Bone Mineral Density Responses to High-Intensity Strength Training in Active Older Women

Jeanne F. Nichols, Karen P. Nelson, Katrina K. Peterson, and David J. Sartoris

The purpose of this investigation was to determine the effects of high-intensity strength training on bone mineral density (BMD) of 34 non-estrogen-repleted, active women over 60 years of age. The study was designed as a randomized, nonblinded trial in which subjects were stratified into rank-ordered pairs by level of physical activity, then randomly assigned into either a weight training (WT) or a control (CON) group. BMD of the spine (L2–L4), hip, and total body was assessed at 0, 6, and 12 months by dual energy x-ray absorptiometry. Group-by-time repeated-measures ANOVA demonstrated no effect of weight training on BMD, despite marked gains in muscular strength for all exercises. The high-intensity weight training utilized in this study did not induce positive changes in BMD of the hip and spine of previously active, non-estrogen-repleted older women. However, the protocol was safe, enjoyable, and highly effective in increasing muscular strength.

Key Words: bone density, exercise, weight training, aging, postmenopausal women

Osteoporosis is a major underlying cause of bone fractures, disability, and premature death in the elderly, and particularly in older women. In 1987, 250,000 hip fractures were reported in the United States, at a cost of 3.9 billion dollars (National Osteoporosis Foundation, 1990). Since the geriatric population in the United States is on the rise, so, too, is the magnitude of the problem.

The decline in bone mineral density (BMD) with age is attributed developmentally to many factors including morphology, hormonal milieu, nutrition, and genetics. This decline may also be partly related to a decrease in physical activity and physical fitness that usually occurs with advancement of age (Ballard, McKeown, Graham, & Zinkgraf, 1990; Krolner, Toft, Nielson, & Tondevold, 1983; Sinaki & Offord, 1988; Stillman, Lohman, Slaughter, & Massey, 1986).

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Aging is also associated with a decline in lean body mass and consequent loss of muscular strength. Chronic endurance exercise, although highly effective in reducing the risk for cardiovascular diseases as we age, has little effect on lean mass (Ballard et al., 1990; Nelson, Meredith, Dawson-Hughes, & Evan, 1988). Resistance training, however, can maintain or increase muscle mass and strength of elders (Nichols, Omizo, Peterson, & Nelson, 1993), even in nonagenarians (Fiatarone et al., 1990). Since high levels of muscular tension serve as a localized osteogenic stimulus at those sites of mechanical loading (Rubin & Lanyon, 1984; Woo et al., 1981), it is possible that heavy resistance training of all major muscle groups may be the most effective mode of exercise for increasing bone mass and thereby reducing the risk of osteoporosis.

Recent cross-sectional studies have reported relationships between muscle mass, muscular strength, and BMD in young adults, including premenopausal women (Davee, Rosen, & Adler, 1990; Gleeson, Prots, LeBlanc, Schneider, & Evans, 1990; Granhed, Jonson, & Hansson, 1987). Thus, the potential exists for heavy resistance exercise to positively affect bone density. Very few longitudinal studies have been conducted in older adults, and the results of those reported are questionable as to whether resistance exercise enhances BMD (Peterson et al., 1991; Pollock et al., 1992). Differences in the training protocol, especially the intensity of the training, as well as differences in initial level of activity or fitness of subjects and probable differences in estrogen and nutritional status are factors that make interpretation and comparisons of previous studies difficult.

It is presently unclear whether strength training can augment bone density of active older women presently engaging in moderate to high levels of weight-bearing exercise. In fact, most of the exercise training studies reporting increases in BMD of older subjects employed previously sedentary or frail subjects (Nelson, Fisher, Dilmanian, Dallal, & Evans, 1991; Smith, Reddan, & Smith, 1981). Thus, any form of weight-bearing exercise would have greater potential for inducing changes in bone density for those populations. The present study was undertaken to examine the effect of high-intensity resistance training on BMD of active older women.

Methods

This study was approved by the Committee for the Protection of Human Subjects at San Diego State University.

SUBJECTS

Thirty-four active women 60 to 84 years of age met the following inclusion criteria: (a) at least 60 years old and 5 years postmenopause; (b) non-estrogen-repleted; (c) active for at least 6 months, defined as exercising at least 3 days/week for a minimum of 30 min/session at an intensity that induced sweating and made breathing noticeable; (d) not taking thyroid medication or any medication known to interact with bone metabolism; (e) no history of cardiovascular disease; (f) willing to be randomized into experimental or control group; (g) willing to increase calcium consumption if suggested.

The physical characteristics of subjects at baseline are reported in Table 1. Subject groups were similar in age, height, weight, activity, and years postmenopause. Dietary intake of calcium was assessed by 4-day diet records and was
Table 1  Physical Characteristics of Subjects at Baseline

<table>
<thead>
<tr>
<th></th>
<th>Weight trainers (n = 17)</th>
<th>Controls (n = 17)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SE</td>
<td>M</td>
</tr>
<tr>
<td>Age (years)</td>
<td>67.8</td>
<td>1.6</td>
<td>65.2</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>162.8</td>
<td>1.2</td>
<td>164.3</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>68.8</td>
<td>2.8</td>
<td>72.0</td>
</tr>
<tr>
<td>Years postmenopause</td>
<td>17.9</td>
<td>1.5</td>
<td>18.0</td>
</tr>
<tr>
<td>Dietary calcium (mg/day)</td>
<td>698.0</td>
<td>58.8</td>
<td>790.5</td>
</tr>
<tr>
<td>Activity (kcal/week)</td>
<td>1,716</td>
<td>203</td>
<td>1,507</td>
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</table>

analyzed with the Ohio State University software program (Ohio State University, Version 5.1, 1985). Consumption ranged from 271 to 1,330 mg/day (741 ± 48 mg/day). Subjects who consumed less than 800 mg/day were instructed to increase consumption of dairy products or take a calcium supplement (calcium citrate was recommended). Consequently, the calcium intake of all subjects during the training phase of the study was at least 800 mg/day.

PROCEDURES

Initially, and at 6 and 12 months, subjects completed the Blair Seven-Day Recall (Blair et al., 1985) by interview with the investigators. Physical activities that elevated breathing and induced sweating for at least 15 min were recorded for the previous week. If the previous week had been atypical for a subject, she was asked to recall a typical week. Since most of the subjects had been engaging in structured exercise programs, recall of moderate to intense activities was not difficult. Brisk walking and/or aerobic dance activities 3 to 7 days per week were the predominant modes of exercise.

Energy expenditure was determined from metabolic equivalents (METs; 1 MET = 3.5 ml O₂ consumed/kg/min) of 4.0 for moderate and 6.0 for higher intensity activities using an estimated kilocaloric value of 5 kcal/L of oxygen consumed (Blair et al., 1985). The subjects were then stratified into rank-ordered pairs according to level of activity and randomly assigned to either a control group (CON), who would continue their current endurance exercise programs, or a weight training group (WT), who would add supervised weight training to their current exercise programs.

Bone mineral density (g · cm⁻²) was measured by dual-energy x-ray absorptiometry (DEXA) (Lunar DPX, Lunar Radiation, Madison, WI, software version 3.4) at the spine (L2–L4), at the hip (femoral neck and trochanter), and for total body. All scans were performed by the same technician. Computer algorithms were used to divide the body into major anatomic segments. A high-resolution computer-generated image of the skeleton allowed for detection of possible position errors. Quality assurance tests were performed each morning of use. The tests were conducted using a standard with tissue-equivalent material with
Bone Density Responses

three bone-simulating chambers of known bone mineral content. The mean coefficient of variation was less than 1.5%. In vivo BMD precision is 0.6–1.2% for the spine, 0.6–1.7% for the femoral neck, and 0.6–0.8% for total body. Precision measurements for the spine were made 40 times on 6 subjects, for the femur 75 times on 15 subjects, and for the total body 10 times on 2 subjects, all over a 1-week period. The DEXA total body scans were also used to determine soft tissue lean mass, which was calculated as total body lean mass, excluding bone mass. Precision error of this procedure has been reported to be less than 1.5% for nonskeletal lean mass (Mazess, Barden, & Hanson, 1989).

The duration of the training program was initially intended to be 6 months. At six months, 64% (9 of 14) of the weight trainers and 57% (8 of 14) of the control subjects consented to continue the study for another 6 months. One repetition maximum (1 RM) testing and all training sessions were conducted on variable-resistance Polaris machines. The 1 RM was tested on WT and CON at 0, 12, 24, 36, and 52 weeks, according to the following procedure. Following 5 min of general warm-up by walking, subjects performed three to five repetitions at the lightest weight possible. The investigator then selected a heavier weight, and the subjects were instructed to attempt a maximum effort without straining themselves. Following 30–60 s of rest, a heavier weight was selected and the attempt was repeated until the subject could not complete the full lift. In each case the investigator attempted to determine the 1 RM within six to seven trials to prevent localized muscle fatigue. One RM testing of back extension was excluded, due to the high risk for injury in this region.

The WT group engaged in supervised, isotonic training 3 days per week according to the following protocol: initially, one set of 10–12 repetitions of eight different exercises (leg flexion and extension, back extension, trunk flexion, bench press, latissimus dorsi pull-down [lat pulls] shoulder press, and seated row) was performed at an intensity of 50% of 1 RM. By the third week, the load was increased to 80% of 1 RM and was maintained as close to that intensity as possible for the duration of the study. The 1 RM was reevaluated every 6 weeks in the weight trainers, and the absolute weight lifted was adjusted to maintain the relative intensity of 80%. The number of sets was increased from one to three by the third or fourth week of training, allowing a 1-min rest period between sets.

Statistical analysis was performed using Statistics With Finesse (Bolding, 1989, Fayetteville, AR). Initial differences between groups were evaluated using a t test for independent measures. Comparisons between groups and time points were made using two separate two-way analyses of variance (ANOVAs) with repeated measures, one for subjects completing the 6-month study (one repeated measure for 0 and 6 months) and the other for the 9 WT and 8 CON subjects who completed the 12-month study (two repeated measures for 0, 6, and 12 months). Pearson product-moment correlations were performed on selected variables of interest at baseline. All data are expressed as group mean ± SE.

Results

Twenty-eight women (14 CON and 14 WT), of the original 34 subjects, completed the first 6 months of the study. The attendance rate of the 14 weight trainers
was 86.8 ± 3.3% for the first 6 months. A total of 17 women (8 CON and 9 WT) completed the entire 12 months of the study. For the second 6 months the attendance rate dropped to 76.0 ± 7.5%; the overall attendance averaged 81.6 ± 9.9%. During the course of the study only one injury was incurred, when a control subject experienced a severe contusion of the sternum during the baseline testing on the trunk flexion machine. The injury was sustained when she forcefully pushed forward against the chestpad, rather than easing herself into the exercise. The subject complained of extreme tenderness for approximately 2 weeks, but medical treatment was not recommended by her physician.

Correlation coefficients of selected variables with initial bone density measurements are presented in Table 2. BMD at all sites correlated significantly with age. BMD of the spine and total body also correlated significantly with years postmenopause. Total body and hip bone density were related to body mass index. Soft tissue lean mass correlated positively with total body BMD, but not with bone density of the hip or spine. Initial BMD was not related to physical activity or calcium consumption.

The 1 RM values for subjects tested at 0, 6, and 12 months are presented in Table 3. Significant group-by-time interaction was noted for all seven exercises. Figure 1 illustrates the relative changes in strength of only those subjects (9 weight trainers and 8 controls) who completed the entire study. The gains in strength of the weight trainers ranged from 14.5% for the seated row to 71% for the shoulder press exercise. Figures 2–5 illustrate the absolute changes in strength for the combined shoulder and bench press exercises (Figure 2), lat pull-down and seated row (Figure 3), trunk flexion (Figure 4), and knee flexion and extension (Figure 5). The strength of the weight trainers reached a plateau by 6 months, then declined slightly, although nonsignificantly, during the last 6 months. The decline observed between 6 and 12 months corresponded to a decrease in attendance, because several subjects went on vacations for 1 to 2 weeks during this time.

Changes in body composition are illustrated in Figure 6. There was a small but significant increase in soft tissue lean mass of the weight trainers during the first 6 months, which was maintained for 12 months. Similarly, the percent body

Table 2  Correlation Coefficients of Selected Variables and Bone Mineral Density at Baseline

<table>
<thead>
<tr>
<th></th>
<th>Total body</th>
<th>Spine</th>
<th>Hip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-0.58**</td>
<td>-0.35*</td>
<td>-0.42**</td>
</tr>
<tr>
<td>Years postmenopause</td>
<td>-0.38*</td>
<td>-0.46**</td>
<td>-0.30</td>
</tr>
<tr>
<td>Body weight</td>
<td>0.50*</td>
<td>0.28</td>
<td>0.41</td>
</tr>
<tr>
<td>Body mass index</td>
<td>0.38*</td>
<td>0.42</td>
<td>0.37*</td>
</tr>
<tr>
<td>Soft tissue lean mass</td>
<td>0.39*</td>
<td>0.22</td>
<td>0.27</td>
</tr>
<tr>
<td>Dietary calcium</td>
<td>0.08</td>
<td>0.06</td>
<td>-0.10</td>
</tr>
<tr>
<td>Activity</td>
<td>0.12</td>
<td>-0.01</td>
<td>-0.01</td>
</tr>
</tbody>
</table>

*Significant at p < .05. **Significant at p < .01.
Figure 1. Percent change in strength (1 RM) of subjects who completed the entire study (9 weight trainers and 8 controls). Values are group mean ± SE for 12 months.

Figure 2. Changes in the 1 RM of weight trainers and control subjects for the shoulder press and bench press exercises. Values are mean ± SE of the two exercises combined.

fat of weight trainers decreased in the first 6 months, and this decrease was maintained. No changes in body composition were noted for control subjects.

There were no differences between groups in initial bone density for any of the sites measured (Table 4). For subjects completing the 6-month study, repeated-measures ANOVA demonstrated no significant group-by-time interaction for any site measured. Likewise, for subjects completing the 12-month study,
Figure 3. Changes in the 1 RM of subjects for the seated row and lat pull-down. Values are mean ± SE of the two exercises combined.

Figure 4. Changes in the 1 RM of subjects for the abdominal exercise.

Analysis of variance with two repeated measures (6 and 12 months) revealed no significant group-by-time interaction for any site. The changes in BMD for those subjects completing the entire study are illustrated in Figure 7.

Discussion

The high-intensity weight training protocol employed in this study had little effect on bone mineral density of older women who previously engaged in
Figure 5. Changes in the 1 RM of subjects for lower body exercises. Values are mean ± SE of the leg flexion and extension exercises combined.

Figure 6. Changes in body composition of subjects. Values are mean ± SE change expressed in kilograms for body weight, body fat, and lean body mass, excluding bone mass. *p < .05 for interaction variance.

weight-bearing exercise on a consistent basis. All of the subjects had been active for at least 6 months prior to the study, but none had engaged in specific muscle-strengthening exercises. Most of the women reported that they had engaged in weight-bearing activities for most of their adult lives. The marked gains in upper body strength, with smaller changes in lower body strength, are indicative of
Table 3  1 RM Values (kg) of Subjects at Baseline, Midpoint, and End of Study (Values are Mean ± SE)

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Weight trainers</th>
<th>Controls</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 (n = 17) 6 (n = 14) 12 (n = 9)</td>
<td>0 (n = 17) 6 (n = 14) 12 (n = 8)</td>
<td></td>
</tr>
<tr>
<td>Shoulder press</td>
<td>9.4 ± 1.1 16.5 ± 1.7 13.5 ± 1.8</td>
<td>7.5 ± 0.8 8.4 ± 0.9 9.3 ± 1.2</td>
<td>.001</td>
</tr>
<tr>
<td>Bench press</td>
<td>21.0 ± 2.2 29.4 ± 0.6 28.8 ± 2.0</td>
<td>17.7 ± 1.6 18.3 ± 1.9 20.5 ± 2.9</td>
<td>.001</td>
</tr>
<tr>
<td>Lat pull-down</td>
<td>30.0 ± 2.2 38.2 ± 1.8 34.5 ± 2.6</td>
<td>29.2 ± 1.9 27.5 ± 2.0 27.3 ± 2.9</td>
<td>.01</td>
</tr>
<tr>
<td>Seated row</td>
<td>43.3 ± 1.8 49.8 ± 2.9 43.1 ± 3.3</td>
<td>39.2 ± 2.5 40.1 ± 2.7 39.4 ± 3.3</td>
<td>.001</td>
</tr>
<tr>
<td>Trunk flexion</td>
<td>27.7 ± 1.5 34.8 ± 2.7 32.2 ± 2.4</td>
<td>24.9 ± 1.3 27.0 ± 1.8 27.1 ± 2.5</td>
<td>.08</td>
</tr>
<tr>
<td>Leg flexion</td>
<td>21.1 ± 1.9 24.2 ± 1.5 21.6 ± 2.2</td>
<td>17.9 ± 1.9 19.5 ± 1.8 20.0 ± 2.3</td>
<td>.009</td>
</tr>
<tr>
<td>Leg extension</td>
<td>31.3 ± 2.3 40.0 ± 0.8 32.0 ± 3.9</td>
<td>28.6 ± 2.7 33.0 ± 2.6 31.3 ± 2.7</td>
<td>.037</td>
</tr>
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</table>

Note. p values indicate significant interaction variance.

Table 4  Bone Mineral Density (g · cm⁻²) of Subjects at Baseline, Midpoint, and End of Study (Values are Mean ± SE)

<table>
<thead>
<tr>
<th>Site</th>
<th>Weight trainers</th>
<th>Controls</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 (n = 17) 6 (n = 14) 12 (n = 9)</td>
<td>0 (n = 17) 6 (n = 14) 12 (n = 8)</td>
<td></td>
</tr>
<tr>
<td>L2–L4</td>
<td>1.036 ± 0.03 1.016 ± 0.03 1.025 ± 0.04</td>
<td>0.998 ± 0.03 1.012 ± 0.03 1.012 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>Femoral neck</td>
<td>0.786 ± 0.02 0.789 ± 0.03 0.776 ± 0.03</td>
<td>0.764 ± 0.02 0.788 ± 0.03 0.772 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>Trochanter</td>
<td>0.664 ± 0.01 0.675 ± 0.02 0.670 ± 0.02</td>
<td>0.639 ± 0.03 0.646 ± 0.03 0.666 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>Total body</td>
<td>1.007 ± 0.02 0.985 ± 0.02 0.976 ± 0.02</td>
<td>0.997 ± 0.02 0.981 ± 0.02 0.979 ± 0.03</td>
<td></td>
</tr>
</tbody>
</table>
their activity patterns, which consisted primarily of brisk walking and/or aerobic dance. The smaller gains in lower body strength may partially explain the lack of change in BMD at the hip and spine. Those sites may not have been adequately loaded to stimulate bone mineralization. Another possible explanation for the lack of a training effect could be that the subjects' BMD in the hip region was already very high, and therefore less likely to show any further change. At baseline, the BMD at the hip was equal to 105 ± 2.2% of that reported from normative data for age-matched women (Lunar Reference Manual, 1990).

Most of the published research showing positive effects of exercise training on BMD of postmenopausal women utilized weight-bearing activities as the mode of training and employed previously sedentary subjects (Dalsky et al., 1988; Krolner et al., 1983; Nelson et al., 1991). Thus, dramatic increases in the volume of weight-bearing activity may have induced the changes observed in those studies.

Cross-sectional studies of young adult subjects engaging in specific muscle-strengthening exercises (weight training) reported greater spinal BMD in weight lifters (Granhed et al., 1987), and in female bodybuilders (Davee et al., 1990) compared with nonathletes. The results of prospective studies of the effects of resistance exercise on BMD of premenopausal women or early postmenopausal women have been conflicting. A lack of bone response to 1 year of weight training in premenopausal women (Gleeson et al., 1990) and early postmenopausal women (Peterson et al., 1991) has previously been reported. Moreover, Rockwell et al. (1990) reported a decrease in BMD of the lumbar spine in premenopausal women following 9 months of moderate-intensity weight training. In contrast, Pruitt, Jackson, Bartels, and Lehnhard (1992) reported increased BMD of the spine, but not of the hip, in early postmenopausal women who underwent a 9-month weight-training program similar to that of the present study. Those subjects, however, had been previously sedentary, unlike the subjects in the present study.
The results of two recent studies suggest that responses of bone to mechanical stimuli may be specific to the type of bone and/or the measurement technique. Nelson et al. (1991) found no changes in spinal BMD of postmenopausal women measured by dual photon absorptiometry (DPA), but they found a significant increase in L1–L3 measured by computed tomography. Likewise, Pollock et al. (1992) found a small but significant increase in lumbar BMD of elderly men and women with a lateral view of the spine by DEXA, but not by frontal view. Neither DPA nor measurement of the lumbar spine from a frontal view by DEXA, which was used in the present study, is discriminatory for trabecular bone, where one might expect to see more rapid changes. The greater surface area of trabecular bone is correlated with a greater metabolic activity, and 25% of all trabecular bone is remodeled annually compared with 2–3% of cortical bone (Riggs et al., 1981). Thus, differences in measurement technique may partially explain the varying results of published studies.

The lack of a training response in spinal BMD in the present study could also possibly be due to the failure of the training equipment to isolate the spinal extensors, and thereby induce the mechanical load necessary for bone to respond. It has previously been shown that variable-resistance machines such as those used in the present study do little to strengthen the paravertebral muscles, even after training for 1 year (Pollock et al., 1989).

Conflicting results of published research may be due to differences in frequency, intensity, and volume of training, as well as differences in initial level of fitness and estrogen status of the subjects. In the present study, women were targeted at 80% of the 1 RM for the duration of the study. This high intensity was difficult for most subjects. Constant attention and motivation were necessary to maintain the intensity. Still, the women enjoyed the program, as is evidenced by the high attendance rate. To facilitate adherence, a 1:5 ratio of exercise trainer to subject was maintained. In addition, drawings for prizes and group socials were conducted periodically.

In conclusion, despite marked gains in muscular strength, particularly in upper body muscles, high-intensity weight training failed to elicit a positive response in bone density of non-estrogen-repleted older women already engaging in moderate to high levels of weight-bearing exercise on a consistent basis. Weight training programs intended to effect bone density must be designed to adequately load those sites of interest. Still, the training protocol used in this study was safe, enjoyable, and highly effective in increasing total body strength, which will help elders maintain long-term independent living.

References


**Acknowledgment**

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