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Resistance Training over 2 Years Increases Bone Mass in Calcium-Replete Postmenopausal Women

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ABSTRACT

Understanding the stress/strain relationship between exercise and bone is critical to understanding the potential benefit of exercise in preventing postmenopausal bone loss. This study examined the effect of a 2-year exercise intervention and calcium supplementation (600 mg) on bone mineral density (BMD) in 126 postmenopausal women (mean age, 60 ± 5 years). Assignment was by block randomization to one of three groups: strength (S), fitness (F), or nonexercise control (C). The two exercise groups completed three sets of the same nine exercises, three times a week. The S group increased the loading, while the F group had additional stationary bicycle riding with minimal increase in loading. Retention at 2 years was 71% (59% in the S group, 69% in the F group, and 83% in the C group), while the exercise compliance did not differ between the exercise groups (S group, 74 ± 13%; F group, 77 ± 14%). BMD was measured at the hip, lumbar spine, and forearm sites every 6 months using a Hologic 4500. Whole body BMD also was measured every 6 months on a Hologic 2000. There was no difference between the groups at the forearm, lumbar spine, or whole body sites. There was a significant effect of the strength program at the total (0.9 ± 2.6%; $p < 0.05$) and intertrochanter hip site (1.1 ± 3.0%; $p < 0.01$). There was a significant time and group interaction ($p < 0.05$) at the intertrochanter site by repeated measures. This study shows the effectiveness of a progressive strength program in increasing bone density at the clinically important hip site. We concluded that a strength program could be recommended as an adjunct lifestyle approach to osteoporosis treatment or used in combination with other therapies. (J Bone Miner Res 2001;16:175–181)

Key words: **osteoporosis, exercise, strength training, resistance training**

INTRODUCTION

Understanding the adaptation of bone to exercise is critically important in designing public health strategies for the prevention of osteoporosis. Previous exercise studies have shown a positive effect of weight-bearing exercise on bone mass.[1–8] However, evidence from animal and human studies suggests that strength training may have more favorable effects on maintaining or increasing bone mass. Bone is sensitive primarily to the short periods of loading[9,10] with unusual strain distributions, high peak strain magnitudes, and rapid change of strain. The results of animal studies suggest that greater strain magnitudes and unusual strain distributions provide the most effective stimulus for bone formation.[11,12] These findings have led to a number of studies that showed a positive effect of strength

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training on bone mass in both premenopausal[13–17] and postmenopausal women.[18–19]

In a previous unilateral exercise study, we compared two strength training regimens that differed only in the number of repetitions of the weight lifted. The strength program significantly increased bone density at the hip and forearm sites whereas the endurance program did not.[19] The effects of strength training were specific to the site of loading and load dependent. Because the study was for 1 year, it was not clear if the positive effects on bone mass could be maintained over a longer time. Therefore, we have designed a 2-year, randomized, controlled trial to compare the same strength training regimen but with different degrees of loading. The purpose was to investigate the effects of two exercise interventions compared with a nonexercise control on postmenopausal bone loss. The strength group aimed at promoting muscular strength gains while the fitness group aimed at improving cardiovascular fitness. We hypothesized that the strength protocol would reduce the rate of bone loss in postmenopausal women whereas the fitness protocol would not.

MATERIALS AND METHODS

Recruitment of subjects was from volunteers who responded to media articles. Telephone screening was completed initially and 163 subjects who were eligible for the study attended an information seminar. After signing an informed consent, 141 women agreed to undergo bone density testing and a final 126 women were randomized into the study. The subjects consisted of 126 women who were more than 4 years past menopause and physically capable of entering exercise groups but who were not already exercising at a moderate intensity more than 2 h/week. Women who had performed resistance weight training in the previous 5 years were excluded. Other exclusion criteria included those on hormone replacement or other medications or who had diseases known to affect bone density and those who had cardiovascular, physical, or orthopedic disabilities that would place the subjects at risk or limit their ability to perform exercise. The study was approved by the Human Rights Committee of The University of Western Australia.

Bone density was measured using the array mode at the hip, lumbar spine, and radial forearm at 6-month intervals from baseline using dual-energy X-ray technology, on a QDR 4500 machine and for the whole body on a QDR 2000 machine (Hologic Inc., Waltham, MA, USA). Throughout the study, daily calibration checks were performed on both machines using spine phantoms provided by the manufacturer. Recalibration also was performed during each maintenance event. As an extra quality assurance measure, rolling averages of phantom-derived data were computed for each machine over the entire period of the study. From these data, look-up tables were devised to permit small corrections for long-term machine drifts, based on the machine and the date of the scan. The hip bone mineral density (BMD) site was measured using the array mode and included the area of the femoral neck, trochanter, and intertrochanter site. The left hip was scanned in all subjects. The neck or femur site was defined as a rectangle 6.0 mm wide traversing the femoral neck placed against the greater trochanter. The trochanter site was a triangular region with boundaries defined as the lateral edge of the femoral neck area to a point where the edge of the femur changes curvature below the trochanter. The intertrochanteric region was the remainder of the femur extending 10.0 mm below the lesser trochanter, and Ward's triangle site was a machine-determined site in the center of the femoral neck.

The radial forearm BMD site was defined as the area of the radius at the ultradistal site (UD), the midsite, and the one-third site as follows: UD site was defined as the area from 2 pixels proximal to the base of the articular surface, at the base of the ulnar-styloid process to 10.0 cm proximally; midsite was defined as the area extending from the proximal edge of the UD area to the distal edge of the one-third site; and the one-third site was defined as the area extending from the edge of the midsite. The forearm was in a horizontal position with the elbow resting on the table and the hand held loosely cupped over the plastic apparatus provided by Hologic. The left forearm was scanned in all subjects except those who were left-hand dominant where the right was used. The lumbar spine BMD was measured according to a standard protocol, with the scanned region from the fourth to the first lumbar vertebrae. The subject's legs were placed on the cushion provided to flatten the lumbar spine. A whole body scan using the array mode was measured every 6 months using a QDR 2000 machine. Subjects were scanned while lying supine on the table with arms at the side. The Step Phantom (tissue bar) was placed beside the subject's feet on the right side and is used to calibrate lean and fat-equivalent tissue. The scans were analyzed using standard software program supplied by the manufacturer for bone mineral content (BMC), BMD, and soft tissue body composition. The CVs in our laboratory were 1% at the lumbar spine and whole body, 1.6% for the radius UD site, 1.4% for the radius midsite, and 1.3% for the radius one-third site. At the hip site, the CV was 1.5% at the femoral neck, 1.3% at the trochanter, 1.3% at the intertrochanter, and 3.3% at Ward's triangle.

Each subject completed an activity record for a 7-day period on three occasions—at baseline, 1 year, and 2 years. From these records, the subject's most active 2 h of the day was scored using tables of metabolic equivalent activities[20] as a measure of the aerobic activity to derive an activity score (MET). One metabolic equivalent was defined as the energy consumed per minute sitting at rest and other activities were measured in relation to that standard. The values for an average 55-kg woman were used.

Study design

Assignment was by block randomization to one of three groups: a strength group (S), fitness group (F), or nonexercise control group (C). The S group protocol was designed to emphasize skeletal loading whereas the F group emphasized aerobic fitness. All subjects were given 600 mg of elemental calcium per day. Compliance with calcium supplementation and the exercise intervention was recorded. Data collection was completed at baseline and every 6 months thereafter.

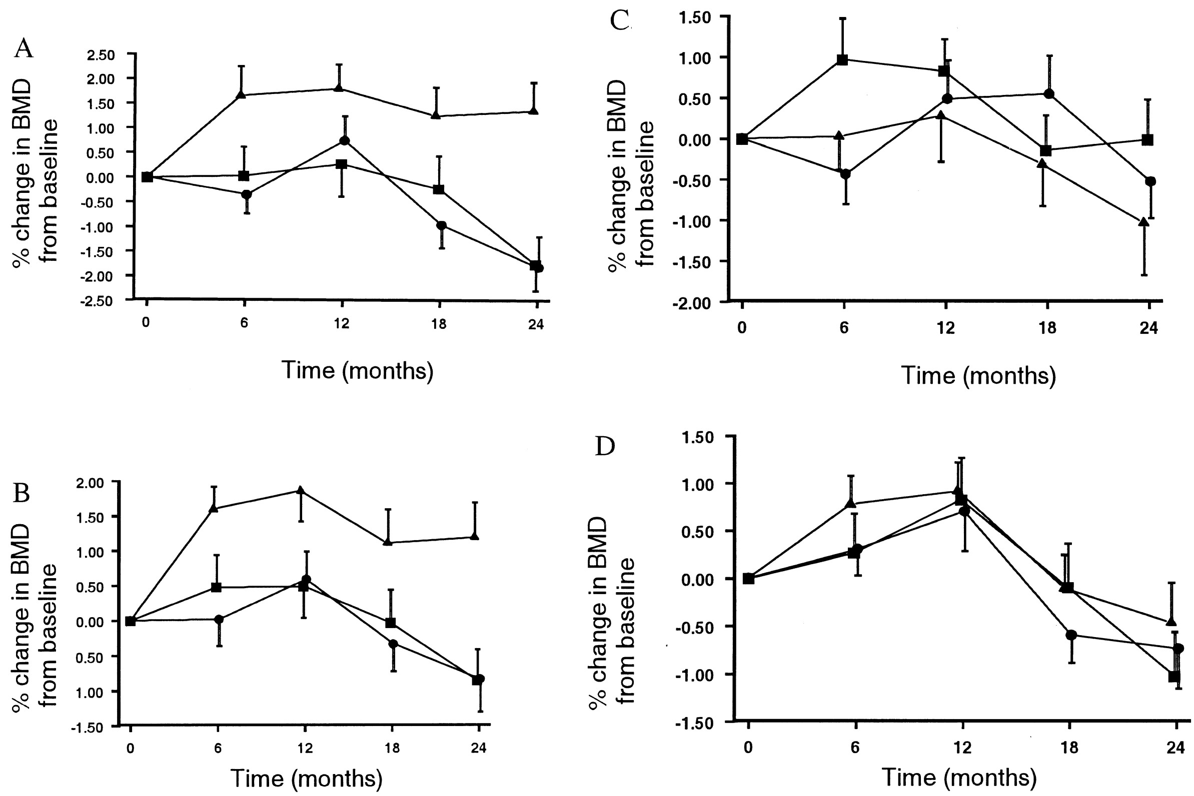

FIG. 1. The percentage change (±SEM) from baseline over the 2 years of the study. (A) The intertrochanter hip site, the S group was significantly different ($p < 0.01$) from the F and C groups; (B) the total hip site, the S group was significantly different ($p < 0.05$) from the F and C groups; (C) the lumbar spine; and (D) whole body, no significant difference between the groups. All p values were calculated from repeated measures (▲, S group; ■, F group; ●, C group).

The two exercise groups attended three, 1-h sessions per week at the Human Movement and Exercise Science Weight Training Laboratory. Both exercise groups completed a warm-up consisting of brisk walking and stretching. This was followed by 30 minutes of resistance weight training exercises. Both groups completed the same nine exercises but the S group completed three sets of eight repetitions (3 × 8 RM). The S group progressively increased their load throughout the study, at an individually tailored increment. The F group exercised for 40-s at each station with a 10-s break between and there was only minimal increase in load for the duration of the study. The F group also performed additional stationary bicycle riding for 40-s stations at a moderate intensity (heart rate less than 150 beats/minute). Although the F group performed the same resistance exercises as the S group, these were done using a minimal load and this load was not altered over the course of the study. The following exercises were selected so as to cause compression or tensile loading at the scanned sites: wrist curl, reverse curl, biceps curl, triceps pushdown, hip flexion, hip extension, latissimus dorsi pull down, and calf raise. Qualified exercise physiologists supervised all exercise sessions.

Statistical treatment

Statistical analysis was conducted using SPSS version 8.0 for Windows (SPSS, Inc., Chicago, IL USA). Time, group, and interaction effects for bone density were examined using a two-way analysis of variance (ANOVA) with repeated measures on one factor (time). All p values were calculated from repeated measures ANOVA. However, the bone density data, as shown in Fig. 1, are presented as the percentage change from baseline for clarity. A linear regression function was calculated by least squares regression for each individual completing the study and was used to derive a measure of the rate of change. Group comparisons were made by one-way ANOVA followed by Tuckey's post hoc test. Statistical analysis was conducted using Spearman's rank correlation and stepwise multiple regression analysis. The dependent variable was the outcome variable and the independent variable was the predictor variable. The results were analyzed also after adjustment for years since menopause and adjustment for weight. Residuals were examined for normality and all significance tests were two-tailed.

RESULTS

There were no differences in the baseline characteristics of subjects, with the exception of age in the C group, who were significantly older than the S or F group (Table 1). There was a difference in the years since menopause between groups, but this was not significant. The baseline

TABLE 1. BASELINE CHARACTERISTICS FOR S, F, AND C GROUPS

Characteristic	*S group*	*F group*	*C group*
No. of subjects	42	42	42
Age (years)	60 ± 5	59 ± 5	62 ± 6*
Years since menopause	11 ± 6	9 ± 5	12 ± 6
Body mass (kg)	72.2 ± 12.0	69.0 ± 11.4	69.3 ± 14.6
Stature (cm)	163.3 ± 5.4	165.3 ± 5.8	162.4 ± 6.6
Body fat (kg)	32.0 ± 9.2	28.8 ± 9.4	29.5 ± 10.9
Percentage body fat[a] (%)	43 ± 6	40 ± 7	41 ± 8
Lean body mass (kg)	39.5 ± 4.2	39.6 ± 4.3	39.0 ± 4.9
Activity (METS)	402 ± 50	390 ± 53	388 ± 59
Total spine BMD (g/cm^2)	0.90 ± 0.16	0.91 ± 0.12	0.94 ± 0.16
Total hip BMD (g/cm^2)	0.86 ± 0.12	0.84 ± 0.11	0.89 ± 0.15
Trochanter BMD (g/cm^2)	0.67 ± 0.10	0.65 ± 0.09	0.70 ± 0.10
Intertrochanter BMD (g/cm^2)	1.01 ± 0.15	1.00 ± 0.15	1.05 ± 0.15
Neck of femur BMD (g/cm^2)	0.72 ± 0.11	0.72 ± 0.09	0.76 ± 0.11
Radius UD BMD (g/cm^2)	0.36 ± 0.07	0.36 ± 0.07	0.36 ± 0.06
Radius midultradistal BMD (g/cm^2)	0.53 ± 0.06	0.53 ± 0.07	0.53 ± 0.07
Radius one-third (g/cm^2)	0.62 ± 0.08	0.62 ± 0.06	0.61 ± 0.08

[a] Calculated from dual-energy x-ray absorptiometry. Results are mean $\pm$ SD.
* $p < 0.05$, the C group is significantly different from the S and F groups.

BMD for all sites is shown in Table 1. There was no difference between the groups at baseline. In addition, there was no difference in body weight between the groups at baseline or at any time point throughout the study.

The overall retention of subjects in the study was 71% at 2 years. The lowest retention at 2 years was in the S group (59%), compared with 69% in the F group and 83% in the control group. Most of the subjects withdrew from the S group in the first 6 months of the study (69%) compared with a 93% retention in the F group and 86% in the control group. The most common reason for withdrawal was "time" with 13 women withdrawing for this reason. Three other women elected to commence hormone replacement therapy and were withdrawn from the study. Two subjects had a preexisting back and shoulder injury and another subject developed an injury to the wrist. These 3 subjects were in the F group and were unable to continue with the exercise program. Four subjects moved interstate and another 4 withdrew for family reasons. There was no difference at baseline between those subjects who withdrew from the study compared with those who finished the study for weight, height, activity score, or hip BMD. Women who withdrew from the study did not attend the final measurement occasion; therefore, we were unable to analyze the data for an "intention-to-treat" analysis.

Exercise compliance was evaluated by a record of attendance kept by the exercise physiologist supervising the session. Compliance was defined as percentage of attendance of all available training sessions. All subjects who finished the study were included in the analysis, regardless of their exercise compliance. There was no significant difference between the groups at any time throughout the study. Exercise compliance was very high in the first 6 months for both groups (S group, $90 \pm 12\%$; F group, $92 \pm 8\%$) but declined from this point on. In the last 6 months of the study, the compliance was $61 \pm 23\%$ for the S group and $67 \pm 20\%$ for the F group. The average exercise compliance over 2 years was $74 \pm 13\%$ in the S group and $77 \pm 14\%$ in the F group.

Percentage changes in BMD for each group are shown in Table 2. There was a significant time and group effect of the strength program on change in BMD at the intertrochanter ($1.1 \pm 3.0\%$; $p < 0.01$) and the total hip site ($0.9 \pm 2.6\%$; $p < 0.05$; Table 2, Fig. 1) as determined by repeated measures ANOVA. The addition of years since menopause and body weight as covariants did not change the result of the repeated measures ANOVA. The maximum gain in BMD in the S group occurred in the first 6 months ($1.6 \pm 3.0\%$) and was maintained for the remainder of the study ($0.2 \pm 3.2\%$ from 6 to 12 months; $-0.5 \pm 2.7\%$ from 12 to 18 months; $0.2 \pm 3.0\%$ from 18 months to 2 years). The F and C groups lost bone at the intertrochanter hip site such that the difference between the S group and other two groups was 3.2% greater at 2 years. There was no difference between the groups at the neck of femur or intertrochanter BMD sites at any time point. There was no significant group effect at the forearm or lumbar spine sites (Table 2). There also was no change in the BMC or area at the forearm, total hip, or neck of femur sites in either group throughout the study. The whole body BMD decreased in all three groups over the 2 years.

Linear regression analysis was performed for the S group using rate of change of BMD at the intertrochanter and total hip sites as the dependent variable. The only significant predictor of BMD at the intertrochanter and total hip sites was the baseline activity score ($r = -0.50$ and $p < 0.05$; $r = -0.46$ and $p < 0.05$, respectively), which was correlated negatively. Exercise compliance was not a significant predictor of the rate of change nor was years since menopause or body weight. There was no relationship in the S

TABLE 2. THE CHANGE IN BMD FOR THE HIP, LUMBAR SPINE, FOREARM, AND WHOLE BODY SITES EXPRESSED AS PERCENT CHANGE PER YEAR FOR THE S ($n = 24$), F ($n = 30$), AND C ($n = 36$) GROUPS FOR SUBJECTS COMPLETING THE STUDY

Site	*S group*	*F group*	*C group*
Intertrochanter	0.70 ± 2.08*	−1.07 ± 2.49	−1.18 ± 2.57
Neck of femur	1.04 ± 2.81	0.03 ± 2.22	−0.11 ± 2.60
Trochanter	0.00 ± 2.33	−0.02 ± 2.60	−0.01 ± 2.74
Total hip	0.57 ± 1.76†	−0.65 ± 1.81	−0.57 ± 1.97
Lumbar spine	−0.65 ± 2.12	−0.32 ± 1.85	−0.01 ± 1.98
Radius UD	−0.71 ± 2.77	−0.39 ± 3.19	−0.55 ± 3.03
Radius mid-UD	−0.35 ± 2.25	−1.21 ± 1.84	−0.47 ± 2.24
Radius one-third	−0.07 ± 2.65	−0.96 ± 2.50	0.05 ± 2.42
Whole body	−0.62 ± 1.38	−0.79 ± 1.73	−0.71 ± 1.69

* $p < 0.01$ and † $p < 0.05$ for S group compared with F and exercise C groups (post hoc analysis positive for Duncans and Tukeys).

group, between baseline BMD or exercise compliance and the rate of change of BMD, as assessed by the regression slope. Multiple regression was performed with rate of change in body density of the intertrochanter site for the S group as the dependent variable and total METS, years since menopause, muscle strength, exercise compliance, and baseline submaximal fitness as the independent variables. The results showed that baseline activity (METS) was a significant negative correlate of rate of change in bone density for the S group [$r = -0.50$, $r^2 = 0.25$, and slope $= -(2.0 \times 10^{-5})$total METS $+ 8.5 \times 10^{-2}$].

DISCUSSION

This study has shown a significant effect of strength training in postmenopausal women over 2 years at the clinically important intertrochanter hip site. Furthermore, we have shown the feasibility of this type of exercise for the prevention of osteoporosis or as an adjunct to other treatments. However, there was no added benefit on bone density of a circuit program, which aimed to improve aerobic fitness, over calcium supplementation alone. This suggests the load applied to the skeleton from strength training is the critical factor for the increased bone density observed.

The maximum change in bone density for the S group occurred in the first year of the intervention. There was a relative decline in the rate of change during the second year but the bone density remained more than a 3% difference between the S, F, and C groups after 2 years. This is consistent with Frost's theory in which he proposed a minimum effective strain (MESm) for bone modeling and remodeling and only when the bone strain exceeds the MESm will a net gain in bone occur.[21] Although subjects were encouraged to increase progressively the loading throughout the study, over time the strains may have fallen below the level required to increase the bone density. We did not find a relationship between compliance and rate of change of BMD. However, compliance was measured by attendance at the sessions but there is no way to be able to measure the intensity of effort.

Our results suggest that in the S group, those women who were least active at the start of the study were the most likely to respond to the intervention. The adaptation to mechanical loading is driven by the strain threshold detected in bone.[12] Low activity in the elderly may be perceived as disuse and contribute to the bone loss, alternatively high activity, or strain thresholds, which are perceived as abnormal may stimulate osteogenesis. However, because the baseline activity only partially accounted for the rate of change in bone density, there are other predictor variables of the rate of change in bone density for the S group that we have been unable to identify.

The results of this study are consistent with our previous findings. In a 1-year strength training study, using a similar exercise protocol, there was a significant increase in the BMD at the trochanter, intertrochanter, and forearm sites.[19] This study was able to show that a strength training program was site specific and load dependent. In the current study, no effect on BMD was observed at the forearm site. The reason for this is not clear but may be caused by differences in the exercise protocol used in the current study. The previous study included a forearm pronation and supination exercise but this was excluded from the current study. This exercise causes torsional loading at the forearm and may be a powerful stimulus for osteogenesis. Of the exercises designed to stress the hip region, hip flexion, hip extension, and leg press were included. The main difference from the previous study was the exclusion of hip abduction and adduction, which may have decreased the amount and direction of loading at the hip site and could account for the lack of effect observed at the trochanter hip site. No relationship was seen between the change in muscle strength and rate of change of bone density at the hip. This was in contrast to our previous findings in which we did show a relationship between the change in strength and bone density at several hip sites. This may be explained by the differences in the exercise protocol between the current and the previous study.

The lack of effect observed at the spine suggests that insufficient loading occurred with the strength training intervention. In younger premenopausal women, strength training has shown a positive effect at the lumbar spine in several studies.[14,17] Snow-Harter et al.[14] found a significant increase of 1.2% at the lumbar spine but no change at the femur with an 8-month strength training program. In an 18-month strength training program in premenopausal women, Lohman et al.[17] showed a significant effect with the exercise intervention at the lumbar spine and femur trochanter. Two studies conducted on postmenopausal women did show an effect at the lumbar spine.[18,22] The study by Pruitt et al.[22] was conducted over 9 months but was not randomized and had only 17 subjects. A significant effect was observed at the lumbar spine but not at the hip or forearm sites. Nelson et al.,[18] in a randomized controlled trial of 1 year of strength training in postmenopausal women, found a significant effect at the femoral neck and lumbar spine. The exercise protocol was similar to the current study except that only two sessions per week were performed and included trunk extension and abdominal flexion exercises, which may have increased the loading on the lumbar spine.

A positive effect of the calcium supplementation on bone density for all three groups cannot be excluded. The study by Prince et al.,[8] which examined the effect of calcium supplementation on postmenopausal women, showed the placebo group lost bone at the trochanter, intertrochanter, and neck of femur sites whereas the calcium supplemented groups did not. In the current study, all three groups received a calcium supplement of 600 mg/day. We did not observe a loss of bone at the trochanter or neck of femur sites in any of the three groups. This suggests that the calcium supplement may have slowed the rate of bone loss in all three groups.

The lack of effect of the fitness program on the BMD suggests that the exercise load was not sufficient to cause skeletal adaptation. Although the subjects performed the same exercises as the S group, they did more repetitions and had only a minimal increase in load throughout the study. The F group did additional stationary cycling but this was a weight-supported activity and was aimed at improving cardiovascular fitness. It would appear that the loads achieved were no more than those achieved with activities of daily living. However, the retention was greater in the F group, which suggests this program was more feasible for the volunteers. This has implications for exercise programming in postmenopausal women. Novices to strength training should be commenced on a fitness circuit program to familiarize them with strength training, gradually increasing the weight lifted and decreasing the number of repetitions. This is particularly important for older participants who may take longer to adapt to exercise training.[23]

We have shown that a strength program is effective in increasing bone density at the intertrochanter hip site. However, strength training does not improve cardiovascular fitness. Walking programs have been shown to be effective in slowing bone loss[8,24] and improving cardiovascular fitness if they are of sufficient duration and intensity. Strength training should not be used as a replacement for other exercise but as an adjunct to other weight-bearing aerobic activities.

In conclusion, a progressive strength training program, designed to promote maximum strength gains, is effective at increasing bone density over 2 years at the clinically important intertrochanter site. The fitness regimen did not increase bone mass but may be more feasible as the retention was greater in this group. Strength training can be recommended as an adjunct lifestyle approach to osteoporosis prevention or in combination with other treatments in postmenopausal women.

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