Effects of High-Intensity Strength Training on Multiple Risk Factors for Osteoporotic Fractures

A Randomized Controlled Trial

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Objective.—To determine how multiple risk factors for osteoporotic fractures could be modified by high-intensity strength training exercises in postmenopausal women.

Design.—Randomized controlled trial of 1-year duration.

Setting.—Exercise laboratory at Tufts University, Boston, Mass.

Population.—Forty postmenopausal white women, 50 to 70 years of age, participated in the study; 39 women completed the study. The subjects were sedentary and estrogen-deplete.

Interventions.—High-intensity strength training exercises 2 days per week using five different exercises (n=20) vs untreated controls (n=19).

Main Outcome Measures.—Dual energy x-ray absorptiometry for bone status, one repetition maximum for muscle strength, 24-hour urinary creatinine for muscle mass, and backward tandem walk for dynamic balance.

Results.—Femoral neck bone mineral density and lumbar spine bone mineral density increased by 0.005±0.039 g/cm^2 (0.9%±4.5%) (mean±SD) and 0.009±0.033 g/cm^2 (1.0%±3.6%), respectively, in the strength-trained women and decreased by −0.022±0.035 g/cm^2 (−2.5%±3.8%) and −0.019±0.035 g/cm^2 (−1.8%±3.5%), respectively, in the controls (P=.02 and .04). Total body bone mineral content was preserved in the strength-trained women (+2.0±68 g; 0.0%±3.0%) and tended to decrease in the controls (−33+77 g; −1.2%±3.4%, P=.12). Muscle mass, muscle strength, and dynamic balance increased in the strength-trained women and decreased in the controls (P=.03 to <.001).

Conclusions.—High-intensity strength training exercises are an effective and feasible means to preserve bone density while improving muscle mass, strength, and balance in postmenopausal women.

(*JAMA*. 1994;272:1909-1914)

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Presented in part at the 40th annual meeting of the American College of Sports Medicine, Seattle, Wash, June 5, 1993, and at the 41st annual meeting of the American College of Sports Medicine, Indianapolis, Ind, June 1, 1994.

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SKELETAL fragility associated with osteopenia, muscle weakness associated with sarcopenia (age-associated reduction in muscle mass), and deteriorating balance are all risk factors for bone fracture due to falls.[1-7] These factors are the consequences and causes of frailty seen with aging, which incurs tremendous economic, societal, and personal cost.[8,9] Exercise in elderly individuals has the potential to modify these risk factors for osteoporotic fractures. We previously have shown modest benefits in trabecular bone density of the spine after 1 year of walking in postmenopausal women with no effects on femoral bone density or total body calcium.[10] We have also demonstrated that muscle mass and strength can be increased substantially with high-intensity progressive resistance training in men and women of all ages, including the oldest old,[11-13] with associated increases in functional capacity.

Because, according to Wolff's law, bone remodeling is directly dependent on the mechanical load placed on it,[14] we hypothesized that a regimen of high-intensity strength training would be a potent stimulus for simultaneous increases in bone, muscle mass, and strength. Although cross-sectional studies of lifetime physical activity and bone density have been suggestive of a positive effect of muscle strength on bone,[15,16] to our knowledge, no randomized, prospective trial of high-intensity progressive resistance training in estrogen-deplete older women examining changes in bone density has been reported. The purpose of this study was to evaluate the effects of a 1-year, high-intensity strength training program on bone, muscle strength, and balance in postmenopausal women.

METHODS

Subjects

Forty postmenopausal white women were recruited from the Boston, Mass, area to participate in this study and gave their written informed consent. The protocol was approved by the Tufts University Human Investigation Review Committee. The women were at least 5 years postmenopausal, but not older than 70 years of age. They did not engage in any regular exercise program (no strength training and less than 20 minutes of aerobic exercise two times per week), weighed less than 130% of ideal body weight, were currently nonsmoking, did not have more than one crush fracture of the spine, had no history of other osteoporotic fractures, and had not taken estrogen or other medications known to affect bone for at least 12 months. Screening consisted of a physical examination, lateral spine roentgenogram, urine and blood tests, and electrocardiogram and blood pressure monitoring during a strength-training session. No subjects had any changes in electrocardiogram tracings related to the activity and only minor blood pressure elevations (<20 mm Hg systolic pressure) were noted. Six women in the study (three in each group) had one crush fracture of the spine; none of the crush fractures were in the lumbar spine.

Design

The study was a randomized controlled, 1-year clinical trial. The mean duration of participation for each woman was 52 weeks (range, 50 to 54 weeks). All baseline and final testing was carried out at the Jean Mayer USDA Human Nutrition Research Center on Aging at Tufts University, Boston, Mass. Twenty-one women were randomized to the exercise-training group and 19 women to the control group. Women were recruited for the study from July 1991 through March 1993. The women were weighed every 2 weeks during the study and were asked to neither gain nor lose more than 1 kg during the year.

One woman in the exercise-training group was excluded from the study owing to a myocardial infarction that occurred while she was on vacation during the first month of the study.

Testing Protocol

The same testing protocol took place at baseline and at the end of the year.

Each volunteer consumed a meat-free diet for 3 days prior to testing. The evening prior to the testing period the volunteer came to the laboratory. The following morning, a 24-hour urine collection was started and a blood sample was drawn after a 30-minute rest in the supine position. In addition, each woman participated in the following procedures: strength testing, meeting with dietitian, dual energy x-ray absorptiometry, balance testing, and activity questionnaire. The following morning the volunteer completed the 24-hour urine collection.

One week later subjects returned to repeat the strength measurements.

Interventions

Strength Training.—Subjects in this group participated in high-intensity strength training (dynamic exercise including concentric and eccentric contractions) 2 days per week for 52 weeks (with 2 weeks off during the study for vacation). The following exercises were used for training: hip extension, knee extension, lateral pull-down, back extension, and abdominal flexion using pneumatic resistance machines (Keiser Sports Health Equipment, Fresno, Calif). These exercises were chosen because they trained the major muscle groups attached to the bones of interest. The intensity of the training stimulus was set at 80% of the most recently determined one repetition maximum (1RM) for each muscle group for hip extension, knee extension, and lateral pull-down exercises and 16 on the Borg scale[17] for back extension and abdominal flexion. The 1RM is the maximum mass of a free weight or other resistance that can be moved by a muscle group through the full range of motion using good form one time only.[18] The 1RM testing was not done on the back extension and abdominal flexion in this group of women to avoid the potential risk of vertebral crush fractures. The Borg scale has been extensively validated for quantitating the intensity of aerobic activity[10]; it is the experience of the research team that 16 on the Borg scale corresponds to 80% of the 1RM (M.A.F., unpublished data, 1994). During the first and second week of training, the resistance was set at 50% and 60% of the baseline 1RM, respectively, and thereafter the goal was 80%. The load was increased each training session as tolerated for each muscle group to maintain the intensity of the stimulus; in addition, 1RM testing was repeated every 4 weeks to establish a new baseline. Each session was separated by at least 1 day of rest and lasted approximately 45 minutes. Prior to each exercise session, subjects cycled at an easy resistance for 5 minutes and then stretched for 5 minutes using a stretching device (StretchMate, Ashland, Mass). All exercises were supervised, with no more than two subjects per trainer. Right and left legs were trained at the same time unless a subject had an injury that would necessitate that she train one leg at a time.

Each repetition lasted 6 to 9 seconds, with a 3-second rest between repetitions and 90 to 120 seconds of rest between sets. Three sets of eight repetitions were done on each machine each training session. One hundred percent compliance for the study was set at 100 training sessions (two times per week for 50 weeks).

Control Group.—The women in the control group were asked to maintain their current level of physical activity during the year. The women were specifically asked not to start any strength-training program, but were promised instruction after the end of the intervention.

Bone Densitometry

Bone mineral density (BMD) of the lumbar vertebrae L2-4, femoral neck, and total body bone mineral content (BMC) were measured by dual-energy x-ray absorptiometry (Lunar Model DPX, Lunar Corp, Madison, Wis) and analyzed with Lunar Software, version 3.6z (Lunar Corp, Madison, Wis). The lumbar spine and femoral neck BMD sites were chosen because of the clinical relevance of the BMD at these sites to fracture risk at these sites.[2] Total body BMC was used as an index of total bone mineral homeostasis. The coefficient of variation in postmenopausal women on this scanner of the BMD of spine, femoral neck, and total body BMC were 1.0%, 2.1%, and 0.6%, respectively.[19] The average of two consecutive measurements of lumbar spine and femoral density with subject repositioning in between was used for analysis.

Muscle Function

The 1RM was used as the measure of dynamic concentric muscle strength of the legs, arm, shoulder, and upper back muscles using the double leg press, knee extension, and lateral pull-down machines. Strength at 16 on the Borg scale was used on the back extension and abdominal flexion machines. The best of two measures of strength obtained approximately 1 week apart was used as the baseline and final 1RM testing. All measurements were made with identical equipment positioning at all time points.

To determine the 1RM, incremental loads were added until failure occurred despite verbal encouragement to exert maximal effort. Failure was defined as a lift short of the full range of motion (determined in the unweighted position) on at least two attempts 45 seconds apart. The highest successfully lifted load was designated as the 1RM for that muscle group. Strength determinations using 16 on the Borg scale were made by having the subject perform three slow repetitions at varying degrees of resistance while pointing to the chart to identify the current level of difficulty until 16 was reached.

The reproducibility of these 1RM measurements in this population is high, with a significant correlation between repeat knee extensor measurements 1 week apart (r=0.88, P=.001).

Balance

Dynamic balance was assessed using the timed backward tandem walk test over a 20-foot course. The subject was

Table 1.—Baseline Characteristics*

	Control (n=19)	Exercise (n=20)	P
Age, y	57.3±6.3	61.1±3.7	.03
Years after menopause	9.8±4.6	11.6±5.0	.18
Weight, kg	62.2±8.9	64.7±7.7	.62
Height, cm	164.0±8.3	162.8±6.3	.54
Body mass index†	23.1±2.2	24.4±2.5	.71
Parity	2.6±1.6	3.4±1.3	.43
Femoral neck BMD, g/cm²‡	0.828±0.109	0.853±0.134	.67
Lumbar BMD, g/cm²§	0.986±0.152	1.020±0.164	.61
Total body BMC, g‖	2154±314	2168±343	.84
Smoking history			.03
Nonsmokers, %	26	65	
Former smokers, %	74	35	

*Data are presented as mean±SD.
†Body mass index obtained by dividing weight in kilograms by the square of height in meters.
‡BMD indicates bone mineral density.
§Lumbar vertebrae L2-4.
‖BMC indicates bone mineral content.

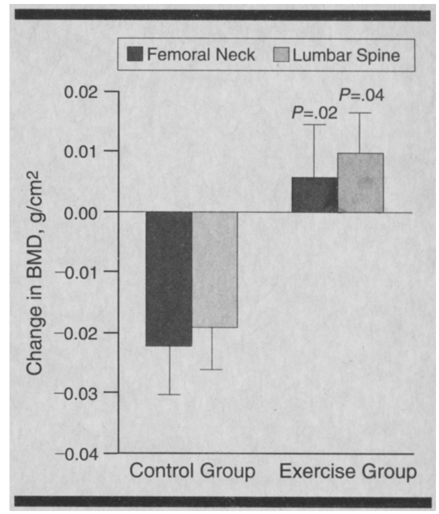

Figure 1.—Changes in bone after the interventions. The values are means±SE for individual change in bone adjusted for age, smoking, and baseline bone mineral density using analysis of covariance; BMD indicates bone mineral density.

instructed to place one foot behind the other, each time making sure that the toe of one foot was placed directly behind the heel of the other with the shoes touching. The subject was told to walk backward as fast as possible without falling down or making any mistakes. The average time recorded to the nearest 0.01 second during two trials was used in the analysis. The reproducibility of this balance measurement in this population is high, with a significant correlation between repeat measurements 1 week apart (r=0.94, P=.001).

Nutritional Intake

Habitual intake of calcium and vitamin D was estimated by a 3-day dietary record because of the relevance of these nutrients to bone. If the calcium intake of the subject at baseline was less than 800 mg/d, the dietitian counseled her on how to best increase dietary calcium intake through foods to meet the Recommended Dietary Allowance of calcium.[20] (Nutrient calculations for calcium and vitamin D were performed using the Minnesota Nutrition Data System software, developed by the Nutrition Coordination Center, University of Minnesota, Minneapolis; Food Database, version 6A; Nutrient Database, version 21; 1993). Twelve women (five in the control group and seven in the exercise group) took multivitamin and/or calcium supplements, which were included in the dietary analysis, before and during the intervention.

Urinary Creatinine and Whole Body Muscle Mass

Urinary creatinine levels were measured by colorimetric reaction[21] using an analyzer (COBAS FARA II, Roche Diagnostic Systems Inc, Nutley, NJ). Total body muscle mass was estimated by the method of Heymsfield et al.[22]

Hormones

Intact parathyroid hormone (PTH) and osteocalcin levels were measured by immunoradiometric assay in serum kits (Nichols Institute, San Juan Capistrano, Calif), with intra-assay and interassay coefficients of variation of 3.4% and 5.6%, respectively, for PTH, and 4.3% and 5.7%, respectively, for osteocalcin. Plasma levels of 25-dihydroxyvitamin D were measured by competitive protein-binding analysis[23] with both intraassay and interassay coefficients of variation of 5% to 10%. Baseline and final samples were batched and all samples were run in duplicate.

Physical Activity

Habitual physical activity was estimated using the Harvard Alumni Questionnaire[24] to determine if the two groups were comparable at baseline in normal weekly activity levels, and to ascertain if either group changed physical activity patterns over the year. This questionnaire has been validated in postmenopausal women.[25] The strength-training activity that the exercise group participated in as part of the intervention was not included in the final analysis.

Statistical Analysis

Primary outcome analysis was by the intention-to-treat principle and all tests of significance were two-tailed. All baseline characteristics were compared between treatment groups by the Student t test, except for difference in smoking history, which was assessed using χ^2. Analysis of covariance (ANCOVA) was used to determine the effect of the exercise intervention on each of the primary outcome measures using baseline measures of age, smoking history, and the initial baseline value for the variable being analyzed as covariates. Age and smoking history were used as covariates in the ANCOVA due to differences in these variables between the two groups at baseline. All data were analyzed using an SAS statistical package.[26] Results were considered significant if P<.05. (Data are reported as mean±SD, with the exception of Figures 1, 2, and 3, where mean±SE is reported.)

RESULTS

Baseline Characteristics

Baseline characteristics of the population are summarized in Table 1. There were no significant baseline differences in body weight, height, body mass index, bone status at any of the sites, parity or years postmenopause between the controls and the exercise group, but the women in the control group were significantly younger than the exercisers and had a greater history of past smoking. There were no baseline differences between groups in hormone levels, dietary intake, muscle mass, strength, balance, or physical activity.

Adherence and Adverse Effects of the Interventions

All but one of the women (discussed earlier) in the study completed the yearlong intervention. There were no changes in body weight or height over the 12-month intervention in either group.

Exercise Group.—Attendance at the exercise sessions averaged 87.5%±1.8%. Training loads averaged over the 4 weeks between strength tests indicated that 84% of the most recent 1RM was used as the training stimulus. Thirteen of 20 women in the exercise group experienced no

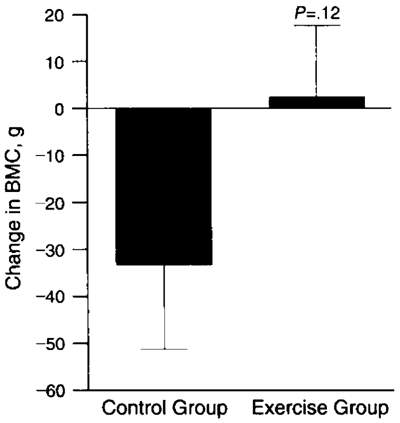

Figure 2.—Changes in total body bone mineral after the interventions. Values are means±SE for individual change in bone adjusted for age, smoking, and baseline bone mineral density using analysis of covariance; BMC indicates bone mineral content.

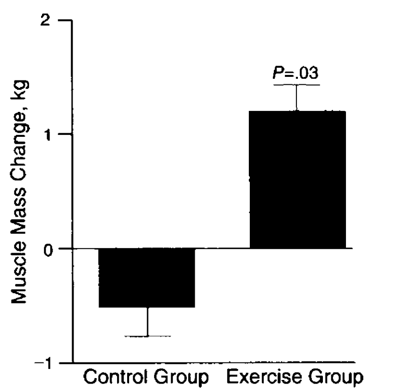

Figure 3.—Changes in muscle mass after the interventions. The values represent the adjusted means±SE for the individual change over total body muscle mass, adjusted for age, smoking, and initial muscle mass by analysis of covariance (P=.03).

Table 2.—Strength and Balance Measurements*

	Control			Exercise			
	Baseline	Final	% Change	Baseline	Final	% Change	P†
Strength‡							
Double leg press, kg	80.5±12.5	84.8±11.7	3.5	84.7±14.1	111.6±19.1	35.2	.001
Knee extension, kg	24.5±8.2	25.8±8.5	14.0	22.1±6.2	37.8±10.4	72.4	.004
Lateral pull-down, kg	19.4±4.6	22.2±4.9	19.2	18.5±4.1	32.4±5.1	76.3	.001
Back extension, kg	28.2±6.4	25.8±8.3	−8.6	27.6±6.8	37.8±7.6	43.5	.001
Abdominal flexion, kg	15.8±3.9	15.3±5.6	−3.2	14.3±5.1	20.4±5.1	42.6	.02
Balance							
Backward tandem walk, s	24.1±8.1	25.8±8.9	+8.5	24.6±5.8	20.4±5.2	−14.3	.005

*Data are presented as mean±SD. All means and analyses presented are adjusted for baseline measurement, age, and smoking history.
†P value refers to the time × group interaction.
‡Strength changes were determined by the one repetition maximum for double leg press, knee extension, lateral pull-down, and by number 16 on the Borg scale for back extension and abdominal flexion.

musculoskeletal problems over the year. The remaining seven women at some time experienced transient musculoskeletal pain that required minor modifications in the training regimen. All of these women completed the exercise program without further problems. No fractures occurred in this group.

Control Group.—One woman sprained her ankle and missed a body weight measurement during the study. Two other women had falls during the study that resulted in wrist fractures. These women were able to finish the study without further problems.

Primary Outcomes

The changes over the year for bone in the two groups are illustrated in Figures 1 and 2. Over the 12-month trial, femoral neck BMD increased by 0.005±0.039 g/cm^2 (0.9%±4.5%) in the strength-trained women and decreased by −0.022±0.035 g/cm^2 (−2.5%±3.8%) in the controls (P=.02). The femoral neck BMD increased in 11 strength-trained women and decreased in nine, whereas the femoral neck BMD increased in five controls and decreased in 14. Lumbar spine BMD increased by 0.009±0.033 g/cm^2 (1.0%±3.6%) in the strength-trained women and decreased by −0.019±0.035 g/cm^2 (−1.8%±3.5%) in controls (P=.04). Lumbar spine BMD increased in 14 strength-trained women and decreased in six, whereas the lumbar spine BMD increased in five controls and decreased in 14. Total body BMC tended to be preserved in the strength-trained women (+2.0±68 g or +0.0%±3.0%) and decreased in the controls (−33±77 g or −1.2%±3.4%, P=.12). The rates of bone loss in the control group were larger than expected, but comparable to other short-term studies in women in this age range.[27,28]

Total body muscle mass estimated by creatinine excretion increased by 1.2±0.4 kg in the exercise group and decreased by −0.5±0.8 kg in the control group (P=.03, Figure 3).

Changes in strength and dynamic balance measurements are shown in Table 2. The differences in strength and balance over the year were significant between groups for each of the measurements (P=.02 to <.001).

Table 3 outlines the dietary intake and activity level in the two groups. There were no changes in dietary intake of calcium or vitamin D between groups over the year. The exercise group increased their energy expenditure in activities exclusive of the intervention itself by 27%±25% compared with the control group, which decreased their spontaneous activity by 25%±24% (P=.02). The concern that this reported increase in physical activity may have had an independent effect on the changes that occurred in bone was examined by adding the change in activity to the ANCOVA. No such interaction was found.

Table 4 presents hormone levels over the year in the two groups. There were no changes between groups in 25-dihydroxyvitamin D levels; however, the levels in both groups tended to increase over the year. Parathyroid hormone levels increased over the year in the exercise group, but remained the same in the control group (P=.04). Osteocalcin levels increased by 14.0%±4.0% in the exercising women and decreased by 5.0%±2.7% in the controls (P=.02).

COMMENT

This trial demonstrates that 1 year of high-intensity strength training has a positive effect on the following individual risk factors for osteoporotic fractures in women 50 to 70 years of age: bone density, muscle mass, muscle strength, dynamic balance, and overall physical activity level. No other single intervention has yet been identified that can simultaneously alter an individual's risk profile for this multifactorial syndrome.

The importance of the finding that bone mineral was preserved in the strength-trained women lies in the fact that bone density is closely related to probability of future fracture, as strongly supported by cross-sectional, case-control, and prospective studies.[29] In a study by Cummings et al,[2] a decrease of 0.11 g/cm^2 in femoral neck BMD was associated with a 2.6 relative risk (RR) of hip fracture in women over 65 years of age. In the present study, it is possible that if the exercise group remained active and maintained bone density at the levels in this study over a 15-year period, while the control group continued to lose an average of 1% per year, then the control group's RR for hip fracture would be similar to that reported by Cummings et al.[2]

These positive changes in bone were

Table 3.—Dietary Intake and Activity Levels*

	Control		Exercise		
	Baseline	Final	Baseline	Final	P†
Dietary intake					
Calcium, mg/d	707±278	908±247	724±350	931±378	.82
Vitamin D, μg/d	4.1±2.8	6.2±4.1	6.1±4.1	6.4±4.6	.70
Activity level, kJ/wk‡	7186±1180	5393±697	6762±1046	8610±1109	.02

*Data are presented as mean±SD. All means and analyses presented are adjusted for baseline measurement, age, and smoking history. The Recommended Dietary Allowances for calcium and vitamin D in this age group are 800 mg/d and 5 μg/d, respectively.[13]

†P value refers to the time × group interaction.

‡Activity level was estimated by the Harvard Alumni Questionnaire.[18]

Table 4.—Hormone Levels*

	Control		Exercise		
Hormone Levels	Baseline	Final	Baseline	Final	P†
25-Dihydroxyvitamin D, nmol/L	79.8±27.5	81.2±34.7	68.3±25.2	78.6±11.7	.57
Parathyroid hormone, pmol/L	2.853±0.851	2.884±0.713	2.855±1.011	3.398±1.160	.04
Osteocalcin, nmol/L	1.163±0.224	1.105±0.195	1.094±0.245	1.247±0.332	.03

*Data are presented as mean±SD. All analyses presented are adjusted for baseline measurement, age, and smoking history.

†P value refers to the time × group interaction.

also associated with increases in muscle mass, muscle strength, dynamic balance, and increased physical activity level with no change in dietary intake and modest changes in hormone levels. Low muscle mass, muscle strength, and poor balance are all risk factors for falls in the elderly[1-7] and as has been demonstrated in this trial, have the potential to be modified by a single intervention.

Two days per week, 45 minutes per session, is a feasible amount of time to ask an older person to exercise, and therefore has the potential to be generalized to the population at large, even to frail elders. Our previous work has indicated that nursing home residents with multiple chronic diseases are capable of performing strength-training exercises and experience improvements in strength, functional status, and mobility.[4,5] We have preliminary data that indicate that a home-based strength-training program with minimal supervision in frail elders is also feasible, producing significant improvements in strength, mobility, and functional status without risk to the subjects (M.A.F., unpublished data, 1994). The next step is to determine whether these exercises in a home-based or similar type setting can improve bone density over the long term, thus further reducing the risk of fracture due to injurious falls.

While several cross-sectional studies have demonstrated an association between habitual physical activity and higher bone and muscle mass,[15,16,30,31] prospective studies have been less clear. Most of the initial studies have examined the effects of aerobic exercise on bone density. Some studies examining aerobic activity and bone density have shown benefits,[27,28,32,33] while others have shown no benefit.[34,35] We previously found that postmenopausal women enrolled in a 1-year walking program maintained trabecular BMD of the spine while it decreased in sedentary controls.[10] Although the intensity of the exercise was high enough to significantly alter aerobic capacity and the women wore weight belts while they walked, changes in bone density in other sites were not seen, perhaps because of the nature of the training stimulus.

Few prospective trials of strength training have been conducted. Notelovitz et al[36] showed in a randomized trial that high-intensity strength training combined with estrogen therapy in women with surgically induced menopause convincingly increased lumbar (8.4%), radial (4.1%), and total body (2.1%) BMD compared with no change in women treated only with estrogen over a 12-month period. This was the first randomized trial of high-intensity strength training on bone and the benefits were of clinical significance.

Interpretation of other prospective trials of resistance training measuring bone density of greater than 5-month duration is hampered by lack of randomization, different training intensities, and varying levels of compliance. Two trials demonstrated improvements in lumbar spine in the strength-trained women with no differences noted in the other sites measured (femoral neck, radial, os calcis BMD) over controls.[37,38] One nonrandomized study in premenopausal women showed decreases in lumbar spine BMD in the strength-trained women with no differences between groups for femoral neck and radial BMD, although the strength-trained women were lighter and leaner than the controls, which may have confounded the results.[39]

Higher body weight and fat-free body weight are associated with denser bones and greater BMC.[40,41] Muscle mass and bone mass have also been shown to be related.[42] The finding that total body muscle mass increased by 1.2 kg in the strength-trained women and decreased by 0.5 kg in the controls is significant in that this is the first randomized study to demonstrate such a change in whole body muscle mass in postmenopausal women. The importance of maintaining muscle mass into advanced age cannot be understated.[43] Muscle mass is directly related to strength[44] and the risk of falls in elders.[3,4,6]

The increase in PTH and osteocalcin levels over the year in the strength-trained women compared with no change in PTH and a decrease in osteocalcin levels in the controls in this study suggest that bone turnover and particularly bone formation may be greater in the strength-trained women. Hormonal results of other prospective strength-training interventions, however, are sparse and conflicting,[37,39] and preclude a definitive conclusion regarding the mechanism of bone remodeling after strength training.

The increase in spontaneous weekly physical activity in the strength-trained women, despite instruction not to alter their habitual activity levels, is of interest. It is possible that as a result of the increasing strength, these women were more physically capable of performing or behaviorally more motivated to engage in physical activity, and as a result, participated in more activities. Fiatarone et al,[12] in a study of high-intensity strength training in the oldest old, found that the spontaneous physical activity of nursing home residents increased by 28% after just 10 weeks of strength training. Frontera et al[45] demonstrated that 12 weeks of lower extremity strength training in older men increased leg cycle aerobic capacity. An increase in aerobic capacity of the muscles involved in the training may make lower-intensity, submaximal exercise easier to perform. This increase in overall activity level related to strength training in older women is another modifiable risk factor for osteoporotic fractures.[46]

In conclusion, high-intensity strength training has a protective effect on the femoral neck BMD and lumbar spine BMD as well as promoting increased muscle mass, strength, dynamic balance, and overall physical activity levels in postmenopausal women. All of these outcomes may mediate a reduction of the risk for future osteoporotic fractures. In contrast, traditional pharmacologic and nutritional approaches to the treatment or prevention of osteoporosis have the capacity to maintain or slow the loss of bone, but not the ability to improve balance, strength, muscle mass, or physical activity level.[36,47,48] Strength training in postmenopausal women, therefore, has the clinical potential to prevent osteoporotic fractures by simultaneously influencing multiple risk factors and should be the focus of continued research into long-term feasibility and effect on fracture rate.

This work has been supported in part by grant P01-DK42618 from the National Institutes of Health, federal funds from the US Department of Agriculture, and Agricultural Research Service contract 53-3K06-5-10. Resistance training equipment was provided by by Keiser Sports Health Equipment, Fresno, Calif, and stretching equipment was provided by StretchMate, Ashland, Mass. Dr Nelson is currently a Brookdale National Fellow.

We wish to especially thank the volunteers whose keen interest and dedication made this study possible. We would like to thank Brenda Crawford, Sharon Bortz, MS, RD, and Christina Economos, MS, from the Human Physiology Laboratory for their care in helping us carry out this study. In addition, we would like to thank members of the Calcium and Bone Metabolism Laboratory, the Nutrition Evaluation Laboratory, the Metabolic Research Unit, and the Dietary Assessment Department for their technical support.

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