Original articles

Effects of one year of resistance training on the relation between muscular strength and bone density in elderly women

E C Rhodes, A D Martin, J E Taunton, M Donnelly, J Warren, J Elliot

Abstract

***Objectives*—There is a paucity of long term studies on exercise training in elderly women. The purpose of this study was to investigate the effects of one year of progressive resistance exercise (PRE) on dynamic muscular strength and the relations to bone mineral density (BMD) in elderly women.**

***Methods*—Forty four healthy sedentary women (mean age 68.8 years) volunteered for this study and were randomly assigned to either an exercise group or a control group. The exercise group were involved in three one hour sessions a week for 52 weeks of supervised PRE to strengthen the large muscle groups of the body, while the control group were instructed to continue their normal lifestyle. The exercise circuit included three sets of eight repetitions at 75% of one repetition maximum focused on the large muscle groups. BMD was measured by dual energy *x* ray absoptiometry (Lunar DPX) at the lumbar spine and at three sites in the proximal femur. Other selected parameters of physical fitness were also measured.**

***Results*—Statistical analyses (analysis of covariance) showed significant strength gains (p<0.01) in bilateral bench press (>29%), bilateral leg press (>19%), and unilateral biceps curl (>20%). No significant difference between groups was evident in body weight, grip strength, flexibility, waist to hip ratio, or the sum of eight skinfolds. Significant relations (p<0.05) were recorded between dynamic leg strength and the BMD of the femoral neck, Ward's triangle, and the lumbar spine.**

***Conclusions*—Significant strength changes, after one year of PRE, were evident in elderly women, and the muscle increases may parallel changes in BMD; however, correlation coefficients were moderate.**

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It seems inevitable that a decline in the physiological capacity of humans will occur as a consequence of the biological aging process.[1] The deterioration in functional capacity can decrease the ability to perform common activities of daily living in the older population. A recent study in the United States showed that, above the age of 74, 28% of the men and 66% of the women could not lift objects weighing more than 4.5 kg.[2] Larson and colleagues[3] reported that reductions in dynamic muscular strength between the ages of 50 and 70 ranged from 24 to 36%. Women are weaker than men at all ages, and the incidence of falls and hip fractures is 2–3-fold higher in women than men.[4–6] The viability of the musculoskeletal system definitely declines with age. However, in the past few years, progressive resistance exercise (PRE) has proven to be effective in improving strength in older men and women.[7–17] Improved strength has been associated with improved muscle and bone mass, balance, and also mobility.[18] All of these factors are important in the prevention of fractures and improved quality of life.

Many of these studies have been of short term (three months or less), and few research studies on women in the 65–75 year age range have been reported. Therefore the purpose of this study was to evaluate the effects of a PRE on strength gains over one year and also to investigate the relation of the strength gains to changes in the bone mineral density (BMD) of elderly women.

Methods and procedures

SUBJECTS

Forty four healthy female subjects, between the ages of 65 and 75 (mean 68.8), volunteered for either the exercise or control group. The subjects were not actively engaged in an organised activity programme and all had independent community dwelling status. They were informed of all procedures, and signed a consent form approved by the university human ethics committee. All subjects were required to undergo medical screening and clearance by their doctors. Exclusion criteria included the following: recent hospital stay, registered blindness, severe hearing impairment, uncontrolled hypertension or diabetes, symptomatic cardiorespiratory disease, severe renal or hepatic disease, uncontrolled epilepsy, progressive neurological disease, chronic disabling arthritis, significant dementia with a Folstein mini mental status score less than 25/30, anaemia, marked obesity with the inability to exercise, regular exercise at the time of screening of more than 30 minutes three times a week, current use of β-blockers, oral anticoagulants, or central nervous system stimulants. Subjects were assigned in a randomised fashion to either the exercise or the control group. The final testing, one year later, included 20 exercisers and 18 control subjects. Two subjects dropped out of the study and four control subjects either refused to participate in the final test or were unavailable.

EXPERIMENTAL TREATMENT

Initially 22 subjects were involved in a three month fully supervised whole body PRE training regimen (one hour three times a week) aimed at strengthening the large muscle groups of the body. Strength was measured as one repetition maximum (1 RM). Before the resistance training, a 20 minute warm up (10 minute cycle ergometer; 10 minutes of easy stretching) was performed. The PRE was administered in a circuit fashion, with subjects completing three sets of eight repetitions at each exercise session at about 75% of 1 RM. The circuit included large muscle exercises—for example, chest press, leg press, biceps curl, triceps extension, quadriceps curl, hamstrings curl. All exercises were performed on a Universal Gym (Fitness Equipment Inc, Weston, Ontario, Canada). The subjects were asked to complete the concentric phase in two to three seconds and slowly lower the weight eccentric phase in three to four seconds. The training stimulus (1 RM) was adjusted at the end of each second week period. The average attendance was 86%, compiled over the three months of supervised training. Professional lifestyle and fitness consultants recorded the performance at each exercise session and monitored each subject to ensure correct technique and avoid injury.[19] No injuries were reported in the study.

For the remaining nine months, subjects exercised in recreation facilities close to their homes. They continued with the same volume (three sets, eight repetitions) of weight lifted while the training stimulus exact weight was adjusted every two weeks. Study personnel often visited the sites to check on the subjects and their exercise technique. Subjects recorded their exercises at each exercise session in a log book. Monthly meetings were held to reinforce the exercise procedures and to include a social component. Compliance with the exercise regimen was excellent: about 85% over the full nine months as recorded in the log records.

Subjects in the control group did not participate in the training programme and were instructed to maintain their normal lifestyle throughout the study duration. They were informed of an opportunity to participate in a training programme at the end of the year.

TESTING PROCEDURES

Body composition was assessed by anthropometry, including eight skinfold thicknesses (biceps, triceps, forearm, subscapular, suprailiac, abdominal, anterior thigh, mid calf) and trunk girths (waist and hip), as well as height and weight.[20]

Flexibility was assessed by the trunk flexion test.[21]

Muscle strength was measured by grip strength (hand dynamometer) and performance strength measures (Universal Gym; 1 RM, where 1 RM is defined as the weight that can be lifted no more than once with acceptable form). "Acceptable form" means that the exercise is performed primarily by the specified muscle groups, moving through a full range of motion, without the use of body momentum.

The last successfully performed weight lifted was noted as the 1 RM. The subjects warmed up with a 5–10 minute aerobic cycle and stretching of the major muscle groups. They received detailed instructions and performed each exercise several times at a very low resistance to enhance familiarisation. Each 1 RM test began at a weight near the expected maximum. Subjects reached their maximum within three repetitions. A one minute rest separated each repetition, and a three to five minute rest was given between exercises. The 1 RM tests were repeated at the end of the 12 month period for test purposes.

Bone density (g/cm^2) was measured at the Department of Nuclear Medicine at the Vancouver General Hospital. Dual energy *x* ray absorptiometry (Lunar DPX, Lunar Radiation, Madison, Wisconsin, USA) was used to measure bone density of the hip region (trochanter, Ward's triangle, and femoral neck) and the lumbar spine (L2–L4). The precision of this instrumentation is within the 1% range.[22]

STATISTICAL ANALYSIS

Differences in BMD, strength, and body composition achieved by the training were tested

Table 1 Physical characteristics of subjects

	Age (years)	*Height (cm)*	*Weight (kg)*	*SSF (mm)*	*Waist (cm)*	*Hip (cm)*	*Ratio**
Exercise							
Pre (n=22)	68.8 (3.2)	160.9 (5.5)	68.4 (12.0)	192.1 (46.6)	85.5 (9.7)	103.2 (10.3)	0.83 (0.06)
Post (n=20)		160.3 (5.6)	68.5 (12.0)	205.0 (52.4)	84.6 (9.4)	104.5 (11.0)	0.80 (0.05)
Control							
Pre (n=22)	68.2 (3.5)	159.3 (4.5)	61.7 (12.9)	145.9 (62.8)	80.1 (12.0)	98.5 (10.2)	0.81 (0.03)
Post (n=18)		159.2 (4.6)	60.7 (13.2)	153.2 (53.9)	75.4 (12.2)	91.2 (10.3)	0.80 (0.02)

Values are mean (SD). SSF, sum of eight skinfolds; ratio, waist to hip ratio. No statistically significant changes in mean gains were calculated for any anthropometric measures.
*Waist to hip ratio.

Table 2 Comparison of bone mineral content (BMC), area, and density (BMD) between exercise and control groups

	Exercise		*Control*	
	Pre	*Post*	*Pre*	*Post*
Femoral neck				
BMC (g)	3.97 (0.21)	4.02 (0.22)	3.71 (0.27)	3.48 (0.19)
Area (cm^2)	4.82 (0.30)	4.87 (0.28)	4.81 (0.28)	4.78 (0.22)
BMD (g/cm^2)	0.82 (0.11)	0.83 (0.12)	0.78 (0.09)	0.73 (0.10)
Ward's triangle				
BMC (g)	1.82 (0.18)	1.85 (0.19)	1.59 (0.17)	1.51 (0.18)
Area (cm^2)	2.61 (0.20)	2.66 (0.21)	2.53 (0.19)	2.54 (0.20)
BMD (g/cm^2)	0.69 (0.13)	0.70 (0.11)	0.63 (0.10)	0.59 (0.12)
Trochanter				
BMC (g)	8.95 (0.31)	9.04 (0.33)	8.59 (0.38)	8.83 (0.36)
Area (cm^2)	12.06 (0.54)	12.00 (0.61)	12.53 (0.58)	13.19 (0.62)
BMD (g/cm^2)	0.74 (0.10)	0.75 (0.11)	0.69 (0.12)	0.67 (0.11)
Lumbar (2–4)				
BMC (g)	45.22 (2.7)	45.86 (2.7)	40.37 (2.8)	42.50 (2.6)
Area (cm^2)	41.10 (3.0)	40.58 (2.8)	39.99 (3.0)	42.09 (2.9)
BMD (g/cm^2)	1.10 (0.17)	1.13 (0.18)	1.01 (0.17)	1.01 (0.17)

Values are mean (SD). No statistically significant changes were evident.

using analysis of covariance (controlling for the initial groups differences). As there is evidence that strength, muscular size, and BMD are related,[19] the relations between strength changes and BMD changes were investigated by regression analysis. A result was judged statistically significant if its p value was less than or equal to 0.05.

Results

Table 1 presents physical characteristics and descriptive statistics. No significant differences were evident in any of the anthropometric data. Although the control group appeared leaner (sum of eight skinfolds 145.9 mm as compared with 192.1 mm for the exercisers), the reasonably high variability precluded any statistical significance.

Table 2 presents the BMD changes. Although there were no statistically significant changes, the trend indicated an increase in BMD for the exercisers and a decrease in BMD for the controls.

Table 3 reports the strength and flexibility changes over the year in the exercise group. No statistically significant changes were evident in trunk flexion or grip strength ($p>0.01$); however, both measures did improve by about 8% in the exercisers. All of the strength measures increased significantly by about 20–50% in the exercisers, and all of the strength gains were statistically significant ($p<0.01$) when compared with the controls.

Table 4 gives zero order correlation coefficients between the mean gains in strength and the mean gains in BMD at the measured locations in the exercisers. The reported Pearson product moment correlation coefficients are statistically significant at the 0.05 level. Although the correlations are low, they do represent corresponding changes in strength and bone, particularly in changes in the quadriceps strength and the relation to the femoral neck, trochanter, and lumbar regions. This helps to clarify a trend for strength and bone changes in the exercisers. No significant relations were evident in the controls.

Table 3 Comparison of strength and flexibility measures between exercise and control groups

	Exercise		*Control*		
	Pre	*Post*	*Pre*	*Post*	*p Value**
Trunk flexion (cm)	26.9 (8.4)	29.0 (8.8)	26.2 (7.9)	27.1 (8.3)	>0.01
Grip strength (kg) (dominant)	24.6 (3.8)	26.7 (3.6)	24.3 (4.2)	24.4 (3.8)	>0.01
Bench press (kg)†	13.4 (2.3)	17.3 (2.8)	13.6 (2.2)	13.8 (2.6)	<0.01
Leg press (kg)	99.5 (10.2	118.5 (9.3)	98.6 (9.5)	99.2 (8.6)	<0.01
Biceps curl (kg)	4.3 (0.9)	6.6 (0.8)	4.2 (1.0)	4.1 (0.9)	<0.01
Triceps (kg)	22.0 (4.2)	33.0 (4.4)	23.0 (4.8)	22.0 (4.4)	<0.01
Quadriceps curl (kg)	29.5 (4.8)	33.5 (4.3)	28.5 (4.2)	28.0 (4.0)	<0.01

Values are mean (SD).
*Univariate repeated analysis of covariance (mean difference in changes).
†Measured as 1 repetitive maximum.

Table 4 Correlational matrix showing the relation between changes in muscular strength and bone density in the exercise group

	Leg press	*Quadriceps curl*
Ward's triangle	0.42*	0.36*
Trochanter	0.38*	0.31*
Femoral neck	0.22	0.27*
Lumbar 2–4	0.18	0.40*

*Correlations significant ($p<0.05$).

Discussion

There is a paucity of data available on strength training in elderly women, particularly in long term studies. This study shows the effects of one year of PRE on strength and concomitant changes in regional BMD. Statistically significant changes were evident in muscle function performance from the results for the bench press, double leg press, biceps curl, triceps extension, and the quadriceps extension. The strength increases ranged from 19 to 53% over the one year period. Also, the changes in muscular strength, associated with the one year intervention, showed significant relations (albeit quite low) to bone changes in the lumbar and femoral regions. Therefore the increase in strength may improve functional capacity,[18] slow the progress of osteoporosis, and contribute to a better quality of life in elderly women.[1 16 23] No significant changes were noted in the sum of eight skinfolds, the waist to hip ratio, trunk flexion, and grip strength over the course of the year. This was somewhat expected as the exercise regimen focused on strength, and therefore body composition and flexibility were not significantly altered.

Morganti *et al*[14] reported similar changes in strength over one year in elderly women (59.5 (0.9) years). This group trained twice a week for 12 months and displayed strength increases in 1 RM from 18.4 to 77.0% in the lateral pull down, knee extension, and double leg press. Pyka *et al*[24] also reported the results of a resistance training study with older people which was administered beyond a four month period. In this study researchers trained three men and five women for 30 weeks and four men and four women for one year. Their protocol consisted of three sets of eight repetitions, three times a week performed at between 65 and 75% of baseline 1 RM. Three quarters of the strength gains over baseline were evident in the first eight weeks, and, although a plateau was not reached, the remaining one quarter strength gain occurred over the following 10 months. The findings in these studies were similar to those in the present study; however, the subjects were younger.

Other studies were much shorter term. Frontera *et al*[12] conducted a study over 12 weeks in 12 60–72 year old men involved in a progressive strength training programme primarily focused on the knee extensors and flexors. This study showed gradual improvements during each week, plateauing at the end of the study. In a somewhat similar situation, Fiatarone *et al*[25 26] conducted studies over eight weeks with 10 frail 86–96 year old men and women. In both of these studies highly significant strength gains were shown. After 12 weeks of training, gains in the 100% range are reported. This is probably because of the debilitated condition of the subjects and the age, when compared with the present study. Hakkinien and Pakarinen[13] reported significant strength gains in 44–75 year old men and women in a 12-week programme. However, the strength increases were measured isometrically for testing purposes. This testing lacks specificity when compared with the dynamic testing of the present study. Nichols *et al*[15] strength trained postmenopausal women for 24 weeks using three sets of eight repetitions at 80% of 1 RM. They also reported significant gains in the strength over seven different exercises. Most of these studies have somewhat similar findings to the present study.

Therefore, although there are indications from the literature on strength changes in the elderly population after a regimen of training, very little research has found that increases in muscle strength significantly influence bone density. It has been reported that normal muscle function and load bearing are necessary to prevent or retard bone loss in people with activity restrictions.[5 19] However, it is hard to separate the effects of weight bearing stresses and forces produced by muscular contractions on bone density. Our data show significant relations between the quadriceps muscle strength and femoral-lumbar bone density changes over one year of exercise. Zimmerman *et al*[27] and Bevier *et al*[28] have reported similar findings in postmenopausal women. It would seem that, if muscular strength is to be a determinant of bone density, the force of muscle contraction must impact on an anatomically related skeletal site or reflect actions of those muscles that do. Although the anatomical origin of the quadriceps muscle groups is not on the lumbar spine, the agonist/antagonist effects of the hip flexors and the knee flexors would directly impact the lumbar spine.[17 28]

Our findings are in agreement with the study of Hughes *et al*.[19] They showed simple correlations between extensors' peak torque and the femoral neck, greater trochanter, and Ward's triangle. These were of the same magnitude as our correlations (0.29–0.33). The fair correlation coefficients do indicate a definite trend towards concomitant strength and bone adaptations. As Ward's triangle is the region of the femoral neck with the lowest bone density, it may well be more responsive to muscular forces because it is high turnover trabecular bone. A more recent study by Ryan *et al*[29] further confirms our findings. As we found a 19–53% strength gain, they reported gains of 36–65% in the upper body and 32–98% in the lower body. This further substantiates that older women can appreciably increase the strength of all muscle groups. The functional changes associated with these strength changes still need to be elucidated. Also the effect of training on BMD is still inconclusive, as statistical significance was not shown in this study. Bone is slow to adapt and seems more responsive to impact forces.[23] Possibly one year of strength training is insufficient time to show statistically significant changes and therefore the training periods should be extended. However, Ryan *et al* also reported significant correlations associated with the leg press and the BMD in regions of L2–L4, the femoral neck, and Ward's triangle. Their correlation coefficients were of a higher magnitude than ours ranging from 0.57 to 0.84. They concluded that a resistive training programme maintains BMD and obviously improves strength in healthy older women. Along with our study, this indicates that strength training may be important in preventing the negative health outcomes associated with age related loss of bone density.[29]

CONCLUSION

Our study is novel in that elderly women were able to train three times a week for 52 weeks during which time attendance averaged about 86%. Most elderly women in our society are not involved in routine physical activity and it is reported that after 60 years of age there is a 15% decrease per decade in muscular strength.[30] The effect of aging and the subsequent loss of strength has a pronounced effect on the capacity of older people to lead viable and independent lives. This study showed significant changes in muscular strength and related changes in bone density. These findings indicate the possibility that structured exercise programmes, focusing primarily on strength exercise, could help to prevent the loss of physical independence and thereby improve the quality of life of elderly women.

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Take home message

Elderly women are outstanding adherers to structural exercise programmes, and resistance training over one year can result in strength changes and related bone density changes.