Journal of Gerontology: MEDICAL SCIENCES
1998, Vol. 53, No. 1, M53–M58

Weighted Vest Exercise Improves Indices of Fall Risk in Older Women

Janet M. Shaw[1] and Christine M. Snow[2]

[1]Department of Exercise and Sport Science, University of Utah.
[2]Bone Research Laboratory, Department of Exercise and Sport Science, Oregon State University.

Background. Bone mass and fall propensity are two major risk factors for hip fracture. Our intent was to determine if weight-bearing exercises with added resistance from weighted vests would improve dynamic balance, muscle strength and power, and bone mass in postmenopausal women, thereby reducing risk for falls and hip fracture.

Methods. Forty-four nonsmoking, community-dwelling, Caucasian women aged 50–75 years participated in the study. All participants were at least 5 years past menopause and most were estrogen-deplete ($n = 36$). Bone mass and body composition were assessed by dual-energy x-ray absorptiometry, muscular strength by isokinetic dynamometry, muscular power by modified Wingate Anaerobic Power Test, and indices of postural stability by dynamic posturography. Half of the subjects participated in a 9-month regimen of weight-bearing exercises performed three times a week that emphasized lower-body muscle strength and power development. Resistance was added progressively and individually by the use of a weighted vest. Controls maintained customary diet and activity patterns.

Results. Significant improvements were observed for indices of lateral stability, lower-body muscular strength (16–33% increase), muscular power (13% increase), and leg lean mass (3.5% increase) in exercisers vs controls ($p < .05$). No significant changes ($p > .05$) were detected for femoral neck bone mass in exercisers or controls at the conclusion of the trial.

Conclusions. Lower body exercise, using a weighted vest for resistance, provides an effective means of improving key indices of falls in postmenopausal women.

IT is estimated that more than a quarter-million hip fractures occur annually, amounting to over $8 billion spent on immediate- and long-term medical care (1). Although the etiology of osteoporotic fractures is complex, it is evident that two factors play important roles: bone loss and falls. Hayes and colleagues (2) have reported that fall severity and bone mineral density (BMD) of the proximal femur are two primary contributors to hip fracture. Greenspan et al. (3) demonstrated that falls to the side with high impact velocity are severe and more likely to result in hip fracture than other falls. Marked reductions in physical activity have a negative impact on bone mass and three determinants of fall propensity: muscle strength, muscle power, and postural stability. A combined decline in muscle strength and bone mass has been associated with an increase in falls and incidence of hip fracture (4,5).

The majority of hip fractures occur with a fall (1). Given that falls and fall severity are central factors in the incidence of hip fracture, the purpose of this study was to design an exercise intervention aimed at improving muscle strength and power, postural stability, and femoral neck BMD. Our intentions were to design a program of function-based, progressive resistance that would mimic daily activities, use nontraditional equipment, be easily adapted to home and community settings, and thus be applicable to large segments of the population who are at risk for falls and osteoporotic fracture.

METHODS

Forty-eight Caucasian, nonsmoking women who were at least 5 years past menopause and between 50 and 75 years of age were recruited from Corvallis, Oregon and the surrounding area. Subjects received physician clearance to participate in the study and provided written informed consent. All testing and training procedures were approved by the Oregon State University Institutional Review Board. Participants were screened for chronic disease, orthopedic problems, and alcohol consumption (> 2 drinks per day) by questionnaire. Women who regularly participated in resistance training were excluded. Those on medications known to alter bone metabolism (with the exception of estrogen) were excluded. Women taking estrogen were included if they had taken hormones for at least 1 year. Initial bone mass at the hip for all participants had to be within normal limits (acceptable z-score range = –2.0 to 1.0). Four women had bone mass values at the femoral neck above this range (z score > 1.0), and were excluded at baseline. Therefore, a total of 44 women participated in the trial.

Bone mass of the right proximal femur was determined by dual-energy x-ray absorptiometry (DXA, Hologic QDR-1000/W, Waltham, MA). All scans were performed and analyzed by one technician. Scans were analyzed using Hologic software version 6.10.01 Rev A (Hologic, Waltham, MA), and all follow-up scans were analyzed using the "compare" mode. The coefficient of variation (CV) for this procedure at the Oregon State University Bone Research Laboratory is < 1.0%.

A whole-body DXA scan (Hologic) was performed to quantify lean and fat mass. Validation of this procedure for body composition analysis has recently been conducted in our laboratory (6). These results demonstrated that DXA is comparable to two- and four-component body composition models. The CV for body composition analysis in our laboratory, whole-body lean mass and fat with DXA, is 1.2 and 1.5% for lean and fat mass of specific regions (i.e., legs, trunk, arms).

Peak force (kilograms) of the ankle plantar and dorsiflexors, hip abductors, and knee extensors was assessed by isokinetic dynamometry (KinCom 500H, Chattex Corp., Knoxville, TN). All tests were conducted at a speed of 30°/s and were corrected for gravitational forces. Following a brief warm-up, subjects performed 3–5 maximal efforts, the highest of which was recorded as peak force. Maximal efforts were separated by approximately 30–60 s of rest. Protocols employed previously in our laboratory have revealed good reliability within this population. The CV is 5% for the hip abductors, 4% for ankle dorsiflexors, 8% for ankle plantar flexors, and 4% for knee extensors.

Muscular power of the lower extremities was assessed by the Wingate Anaerobic Power Test (WAPT) for older individuals (7). The test involves maximal pedaling against high resistance for 15 s on a bicycle ergometer (Monark, Varberg, Sweden, model 814E). An optical sensor was used to detect reflective markers on the flywheel of the ergometer during the test. The optical sensor was interfaced with an IBM PC with software from Sports Medicine Industries (St. Cloud, MN) to calculate indices of power. Subjects performed a 5-min warm-up against very light resistance (0.5 kg) at 40–60 rpm. The resistance added to the flywheel was a relative workload representing 8–10.5% of whole-body lean mass, as determined by the whole-body DXA scan. The range of workloads was determined to optimize power output during an in-house pilot study. Subjects were instructed to pedal as fast as possible; upon exceeding 100 rpm, the weight was engaged on the flywheel. Following the test, subjects continued pedaling at a reduced rate for 3–5 minutes. Measures obtained from the WAPT included absolute (watts) and relative (watts per kilogram leg lean mass) maximum power. The CV for maximal power on the WAPT in our laboratory in older women is 4.4%.

Indices of postural stability during voluntary movement were evaluated using the Pro Balance Master (Neurocom International, Clackamas, OR). The machine is equipped with dual force plates that house four load cells to detect pressure. The force plates are installed within a platform flush with the surrounding surface, and a monitor mounted at eye level in front of the subject is used to direct test protocols. A standardized foot position allows detection of the subject's center of gravity (COG) throughout testing sessions. The test protocol was identical for all subjects at every testing session, and the same technician administered all tests throughout the study. The protocol required the subject to shift the COG (indicated by a cursor on the video screen) when cued visually from a center target to each of four peripheral targets placed at 65–75% of maximal limits of stability (LOS), depending on individual ability. Participants were instructed to move as quickly and accurately as possible from the center target to each of four peripheral targets. Subjects made two excursions to targets in the anterior, posterior, right, and left lateral positions; this order remained constant across all testing sessions. A 10-s pacing interval was used for each excursion. A familiarization period was provided 1 week prior to baseline testing to reduce changes in performance associated with learning effects. Movement time (MT) and path sway (PS) were determined during this assessment. The MT score represents the time (sec) required for the subject to move the COG cursor from the center target to the peripheral target after a visual cue was given. The PS measure was scored as a percentage of path length, or deviations from a straight line. The mean scores obtained from the two excursions were used for scoring purposes. The CVs for MT and PS assessment used in the present study ranged from 7 to 9%.

Subjects who met inclusion criteria were tested and matched for BMD of the femoral neck, age, and years postmenopause between December 1993 and March 1994. Participants who completed baseline testing by February 1994 (n = 37) were assigned to the exercise group (n = 22) or the control group (n = 15). More women were assigned to the exercise group because February 1994 marked the commencement of the exercise classes. Four of the original 37 women were assigned to the control group because of conflicting schedules (i.e., work) with the exercise training sessions. In March 1994, seven women were added to the control group so that there would be equal numbers in each group (n = 22); thus, the study was not completely randomized. Four exercisers discontinued participation and were not available for the 9-month data collection. Therefore, data are provided for those who completed the entire 9-month trial (n = 22 controls, n = 18 exercisers).

The 9-month exercise training program was designed to increase strength and power of the lower extremities. Exercise classes were held three times a week with at least 1 day of rest between classes. Each 60-min class began with 10 min of warm-up activities such as walking and mild stretching, followed by 35 min of lower-body resistance training, finishing with 10–15 min of cool-down activities including walking and more intensive stretching for the lower back and legs. The resistance for the lower-body exercises was applied with a weighted vest. Subjects were weighed once per week on a standard physician's scale to determine the amount of weight added to the vest, which was calculated as a percentage of body weight. The initial weight and progression were based on a 10-week pilot study. Vests were not used in the first 2 weeks of training. Initial vest resistance was set at 5% of body weight and was gradually increased (approximately 1 to 2% every 2 weeks) until 10% of body weight was achieved. Beyond 10% of body weight, increases in resistance were more conservative (0.5 to 1% every 2 weeks). Resistance was progressively increased in this manner during the 8- to 12-week build-up phases ("peaks") and then decreased for 2 weeks (by approximately 4%, "valleys"), three times throughout the 9-month program. After the active recovery afforded by the valleys, weight was added to achieve peaks in resistance that were higher than those previously achieved. Within this general framework, vest weight was individualized depending on subject tolerance. The deviation in resistance from the basic prescription was within 4% of body weight for all subjects. The highest resistance achieved at the end of the program was 16–20% of body weight.

Subjects completed four of six resistance exercises during each session while wearing the weighted vest. The exercises performed included stepping, squats, chair raises, forward lunges, lateral lunges, and toe raises. Stepping was conducted on an 8-in wooden step. Knee and toe raises were added to the stepping exercises to challenge the participant's ability to coordinate these skills while standing on one leg. Squats were performed in a wide stance that places less stress on the knee and encourages development of hip musculature. A full squat was encouraged (~90° knee angle); however, few could achieve a full squat at the beginning of the program, and therefore, a half-squat at 120° knee angle was performed. Chair raises were performed in an armless chair that allowed for ~90° knee angle. Subjects stood up without use of the hands, then sat down for one repetition. Chair raises and squats were performed on alternate days. Lunges were performed onto an 8-in step as well as onto the floor in forward and lateral directions. Forward and lateral lunges were performed on alternate days. Ankle development was promoted through toe raises, which required that subjects rise up to the toes and rock back to the heels while lifting the toes for one repetition. The eccentric portion of the resistance exercises was performed slowly (i.e., to a count of 2 s) while the concentric actions were performed more quickly (i.e., to a count of 1 s).

The resistance exercises were performed in sets and repetitions. To provide overload, a high volume of work was imposed because there was a limit to the amount of weight that could be added to the vest (40 lb maximum) and a conservative progression was desirable. The number of sets ranged from 3 to 5 and the number of repetitions between 10 and 15. When the resistance in the vest increased, the number of sets and repetitions was at the low end of the range. After subjects adjusted to the new resistance, sets and repetitions were elevated to the high end of the range.

To encourage muscular power development and to impose impact forces on bone, jumping exercises were included during the fourth month of training. Subjects began jumping 1 time, increasing to 5 times per session, in place on a 1-in thick pad. At month 5, jumping increased to 6 times per session, 3 on the pad and 3 from a 4-in step. Subjects were instructed to stand on the step and jump onto the 1-in pad, landing on both feet and bending at the knees upon impact. In month 7, the number of jumps was gradually increased to 12, divided equally between in-place on the pad and from a 6-in step. Lastly, in months 8–9, the number of jumps progressed to 28 per session in the same manner except from an 8-in step. Weighted vests were not worn during jumping exercises. Subjects wore sturdy athletic shoes during all resistance exercises and jumps.

Attendance and participation characteristics (number of sets, repetitions, vest weight, and jumps) were recorded at each training session by the same instructor throughout the trial, which was taught in a supervised, class format. Training logs were maintained by all exercisers and were used to corroborate the instructor's records. Activities performed outside the supervised sessions were also recorded. Exercisers were provided with written exercise instructions for times when they were absent from the program. Sessions away from the class were performed without a vest.

Controls were reminded at three-month intervals to maintain and record their physical activity during the study and were asked to refrain from engaging in any new form of exercise. Activity logs were collected from controls at 3-month increments. In addition, they were asked to maintain dietary practices.

Diet was assessed with the Block Food Frequency questionnaire, which assesses past-year nutrient intake (8). Participants noted the foods they ate regularly (number of times per week) as well as the quantity of each food. This scale has been validated for assessing calcium intake and was used primarily for that purpose in this study (9).

The overall design employed a 2 (group) × 2 (time) repeated-measures format. Uni- and multivariate repeated-measures techniques were conducted to determine time by group interactions. For multivariate analyses, univariate follow-up procedures were utilized to determine which dependent variables contributed to significant findings. Multiple stepwise regression analyses were utilized to define independent predictors of improvement in balance measures. Those on estrogen were included in the BMD analyses, since they were stabilized on hormones and their bone mass values did not reflect a change that was significantly different from their estrogen-deficient counterparts. For dynamic balance measures, the anterior–posterior (AP) scores were collapsed (as a sum of the two), as were the right and left lateral (LAT) scores for MT and PS, and entered into the analysis as four separate variables. All statistics were computed using Statview version 4.1 and SuperANOVA version 1.11 software for the Macintosh (Abacus Concepts, Berkeley, CA) for univariate and multivariate analyses, respectively. All data are presented as mean (± standard deviation). The level of significance was set at $\alpha = 0.05$.

Subject numbers were determined from formal power calculations. It was hypothesized that BMD of the proximal femur would increase significantly over the 9-month period. The most demanding comparisons to test these hypotheses are Student's t analyses of BMD measures to compare changes within groups with respect to zero. With a power = 0.8, $\alpha = 0.05$, and an expected difference between groups of 1% at the proximal femur, 17 subjects per group were needed in order to determine significance.

RESULTS

Baseline characteristics of participants were very similar with the exceptions of body weight, body composition, and estrogen use (Table 1). The difference in body composition was attributed to higher fat mass in the exercise group, as there was no difference in whole-body lean mass. The number of estrogen users was higher in the control group than in the exercise group. There were no differences in femoral neck (Fn) BMD, age, years postmenopause (PM), average hours of weight bearing (WB) activity, or past-year calcium intake. Strength, power, and dynamic balance measures were comparable at the onset of the study.

Average attendance to the training program was 81% (± 8.8, range = 63–95%). Four of the original participants discontinued involvement in the exercise group, resulting in a compliance rate of 82%. Two women terminated participation within the first 3 months due to the time commitment associated with the training. The other two women left due to knee strain at months 5 and 6. Both had knee pain prior to entry

Table 1. Baseline Characteristics

Measure	Control (n = 22)		Exercise (n = 18)	
Age (yrs)	62.5	(6.6)	64.2	(5.8)
Years PM	12.0	(6.1)	14.1	(5.7)
Height (cm)	163	(5.0)	165	(7.0)
Weight (kg)	63.7	(7.7)	70.2	(11.3)*
Body composition (%)	28.6	(4.5)	33.3	(6.6)*
Lean mass (kg)	43.3	(4.3)	44.2	(5.6)
Fat mass (kg)	18.4	(4.8)	23.8	(7.6)*
FnBMD (g/cm^2)	.651	(.083)	.683	(.062)
W-B activity (h/wk)	4.4	(2.9)	4.1	(3.6)
Calcium (mg/d)	896	(478)	900	(367)
Number on estrogen	7		1	

*Exercise greater than control $p < .05$.

Table 2. Regional and Total Fat Mass, Lean Mass, Body Composition, and Body Weight Pre and Post 9-Month Intervention or Control Period

Measure	Control Pre	Control Post	Exercise Pre	Exercise Post
Arms fat (kg)	2.3 (.6)	2.4 (.6)	2.6 (.7)	2.6 (.9)
Legs fat (kg)	7.9 (2.0)	7.9 (2.0)	10.1 (2.8)	9.5 (3.1)†
Trunk fat (kg)	7.4 (2.8)	7.4 (2.6)	10.2 (4.6)	9.4 (5.0)*
Whole fat (kg)	18.4 (4.8)	18.5 (4.6)	23.8 (7.6)	22.3 (8.5)*
Arms lean (kg)	3.8 (.5)	3.9 (.6)	3.9 (.6)	3.9 (.6)
Legs lean (kg)	12.6 (1.3)	12.8 (1.4)	12.9 (1.7)	13.4 (1.8)*
Trunk lean (kg)	23.6 (2.5)	23.5 (2.6)	24.1 (3.4)	23.8 (3.1)
Whole lean (kg)	43.3 (4.3)	43.4 (4.5)	44.2 (5.6)	44.3 (5.4)
Body weight (kg)	63.7 (7.7)	63.9 (8.0)	70.2 (11.3)	68.7 (12.2)*
Percent fat	28.6 (4.5)	28.5 (4.4)	33.3 (6.6)	31.6 (7.1)†

*Significantly different at post test, $p < .05$.
†Significantly different at post test, $p < .01$.

Table 3. Muscular Strength Pre and Post 9-Month Intervention or Control Period

	Control Pre	Control Post	Exercise Pre	Exercise Post
Hip abduction (kg)	29.1 (4.9)	31.0 (6.0)	26.4 (6.8)	32.9* (4.1)
Knee extension (kg)	41.6 (8.0)	43.3 (6.7)	41.9 (6.7)	48.5* (8.2)
Plantar flexion (kg)	23.1 (5.7)	24.3 (6.2)	26.0 (4.3)	34.3† (5.7)
Dorsi flexion (kg)	15.5 (3.0)	15.7 (3.1)	16.1 (3.7)	17.3 (3.8)

*Significantly different from control at post test, $p < .05$.
†Significantly different from control at post test, $p < .01$.

into the program, and the combination of exercises and progression increased symptomology. No injuries resulted directly from the training. The exercise group averaged 4.1 (± 3.6) hours a week of weight-bearing exercise at baseline vs an average of 4.4 (± 2.0) hours a week at the end of the 9-month trial ($p > .05$). The latter value represents outside activity in addition to the training sessions. Activity logs maintained by controls confirmed that weight-bearing exercise did not change over the study period (4.4 ± 2.9 to 4.7 ± 3.6 hours a week, $p > .05$). Compliance among controls was 100%.

Bone mineral density in both groups was very close to the aged-matched mean for the femoral neck at the onset of the study. Results of repeated-measures ANOVA revealed no significant changes ($p > .05$) in BMD at the hip in either the exercise (.683 ± .062 vs .684 ± .057) or control group (.651 ± .083 vs .650 ± .078) after the 9-month trial.

Body composition and weight changed in the exercise group, notably in the lower body, where leg lean mass increased and leg fat mass decreased. Changes observed in the control group were not statistically significant (Table 2).

Repeated-measures MANOVA revealed a significant group by time interaction ($F_m = 6.43$, $p = .0003$) for muscular strength. Univariate follow-up analyses revealed that hip abduction, knee extension, and ankle plantar flexion accounted for the significant strength increases attributable to the training program (Table 3). The exercise group experienced a 30.3% (± 28.9) increase in hip abduction, a 16.6% (± 16.5) increase in knee flexion, and a 33.3% (± 21.8) increase in ankle plantar flexion. There were no observable changes in ankle dorsiflexion strength. The control group exhibited no significant improvement in any of the four strength measures.

At baseline, it was noted that absolute maximal power was significantly correlated with leg lean mass ($r = .60$, $p < .01$). To account for this association, only changes in maximum power relative to leg lean mass will be addressed. Exercisers exhibited increases in relative maximum power (22.5 ± 4.7 vs 25.1 ± 4.1 W/kg leg lean mass, $p < .01$). This represents a 13% (± 12.0) increase in relative power, even when corrected for the 3.5% (± 3.3) increase in leg lean mass ($p < .05$). Relative maximum power did not change in controls (23.4 ± 4.7 vs 24.2 ± 4.7, ns).

Results of repeated-measures MANOVA revealed a significant time by group interaction ($F_m = 3.466$, $p < .05$) for indices of dynamic balance. Univariate follow-up analyses indicated that LAT MT and PS contributed to the interaction. The exercise group experienced a 20% (± 21.6) decline in LAT MT (5.9 ± 1.6 vs 4.6 ± 1.2 s), which was significantly different from the .4% (± 19.5) increase among controls (5.6 ± 1.7 vs 5.7 ± 2.4 s, $p < .01$). For LAT PS, the exercisers exhibited a 6% (± 12.6) decline (315 ± 56 vs 291 ± 35% path length), while the controls demonstrated a 4.5% (± 11.4) increase (274 ± 32 vs 284 ± 25% path length) after the 9-month trial. This difference was statistically different ($p < .05$). In addition, there was a ($p < .05$) time effect across groups noted for AP MT, indicating that the exercisers and controls improved similarly on this measure (6.4 ± 2.3 vs 5.3 ± 1.8 s and 6.7 ± 2.4 vs 6.1 ± 2.2 s, respectively). No significant changes were observed for PS in the AP direction. In multiple stepwise regression analyses, percent change in hip abductor strength was the only independent predictor of LAT MT ($R = .352$, $p < .05$, Figure 1). The only predictor of LAT PS was relative maximum power (W/kg leg lean mass), which accounted for approximately 20% of the variance ($p < .01$, Figure 2).

DISCUSSION

Results reported herein demonstrate improved lower-body strength, leg power, leg lean mass, and dynamic balance after 9 months of resistance training. Poor lower-body strength, reduced muscle power, and postural instability have been linked to increased fall risk in older adults (10–14). Therefore, the exercise intervention utilized in this study was an effective, practical means of decreasing these parameters of fall risk in postmenopausal women who are generally healthy. Although hip fractures are highly associated with falls, the intervention did not induce changes in femoral neck BMD, and therefore the potential for this program to alter hip fracture risk remains undetermined.

The improvements in maximal muscular force probably reflected muscular hypertrophy and, even though it was not assessed directly, neural mechanisms. Ankle dorsiflexor strength did not increase, most likely because this was a difficult group to isolate in training. Although the participants routinely lifted their toes off the floor, this motion involved no additional loading. Lean mass of the legs increased 3.5% in the exercise group. Fiatarone et al. (15) attributed much of the strength gain in nursing home residents engaged in high-intensity resistance training to hypertrophy based on CT scan results. In the present study, only 10–14% of the variance in strength change can be explained by increased leg lean mass. Lacking specific data on neural changes, contribution to strength improvements via this mechanism is speculative.

Previous research has indicated the significance of lower body strength as it relates to fall risk in older women (11). To our knowledge, a definitive threshold for muscular strength values associated directly with falls and impaired physical function has not been defined. However, increased risk of falling has been associated with hip weakness (14), reduced knee extensor strength (10,11,13,14), poor ankle strength, particularly of the dorsiflexors (10,11,13), and lower extremity disability (12). Although our exercising subjects did not exhibit an increase in ankle dorsiflexion strength, improvements in hip abduction, knee extension, and plantar dorsiflexion strength likely provided some reduction in fall risk.

Increased leg lean mass likely contributed to increases in leg power. Leg power was correlated with leg lean mass at baseline, so it was important to consider this, given the significant increase in leg lean mass in the trained group. Lean mass increases accounted for 7.5–8% of the variance in power changes. It is possible that improved neural mechanisms accounted for some of these changes, but this factor was not measured. There are no published reports of leg power changes assessed by the WAPT with an exercise intervention in older adults, but it has been proposed that leg extensor power is a major determinant of functional ability in older adults, and that power may supersede strength as a predictor of function in older adults (16). Further, muscular power plays an important role with respect to control during voluntary movements and has been distinguished as a determinant of falls in nursing home residents (10).

Postural instability has been cited as a risk factor for falls in older adults (11–13). The primary changes in balance in the present study were demonstrated in dynamic movements in the lateral directions. These findings indicate that the women in the exercise group were able to move more quickly and accurately in the medial-lateral direction after the exercise intervention. This may have clinical meaning given that fall severity is greatest when falls occur to the side and the area of impact is likely to be directly at the hip (2,3). Stepwise regression analyses revealed that hip abductor strength and maximal leg power were independent predictors of LAT MT and LAT PS, respectively. Only 12.5–20.5% of the variance in balance changes were explained by these models, so other mechanism(s) not assessed contributed to these improvements. Sensory input, integration of sensory information by the central nervous system, and appropriate musculoskeletal response are all essential mechanisms required for balance (17). It is not known whether sensory input or integration changes occurred with the training program. The regression models explained mechanisms that were likely involved in the musculoskeletal response, namely increases in hip abductor strength and leg power.

It was hypothesized that hip BMD would improve due to the forces imposed from the exercise using weighted vests. Jumping likely afforded the greatest lower-extremity loading in the exercisers. Jumping was not added until the fourth month of the program for safety purposes, and it is probable

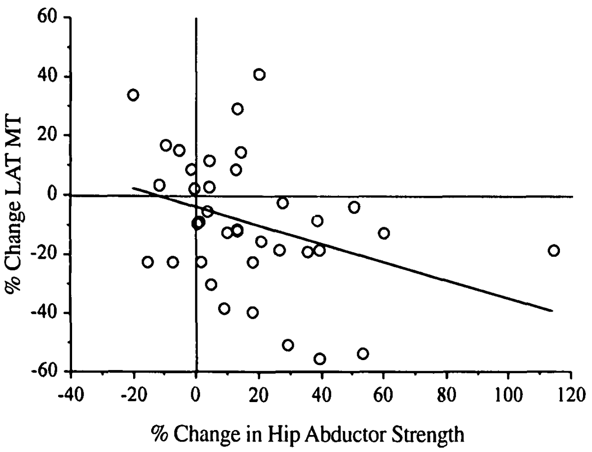

Figure 1. Percent change in lateral movement time vs percent change in hip abductor strength ($R = .352, p < .05$).

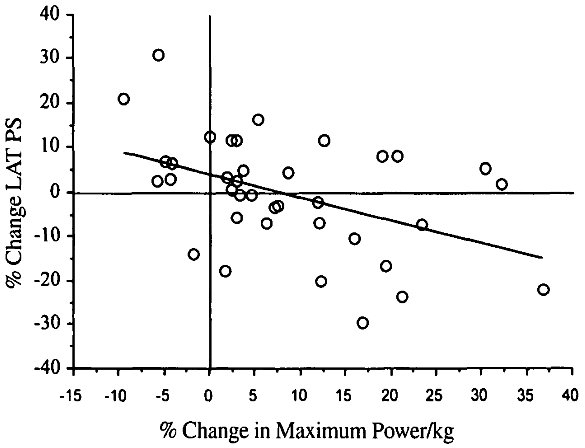

Figure 2. Percent change in lateral path sway vs percent change in maximum power corrected for leg lean mass ($R = .453, p < .01$).

that the exposure to the stimulus was insufficient to observe BMD changes. Bassey and Ramsdale (18) demonstrated increases in BMD at the hip in premenopausal women who participated in a 6-month aerobic dance program plus a home jumping regimen. Participants performed 50 jumps a day, 3 days a week, in place while in stocking feet. Those who performed-upper body exercises instead of jumps did not exhibit improvements in hip BMD. Participants in the present study began jumping only once per session and progressed up to 28 jumps per session. Thus, Bassey's group performed more jumps, the jumps were performed without shoes, and the women were estrogen replete.

The initial level of the participants' physical activity may have contributed to lack of change in BMD. At the onset of the program, the average amount of weight-bearing activity for both groups was approximately 4.5 hours a week. The exercises may have had more of an influence on bone if the participants had been less active. Nelson et al. (19) observed significant increases in BMD at the spine and hip in estrogen-deplete postmenopausal women after 1 year of high-intensity weight training. The program involved two supervised training sessions per week on pneumatic resistance machines, and participants were minimally active prior to the onset of the study. The participants in the present study were not sedentary. In addition, the exercisers in the present study replaced activity at baseline with the intervention. Since initial physical activity levels were fairly high, it is possible that the majority of the program was not of sufficient magnitude to stimulate bone mass accretion at the hip, even though muscle strength and power increased. Estrogen status did not affect the statistical outcome of BMD changes at the femoral neck, although the number on hormone replacement was too low to address this question adequately. Planned, weight-bearing activity levels of both groups remained high during the course of the study (~4.5 h/wk), and this may be one reason why the controls did not exhibit significant declines. In addition, past-year calcium intake was similar between groups. Calcium intake was above the RDA for adults (800 mg/d) yet below the recommended levels proposed by the National Osteoporosis Foundation (20).

A primary goal of this exercise intervention was to design a regimen that effectively decreased fall and fracture risk. Our results demonstrate that elements of fall risk were favorably altered by the training but that the influence on hip fracture risk is uncertain given no significant improvement in hip BMD. It is important to note that falls were not monitored during the study, so our conclusions are limited to the factors we measured that infer fall risk, not falls per se. Strengths of the present exercise program include its adaptability to a home-based program or community-living facility, because of its simplicity and the readily available equipment utilized, as well as inclusion of function-based activities (i.e., chair raises, stepping). Based on their anecdotal comments, the functional specificity of the training was noticed by the participants. They frequently reported how much easier it was to climb stairs, to stand from a seated position, to get out of a tent while camping, or to hike in the mountains. Thus, a simple program that does not rely on expensive equipment such as presented in this study may have preventive potential in decreasing fall risk in aging women.

ACKNOWLEDGMENTS

This work was funded in part by the AARP Andrus Foundation and the AAUW Educational Foundation.

Address correspondence to Janet M. Shaw, Ph.D., Department of Exercise and Sport Science, University of Utah, 300 S. 1850 E. Rm 259, Salt Lake City, UT 84112-0920. E-mail: Janet.Shaw@health.utah.edu

REFERENCES

1. Melton LJ III. Hip fractures: a worldwide problem today and tomorrow. *Bone.* 1993;14:S1–8.
2. Hayes WC, Meyers ER, Morris JN, Gerhardt TN, Yett HS, Lipsitz LA. Impact near the hip dominates fracture risk in elderly nursing home residents who fall. *Calcif Tiss Int.* 1993;52:192–8.
3. Greenspan SL, Myers ER, Maitland LA, Resnick NM, Hayes WC. Fall severity and bone mineral density as risk factors for hip fracture in ambulatory elderly. *JAMA.* 1994;12:128–33.
4. Anniansson A, Zitterberg C, Hedberg M. Impaired muscle function with aging. *Clin Orthoped Rel Res.* 1984;191:193–210.
5. Nevitt MC, Cummings SR, Hudes ES. Risk factors for injurious falls: a prospective study. *J Gerontol.* 1991;46:M164–70.
6. Wegner M, Snow-Harter C, Wilcox A, et al. The accuracy of dual energy x-ray absorptiometry in determining percent body fat: comparison with a multicomponent model. *Med Sci Sports Exer.* 1994;26:S202.
7. Bar-Or O. An abbreviated wingate anaerobic test for women and men of advanced age. *Med Sci Sports Exer.* 1992;24:S22.
8. Block G, Hartman AM, Dresser CM, Carroll MD, Gannon J, Gardner L. A data-based approach to diet questionnaire design and testing. *Am J Epidemiol.* 1986;124:453–69.
9. Cummings SR, Block G, McHenry K, Baron RB. Evaluation of two food frequency methods of measuring dietary calcium intake. *Am J Epidemiol.* 1987;126:796–802.
10. Whipple RH, Wolfson LI, Amerman PM. The relationship of knee and ankle weakness to falls in nursing home residents: an isokinetic study. *J Am Geriatr Soc.* 1987;35:13–20.
11. Lord SR, Ward JA, Williams P, Anstey KJ. Physiological factors associated with falls in older community-dwelling women. *J Am Geriatr Soc.* 1994;42:1110–7.
12. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. *N Engl J Med.* 1988;319:1701–7.
13. Gehlsen GM, Whaley MH. Falls in the elderly: part II, balance, strength, and flexibility. *Arch Phys Med Rehab.* 1990;71:739–41.
14. Robbins AS, Rubenstein LZ, Josephson KR, Schulman BL, Osterweil D, Fine G. Predictors of falls among elderly people: results of two population-based studies. *Arch Intern Med.* 1989;149:1628–33.
15. Fiatarone MA, Marks EC, Ryan ND, Meredith CN, Lipsitz LA, Evans WJ. High intensity strength training in nonagenarians. *JAMA.* 263:3029–34.
16. Bassey EJ, Fiatarone MJ, O'Neill EF, Kelly M, Evans WJ, Lipsitz LA. Leg extensor power and functional performance in very old men and women. *Clin Sci.* 1992;82:321–7.
17. Nashner LM. Sensory, neuromuscular, and biomechanical contributions to human balance. Proceedings of the APTA Forum, "Balance," Nashville, TN, 1989.
18. Bassey EJ, Ramsdale SJ. Increase in femoral bone density in young women following high-impact exercise. *Osteopor Int.* 1994;4:72–5.
19. Nelson ME, Fiatarone MA, Morganti CM, Trice I, Greenberg RA, Evans WJ. Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures: a randomized controlled trial. *JAMA.* 272:1909–14.
20. Peck WA, Riggs BL, Bel NH. *Physician's Resource Manual on Osteoporosis.* National Osteoporosis Foundation, Washington, DC, 1987.

Received May 7, 1996
Accepted March 17, 1997