L) were not significant in the aerobic group. The control group showed a significant decrease in all SE values (Table 3). The left direction was the hardest direction in the SE test for all groups. After the exercise program, the score for this direction showed the largest increase (+22.31 %) and the largest decrease (−15.01 %) in the weighted-vest and control groups, respectively.

Discussion

In this study, we assessed the effect of a 6-week submaximal aerobic exercise program with and without external

Table 1 Physical characteristics in the three groups (mean ± SD)

Variable	Aerobic group		Weighted-vest group		Control group	
	Pre	Post	Pre	Post	Pre	Post
Weight (kg)	66.90 ± 5.58	65.75 ± 5.66*	64.42 ± 7.1	64.01 ± 6.53	62.83 ± 4.79	62.88 ± 4.83
BMI (kg/m^2)	27.55 ± 2.46	27.03 ± 2.45*	26.29 ± 1.71	26.14 ± 1.66	25.79 ± 2.22	25.81 ± 2.20
Fat mass (kg)	33.78 ± 6.18	32.76 ± 4.87†	33.33 ± 3.67	30.55 ± 4.3*,†	28.28 ± 6.26	31.76 ± 3.99*
Fat-free mass (kg)	33.11 ± 6.51	32.98 ± 6.27†	31.08 ± 5.24	33.45 ± 5.57*,†	34.62 ± 7.31	31.12 ± 6.14*

* Significant difference between before and after 6 weeks in each group

† Significant difference related to the control group

Table 2 Serum data in the three groups (mean ± SD)

Variable	Aerobic group		Weighted-vest group		Control group	
	Pre	Post	Pre	Post	Pre	Post
NTX (nM)	20.80 ± 2.37	19.51 ± 1.88*,†	21.10 ± 2.33	19.72 ± 1.91*,†	21.08 ± 2.32	21.20 ± 2.38
BALP (U/L)	156.12 ± 38.08	173.37 ± 51.20*,†	154.22 ± 33.73	166.44 ± 43.92*,†	139.70 ± 59.55	136.60 ± 57.37
tALP (U/L)	218.00 ± 68.32	226.12 ± 72.11	222.44 ± 60.96	221.55 ± 80.04	181.50 ± 83.36	186.70 ±80.04
Ca (mg/dL)	9.10 ± 0.11	9.16 ± 0.25	8.91 ± 0.16	9.23 ± 0.23*,†	9.06 ± 0.38	9.07 ± 0.20
P (mg/dL)	3.86 ± 0.40	3.84 ± 0.35	3.33 ± 0.43	3.53 ± 0.26	3.79 ± 0.42	3.83 ± 0.66

* Significant difference between before and after 6 weeks in each group

† Significant difference related to the control group

loading on bone markers (NTX and BALP) and balance in postmenopausal women with OP. Our results showed that the two exercise programs increased BALP and decreased NTX, but that the aerobic program with external loading led to greater improvement in the Ca–P level and balance, a larger decrease in fat mass, and a larger increase in fat-free mass. Women with OP are at a higher risk for fracture than women without OP not only because of a lower bone mass, but also because of a higher risk for falling [6]. During the postmenopausal period, physical fitness decreases due to a decrease in physical activity, an increase in body weight, a decrease in muscle mass and strength, and postural changes [3]. Furthermore, the risk of falling increases due to hormonal changes that affect postural stability [23]. There is also a strong relationship between balance deficit and the incidence of falls. All of these factors can decrease independence and quality of life [7]. Several studies have confirmed that physical activity can improve physical fitness and quality of life [25, 26].

In the present study, both the aerobic and the weighted-vest groups showed a decrease in fat mass, but this decrease was significant only in the weighted-vest group. Moreover, a significant increase in fat-free mass was seen in the weighted-vest group. These results revealed the positive effects of aerobic exercise with a weighted vest on body composition variables in postmenopausal women. Our findings are in agreement with those of previous studies [21, 22].

To compare the effects of the two exercise regimens on bone turnover, we measured BALP and NTX. BALP levels are sensitive to aerobic exercise, and NTX is more sensitive to aerobic exercise than C-terminal telopeptide of type 1 collagen (CTX) [27]. After 6 weeks, BALP levels were increased, and NTX levels were decreased in the two exercise groups compared to the control group, but no significant difference was seen between the two exercise groups. It seems that short-term submaximal exercise can improve bone formation and decrease bone resorption in postmenopausal women with OP.

In regard to the mechanism by which exercise brings about positive effects on bone mass in postmenopausal women with or without osteopenia/osteoporosis, several studies have reported the effect of physical activity on bone markers.

A submaximal walking program resulted in a decrease in urinary NTX levels and protection of lumbar BMD in postmenopausal women with osteopenia/osteoporosis [9]. Adami et al. [11] reported that even minimal changes in physical activity levels in sedentary healthy women were associated with an increase in bone formation marker levels. Six weeks of aerobic weight-bearing exercise was shown to significantly increase bone formation marker levels of BALP, osteocalcin (OC); however, resorption marker levels, CTX and receptor activator of nuclear factor kappa-B ligand (RANKL), were not significantly changed [28].

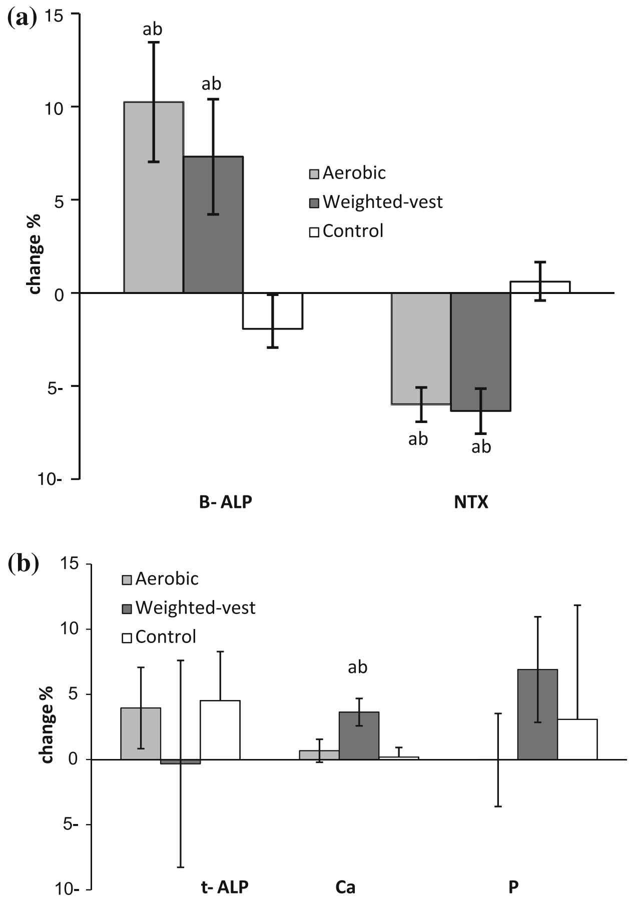

Fig. 3 Percent changes in serum data in the three groups. **a** percent changes in bone biomarkers, **b** percent changes in other serum factors. *a* Significant difference related to baseline serum measurements. *b* Significant difference related to the control group

Table 3 Percent changes in star-excursion test between before and after the 6 weeks in the three groups

Variable	Aerobic group change (%)	Weighted-vest group change (%)	Control group change (%)
SE (A)	+7.96*,†	+11.55*,†	−7.94*
SE (AR)	+6.68†	+12.21*,†	−8.95*
SE (R)	+10.92†	+9.73*,†	−10.72*
SE (PR)	+13.06*,†	+20.52*,†	−8.17*
SE (P)	+16.29*,†	+10.52*,†	−10.61*
SE (PL)	+14.86*,†	+12.43*,†	−12.53*
SE (L)	+7.55	+22.31*,†	−15.01*
SE (AL)	+8.44*,†	+8.14*,†	−9.48*
Mean	+10.72*,†	+13.43*,†	−10.43*

* Significant difference between before and after 6 weeks in each group

† Significant difference related to the control group

Lester et al. [19] showed that resistance and combined exercise for 8 weeks is more efficient for increasing bone formation marker levels than simple aerobic exercise. Twelve weeks of weight-bearing Tai Chi results in significant changes in bone metabolism and bone turnover markers [29]. Although the results of these studies are inconsistent, all of the studies emphasized the positive effects of exercise on bone mass in postmenopausal women with or without OP.

Physical activity can affect serum Ca and P concentrations [30]. Assessment of the serum Ca–P homeostasis is the impact manner for control of the bone loss decrease in postmenopausal women [31]. Increase in Ca level without concomitant rises in P level indicates insufficient bone formation, but balanced Ca–P levels indicate skeletal system homeostasis [32]. In the present study, the serum Ca level significantly increased in the weighted-vest group after 6 weeks of exercise. Although serum P levels showed no significant increase in the weighted-vest group, the Ca–P level remained balanced only in this group. Therefore, it seems that this form of exercise is more effective than simple aerobic exercise for bone formation.

Assessment of the urinary Ca–P level can also be used to estimate accurate osteogenic response, but we were unable to assess urinary samples because of study limitations.

The magnitude of applied load on bone increases directly with the exercise intensity [maximum heart rate (HRmax), maximum oxygen consumption (VO_2max), and repetition maximum (RM)] [33].

The intensity of exercise in studies of postmenopausal women with or without OP has ranged from 50 to 85 % HRmax [9, 22, 23, 34]. To prevent probable injuries and, more importantly, to apply loads higher than ordinary daily loads for the aging women comprising our study population, the walking exercise intensity was chosen as 50–60 % HRR (65–75 % HRmax). The positive effect of progressive and periodic exercise on bone mass and bone loss has been shown [10, 35]; thus, to take into consideration bone adaptation to applied loading and to prevent bone fatigue, we gradually increased walking intensity and the inner weight of the vest. Walking on a treadmill is a dynamic exercise that results in skeletal loading from two main sources, body weight and muscle contraction. In the weighted-vest group, in addition to body weight and muscle contraction, the inner weight of the vest also applied load to the pelvic and lumbar spine regions. Wearing the vest during walking stimulates more muscle fiber contraction, especially type II muscle fibers, than during simple walking [36]. Therefore, the applied load on the skeleton, especially the pelvic and lumbar spine regions, is increased. Submaximal walking on a treadmill while wearing a weighted vest is effective exercise for stimulating bone formation and maintaining the balance between bone formation and resorption in postmenopausal women with OP. There was no significant difference in the effect on bone metabolism between the weighted-vest and aerobic groups, likely due to our study limitations.

A major limitation of the present study was the short duration. Significant changes between exercise groups might be seen in a long-term study. There were also limitations in terms of increasing the weight of the vest because of the ages and low tolerance levels of the subjects.

Another purpose of this study was to compare the effect of the two exercise programs on balance in postmenopausal women with OP. Our results showed an increase in NTS and SE scores in the two exercise groups, while the control group showed a significant decrease in both balance test scores. Compared to women in the control group, women in the weighted-vest group showed significant improvements in all balance criteria (NTS test and all directions of SE); that is, they were better than those in aerobic training group. The most difficult direction scores (L) showed the largest increases in the weighted-vest group (22.31 %). There have been some studies on the role of applied external loading on balance [8, 21, 37]. A review article showed that weight-bearing and strengthening exercises, along with other exercises, should be proposed to individuals with OP for improving balance, mobility, postural stability, and for decreasing falling risk and related disabilities [38].

Our important findings showed that adding an external load (i.e., weighted vest) to simple aerobic exercise has more effect on balance in women with OP than a simple aerobic training. Notably, these effects were obtained in only 6 weeks. Although at least 3 months of exercise was suggested to reduce the incidence of falls in aging women [23], several studies with programs of different duration showed incongruous results [23, 39]. This discrepancy in results may be due to differences in the type, intensity, frequency, and duration of the exercise programs. Improving balance does not guarantee prevention of falling [23]. The duration of the present study was too short to show the beneficial effects of the two exercise regimens on the rate of falling. This short duration was the main limitation of our study in terms of assessing the effects of exercise on the rate of falling. Therefore, randomized controlled studies with longer durations must be conducted to determine the effects of these exercise programs on the rate of falling in postmenopausal women with OP. The significant decrease in balance in the control group after 6 weeks is an important warning for postmenopausal women. Controlled walking with an inexpensive weighted vest is an effective way for women with OP to improve neuromuscular fitness and maintain balance.

Conclusion

Exercise is an effective nonpharmacologic intervention to protect bone integrity and, more importantly, improve balance and physical fitness in postmenopausal women with OP. Results of this study showed that both simple aerobic exercise and exercise while wearing a weighted vest decrease NTX and increase BALP levels in postmenopausal women with OP. Furthermore, compared to simple aerobic exercise, weighted-vest aerobic exercise is more effective for improving balance in postmenopausal women with OP. To maintain these changes, exercise must be a part of daily activities.

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Conflict of interest The authors declare that there are no conflicts of interest.

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