Musculoskeletal responses to high- and low-intensity resistance training in early postmenopausal women

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ABSTRACT

Purpose: The purpose of this study was to compare the effects of a high-load (80%, 1-repetition maximum (RM), 8 reps) and a high-repetition (40%, 1-RM, 16 reps) resistance training protocol on muscular strength and bone mineral density (BMD) in early postmenopausal, estrogen-deficient women. The 6-month programs were matched initially for training volume (3 sets, 3 d·wk⁻¹) for 12 exercises selected to specifically load the spine and hip. Methods: Subjects included 25 women (41–60 yr) who were matched by spine BMD then randomly assigned to either the high-load (HL, N = 10), high-repetition (HR, N = 7), or control (C, N = 8) groups. Dietary calcium intakes were supplemented to ∼1500 mg·d⁻¹. Total body, spine, and hip BMD (DXA, Lunar Model DPX-IQ), upper and lower body muscular strength, and biochemical markers of bone turnover were measured at baseline and after 6 months of training.

Results: There were no group differences in the baseline measures. Both training groups showed similar increases in biceps (20%) and rectus femoris (28–33%) cross-sectional areas, in lower body strength (30%) and in hip strength (37–40%). HL showed greater improvements in upper body strength (HL 25%, HR 16%). Neither training group experienced significant increases in spine or hip BMD, although the HL total body BMD tended to decrease (±1.1% ± 0.4, P = 0.054) after training. Osteocalcin tended to increase (P = 0.08) in all groups after training, and the % change in osteocalcin was positively related to % changes in the total hip (r = 0.41, P = 0.048) and the trochanter (r = 0.42, P = 0.04) BMD.

Conclusion: The high-load and high-repetition resistance training protocols were both effective in improving muscular strength and size in postmenopausal women, indicating low-intensity resistance training can be beneficial for the muscular fitness in women for whom high-intensity exercise is contraindicated. Key Words: BONE REMODELING, OSTEOPOROSIS, STRENGTH, HYPERTROPHY, OSTEOCALCIN

Osteoporosis is a bone disease associated with reduced bone mineral density (BMD) and increased incidence of hip and spine fractures (8). Aging is associated with gait and balance problems, which increase risk for falls and subsequent osteoporotic fractures; therefore, weight-bearing activities may have important benefits for older women by preventing further bone loss and by increasing strength, coordination, and balance, which could decrease the risk for falling (2). Body weight, physical activity, and muscle strength are mechanical factors that determine the voluntary loads placed upon the skeleton (5,10). Recently, it has been proposed that muscle strength is the most important of these factors because voluntary muscular forces place greater loads on the skeleton than the gravitational forces associated with body weight (5,10). Early postmenopause is a critical time for loss of muscular strength (21) and bone mass (25) in women. There may be a relationship between these two phenomena as age-related losses in muscle strength precede losses in bone; and the resultant decreased muscular forces placed upon bone cause a disuse-mode bone remodeling response (10). This model suggests that mechanical loading interventions that increase muscular strength may then prevent bone loss.

Animal studies have shown that bone formation is proportional to the peak strain magnitude caused by the dynamic mechanical loading stimulus (28) and that only a small number of loading cycles are required for the bone to adapt (27). Dynamic resistance exercises that involve high peak forces should effectively load the skeleton (15). Several prospective resistance training studies have documented that the traditional high intensity strength training program (80%, 1-repetition maximum) can have an osteogenic effect.
at the lumbar spine (17,22) and femoral neck (12,17) BMD sites in postmenopausal women not taking estrogen. Conversely, a lack of BMD response to resistance training also has been reported (20,23,30), which may be explained by the lack of randomization of subjects, deficient calcium intakes, and insufficient loading of the clinically important BMD sites. There is a paucity of human studies that have directly compared the effects of different resistance training programs designed to emphasize either load magnitude or the number of load cycles on the adaptive response of bone in postmenopausal women. Pruitt and associates (23) reported that BMD was not influenced by either high- or low-intensity resistance training; however, the results were confounded by the use of hormone replacement therapy and low calcium intakes. In contrast, Kerr et al. (12) found that hip BMD increased in postmenopausal women in response to high-load, low-repetition resistance training protocol but not to a low-load, high-repetition program, suggesting that maximum load was more important than the number of load cycles for influencing BMD. In this study, it was not clear whether the total volume of work was the similar for both programs or whether calcium intake was sufficient to support bone formation.

There remains much to be elucidated about optimal mechanical loading regimens in humans, such as the dose–response relationship and the effects of different training protocols on bone and muscle. The purpose of this study was to compare the effects of a high-intensity—low-repetition resistance training protocol and a high-repetition—low-intensity resistance training protocol for 6 months on the BMD and muscular strength in estrogen-deficient early postmenopausal women. The training protocols were designed to produce similar volumes of work.

**MATERIALS AND METHODS**

**Subjects.** Twenty-five healthy, early postmenopausal estrogen-deficient women, 41–60 yr of age (mean = 51.4 yr, SD = 5.5), completed the 6-month resistance training study. Women volunteers for the study were recruited from the Norman/Oklahoma City area by media advertisements. Initially, subjects were entered into the study if they were 1–7 yr postmenopausal and had not performed any resistance training in the previous 6 months. Exclusion criteria for the study were: 1) diagnosed osteoporosis or a BMD site ≥ 2.5 SD below the mean for the young-adult reference population; 2) a history of cardiovascular disease; 3) physical or orthopedic disabilities; 4) a history or current diagnosis of renal disease, chronic digestive or eating disorders, rheumatoid arthritis, or thyroid disease; 5) a history of prolonged bed rest; and 6) current or recent use of medications that affect bone density (i.e., estrogen, steroid hormones, calcitonin, or corticosteroids). All subjects provided written informed consent, which was approved by the Institutional Review Board at the University of Oklahoma. Information on menopausal status and menstrual history was obtained from a menstrual history questionnaire completed by all subjects at baseline. Height and weight were measured before and after training. Body mass index (BMI) was calculated as kg/m$^2$. Thirty-five subjects were originally included in the study; however, due to injuries not related to training, time commitment, job relocation, and noncompliance, 10 subjects (4 HR, 3HL, 3C) discontinued and/or were eliminated from the study. Therefore, 71% of the original participants completed the study.

**Research design.** The experimental protocol utilized a partially randomized control trial design to assess the effects of varying resistance training intensity (high vs low) and number of repetitions (high vs low) on BMD of the proximal femur, lumbar spine, and total body and muscular strength. To avoid group bias, subjects were matched according to the BMD of the spine after baseline testing, then they were randomly assigned to the high-intensity—low-repetition resistance training group (high load, HL), high-repetition—low-intensity resistance training group (high repetition, HR), or to the control group (C). The number of sets (3) and the frequency (3 d·wk$^{-1}$) were matched for the HL and HR protocols. However, the HL group performed 8 repetitions of each exercise at an intensity of 80% of 1-repetition maximum (RM), and the HR group performed 16 repetitions of each exercise at 40% of 1-RM. These protocols were selected in order to have the two training groups performing similar volumes of work as determined by sets × repetitions × load. For example, training subjects in each group with the same 1-RM for an exercise would have the same training volume:

- **HL subject quadriceps training volume = 3 (sets) × 8 (reps)**  
  \[ \times (1 - \text{RM 87.5 lbs } \times .8) = 1680 \text{ lbs} \]

- **HR subject quadriceps training volume = 3 (sets) × 16 (reps)**  
  \[ \times (1 - \text{RM 87.5 lbs } \times .4) = 1680 \text{ lbs} \]

The initial volumes of work for the two training groups were similar for each exercise because the baseline strength values were not significantly different. The initial training volumes averaged over the 12 exercises were 1607 lbs ± 696 for the HL group and 1468 lbs ± 502 for the HR group. The average attendance for the 6-month intervention was 93% for HR and 87% for HL. Control subjects were instructed to continue their normal dietary and physical activity habits but not to start any new exercise programs for the duration of the study.

**Training protocols.** The previously described training protocols lasted for 6 months. The resistance training groups exercised three nonconsecutive days per week at the Neuromuscular Laboratory located in the Huston Huffman Center. The training sessions were supervised by two research assistants who were responsible for monitoring the correct lifting form of the subjects, the maintenance of the daily exercise logs, and for determining the progression for the exercises. During the first 2 wk of training, subjects were instructed on proper weight lifting techniques, warm-up, cool down, and stretching exercises. The workloads for the first 5 wk were progressively increased, allowing the subjects to acclimate to the resistance training protocols. The rate of progression was individualized in order to have an
optimal stimulus for each subject. The weight lifted was increased by the training supervisor when a subject performed the prescribed number of repetitions easily, typically in increments of 3.1 lbs (1/4 plate), 6.3 lbs (1/2 plate), or 12.5 lbs (1 plate), depending on the exercise. Retrospectively, we noted that this approach to the rate of progression allowed subjects in the HR group to progress more quickly due to their lighter loads; thus, the HR average training volumes for each exercise were about 30% greater than those of the HL group toward the end of the program.

Each training session involved a 10-min warm-up, approximately 45 min of weight lifting, and ended with a 5-min cool-down. Detailed, daily workout records were used to monitor the amount of weight lifted, repetitions, and date of training for each subject. The subjects performed three sets of the following exercises using Cybex (Ronkonkoma, NY) isotonic resistance training equipment: quadriceps extension, hamstring flexion, leg press, shoulder press, biceps curl, triceps extension, seated row, and latissimus pull. Only one set was performed for each right and left hip exercise (hip extension, hip flexion, hip abduction, hip adduction) as the facility had only one hip machine. The hip exercises, quadriceps extension, leg press, latissimus pull, and seated rows were selected because of their attachments (origin and insertion) to the proximal femur and lumbar spine, respectively. The shoulder press was used because of its load effect on the vertebral column. The remaining exercises were used to promote overall muscular fitness.

Muscular strength. Muscle strength was assessed by a 1-RM test for each lift at the beginning, at 3 months, and at the end of the study. The standard Cybex resistance training equipment was selected to minimize the problems experienced by a resistance training beginner such as the inability to balance the free-weight equipment and the fear of injury when using free weights. Each subject warmed-up on a stationary bicycle for 5 min and was then instructed on proper lifting techniques for each resistance training machine. Subjects then warmed-up each muscle group by doing 5–10 repetitions at 40–60% of their perceived maximum. After a 3-min rest, each subject began the process of reaching her 1-RM, which was achieved within five attempts. One-minute rest intervals were allowed between each attempt. Testing of agonistic and antagonistic muscle groups was conducted on two separate days, and the 1-RMs were assessed on the right side for the hip exercises. Post-testing occurred within 3 d after the last training session.

Muscle cross-sectional areas. Each subject had her right biceps brachii and rectus femoris muscle groups measured by ultrasound to obtain the cross-sectional areas (CSA). This procedure has been shown to be a reliable and valid method in our laboratory for assessing muscle size as compared with magnetic resonance imaging (4). Subjects did not participate in any vigorous arm or leg exercises on the days of assessment. The biceps brachii scan was performed at maximal girth with the subject in a supine position with her shoulder in 90° abduction, elbow at 180° extension, and hand supinated. The rectus femoris scan required the subject to be in a supine position with a rolled-up towel placed under the popliteal fossa of the right leg. To locate the exact evaluation site, the proximal pole of the right patella was marked with indelible ink, then a point 15 cm proximal to the patellar mark, following the midline of the anterior surface of the thigh, was also marked. A Fukuda Denki, model 4500 ultrasound, utilized a 5-Mz transducer (FUT-L104) and water-soluble transmission gel to image both muscles (Tokyo, Japan). Care was taken to ensure that the transducer was always placed perpendicular to the anterior surface of the thigh and that no depression of the skin surface occurred. Once the image was obtained, the image was frozen on the screen and with the aid of a track ball the muscle was outlined on the inside edge of the connective tissue that surrounded the muscle to obtain that muscles CSA. All scans were performed by the same technician. Two trials were obtained during each test session, which were averaged for use in further data analyses.

BMD measurements. Dual energy x-ray absorptiometry (DXA; Lunar DPX-IQ) (Madison, WI) was used to measure the BMD (g/cm^2) of the total body, anteroposterior (AP) lumbar spine (L2–L4), and the proximal femur (femoral neck, Ward’s triangle, trochanter, total hip) at the beginning and at the end of the study. Body composition (% body fat, fat mass, lean body mass) was determined from the total body scan. Baseline and posttest scans for each subject were performed and analyzed by the same technician. To minimize variability, subject positioning, use of anatomical landmarks, and scan speeds recorded for each subject during the baseline evaluation were used again for the posttest scan. Scanning instructions and procedures were standardized for all subjects. Scan speeds were determined by the measured thickness of the subject’s trunk region. The AP spine and femur scans used the scan modes of hi-res fast 3000 mA, hi-res medium 3000 µA, and hi-res medium 750 µA for subjects with thicknesses of 15–26 cm, 26–30 cm, and 12–15 cm, respectively. The total body scan required the fast 150 µA, medium 150 µA, and slow 150 µA modes to scan subjects with trunk thicknesses of 15–26 cm, 22–28 cm, and over 28 cm, respectively. A compare scan function provided by the Lunar DPX-IQ software was used to compare pre- and post-test scans, which helps to reduce the variability from technician analysis. Coefficients of variation for accuracy and precision for the spine phantom are 0.6% and 0.8%, respectively, for this laboratory. In vivo short-term precision for the proximal femur ranges from 0.7% for the total hip site to 1.3% for Ward’s triangle.

Biochemical markers of bone turnover. Blood samples were obtained in the morning after an overnight fast via venipuncture at baseline and within 48 h of the last training session. Samples were allowed to clot and then centrifuged to separate serum from the cells. Subjects also gave a second morning void urine specimen at times corresponding to the blood collection. The urine and serum samples were pipetted into 1-mL aliquots and kept frozen at −70°C for the subsequent assays. Biochemical assays were conducted in the biochemistry area of the Human Performance Laboratory at the University of Oklahoma.
TABLE 1. Subject baseline characteristics.

<table>
<thead>
<tr>
<th>Variables</th>
<th>HL (N = 10)</th>
<th>HR (N = 7)</th>
<th>C (N = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>162.1 ± 1.6</td>
<td>164.6 ± 1.6</td>
<td>158.5 ± 1.8</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>74.7 ± 5.6</td>
<td>62.7 ± 3.4</td>
<td>66.5 ± 4.2</td>
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<tr>
<td>Age (yr)</td>
<td>50.5 ± 2.0</td>
<td>51.9 ± 2.3</td>
<td>52.3 ± 1.4</td>
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<tr>
<td>Years PM</td>
<td>3.6 ± 0.7</td>
<td>2.4 ± 0.7</td>
<td>3.0 ± 0.7</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>28.7 ± 2.4</td>
<td>23.2 ± 1.2</td>
<td>24.8 ± 1.7</td>
</tr>
<tr>
<td>% Fat</td>
<td>41.4 ± 3.4</td>
<td>33.0 ± 3.1</td>
<td>37.8 ± 2.4</td>
</tr>
<tr>
<td>LBM (kg)</td>
<td>42.1 ± 1.9</td>
<td>39.9 ± 0.6</td>
<td>40.1 ± 1.5</td>
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<tr>
<td>Calcium (mg d⁻¹)</td>
<td>902 ± 159</td>
<td>1279 ± 276</td>
<td>1573 ± 534</td>
</tr>
</tbody>
</table>

Values are means ± SE. HL, high load resistance training group; HR, high repetition resistance training group; C, control group; PM, postmenopausal; BMI, body mass index; % Fat, percent body fat; LBM, lean body mass.

All pre- and post-test samples for each subject were measured in duplicate in the same assay. Serum osteocalcin, a marker of bone formation, was determined by a commercial immunoradiometric assay kit (Diagnostic Systems Laboratories, Webster TX). The intra-assay variation was ≈ 3% and the inter-assay variation was 13.5%. Urinary cross-laps (CTx) were measured as a marker of bone resorption using an enzyme-linked immunosorbent assay (Diagnostic Systems Laboratories, Webster TX). CTx values were corrected for urinary creatinine concentrations measured by standard laboratory procedures (Sigma Diagnostics, St. Louis, MO). The intra-assay variation was ± 6.1% and inter-assay variation was 12%.

**Nutritional analyses.** Food frequency questionnaires were used to assess daily dietary calcium intake levels at the beginning of the study. These questionnaires were completed by all subjects with the guidance of a nutrition specialist. Nutritionist IV Version 3.5 (N-Squared Computing, Salem, OR) computer software program was used to analyze the food frequency questionnaires. Subjects found to consume less than 1500 mg d⁻¹ of calcium (18) were supplemented with a generic brand of calcium plus vitamin D (calcium carbonate = 600 mg d⁻¹, vitamin D = 125 IU). Subjects picked up their individualized calcium packets during the resistance training sessions. The packets contained the required amount of calcium (mg d⁻¹) for 2 d, except the weekend packet that contained enough calcium (mg d⁻¹) for the weekend. Subjects were required to record the days that they took the supplements on their workout schedules to monitor compliance.

**Data analyses.** All data were reported as means ± standard error (SE). Descriptive statistics and repeated measures analysis of variance (ANOVA) were used to evaluate the data using the SPSS program (SPSS for Windows version 6.13). One-way ANOVA was used to identify group differences in the baseline values and in absolute and percent changes in BMD and strength variables. The Bonferroni post hoc test procedure was used to identify which groups were significantly different. Group (3) × trial (2) repeated measures ANOVA was used to detect changes between trials and/or group by trial interaction for the strength and BMD variables. Paired t-tests were performed post hoc within each group for variables that had significant group by trial interactions. Zero-order correlation coefficients were used to determine the relationship between the BMD sites, body composition, and muscular strength variables. Statistical significance was set at P ≤ 0.05 level.

**RESULTS**

**Physical characteristics.** Table 1 presents the physical characteristics at baseline of the women who completed the study. No significant (P > 0.05) group differences existed in number of years postmenopausal or in body composition variables. Also, the body weights before and after training were similar for each group. Based on the food frequency questionnaire, levels of calcium intake were not significantly different between the three groups.

**Muscle strength and CSA.** There were no significant differences (P > 0.05) between the groups for the baseline values of the 12 strength training exercises (Table 2). Both training protocols produced significant increases (P < 0.05) for two of five upper body exercises (latissimus pull, seated row) and four of seven lower body exercises (hamstrings, leg press, hip adduction, hip extension). Only the HL protocol

<table>
<thead>
<tr>
<th>Exercises</th>
<th>Pre HL (N = 10)</th>
<th>Post HL (N = 10)</th>
<th>Pre HR (N = 7)</th>
<th>Post HR (N = 7)</th>
<th>Pre C (N = 8)</th>
<th>Post C (N = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper body (N)</td>
<td>Biceps</td>
<td>209 ± 22</td>
<td>232 ± 18</td>
<td>196 ± 18</td>
<td>223 ± 13</td>
<td>183 ± 13</td>
</tr>
<tr>
<td></td>
<td>Latissimus pull</td>
<td>258 ± 22</td>
<td>361 ± 27*</td>
<td>263 ± 18</td>
<td>316 ± 13*</td>
<td>281 ± 13</td>
</tr>
<tr>
<td></td>
<td>Seated row</td>
<td>320 ± 22</td>
<td>419 ± 22*</td>
<td>321 ± 18</td>
<td>365 ± 18*</td>
<td>325 ± 18</td>
</tr>
<tr>
<td></td>
<td>Shoulder press</td>
<td>330 ± 31</td>
<td>392 ± 27*</td>
<td>352 ± 27</td>
<td>365 ± 18</td>
<td>367 ± 22</td>
</tr>
<tr>
<td></td>
<td>Triceps</td>
<td>205 ± 18</td>
<td>236 ± 22</td>
<td>200 ± 18</td>
<td>223 ± 14</td>
<td>178 ± 13</td>
</tr>
<tr>
<td>Lower body (N)</td>
<td>Hamstrings</td>
<td>468 ± 40</td>
<td>548 ± 27*</td>
<td>454 ± 45</td>
<td>544 ± 31*</td>
<td>419 ± 27</td>
</tr>
<tr>
<td></td>
<td>Leg press</td>
<td>797 ± 67</td>
<td>1046 ± 120*</td>
<td>610 ± 89</td>
<td>820 ± 89*</td>
<td>637 ± 45</td>
</tr>
<tr>
<td></td>
<td>Quadriceps</td>
<td>414 ± 40</td>
<td>535 ± 27*</td>
<td>356 ± 27</td>
<td>432 ± 31</td>
<td>352 ± 40</td>
</tr>
<tr>
<td>Hip (N)</td>
<td>Abduction</td>
<td>396 ± 45</td>
<td>401 ± 22*</td>
<td>352 ± 40</td>
<td>343 ± 40</td>
<td>294 ± 31</td>
</tr>
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<td></td>
<td>Addition</td>
<td>307 ± 18</td>
<td>450 ± 31*</td>
<td>263 ± 27</td>
<td>401 ± 27*</td>
<td>334 ± 31</td>
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<td></td>
<td>Extension</td>
<td>486 ± 27</td>
<td>686 ± 40*</td>
<td>428 ± 45</td>
<td>650 ± 40*</td>
<td>468 ± 62</td>
</tr>
</tbody>
</table>

Values are means ± SE. HL, high load resistance training group; HR, high repetition resistance training group; C, control group.

1) Significant trial effect (P ≤ 0.05).
2) Significantly different (P ≤ 0.05) between HR and C groups.
3) Significantly different (P ≤ 0.05) between HL and C groups.

resulted in significant increases in shoulder press, quadriceps, and hip flexion strength. Neither training group exhibited significant improvements \((P > 0.05)\) in biceps curl, triceps extension, or hip abduction. Biceps strength significantly declined \((P < 0.05)\) for the C group. There were significant group differences in the percent changes in strength with both HL and HR groups having greater increases than C for latissimus pull, hamstrings, hip flexion, and hip adduction exercises (Fig. 1). In addition, HL had significantly greater improvements \((P < 0.05)\) in strength than C for quadriceps extension and seated row. The overall percent changes in muscular strength (averaged for all exercises) for the resistance training groups were 30% and 27% for HL and HR respectively, compared with −3% for C. Both training groups showed similar improvements in the lower body (HL 30%, HR 30%, C −3%) and hip strength (HL 37% HR 40%, C −1%); however, HL tended to show greater improvements in upper body strength (HL 25%, HR 16%, C −6%).

Figure 2 depicts the group and trial CSA comparisons for the biceps brachii and rectus femoris muscle groups. There were no significant \((P > 0.05)\) group differences in pretest muscle CSA for either muscle group. Both training groups showed significant \((P < 0.01)\) improvements of approximately 20% in rectus femoris CSA. The biceps brachii CSA significantly \((P < 0.01)\) increased 33% for HL and showed a trend \((P = 0.07)\) to increase (28%) for the HR group.

**BMD and biochemical markers.** At the start of the study, there were no significant differences \((P > 0.05)\) between groups for total body, spine \((L_2-L_4)\), total hip, femoral neck, Ward’s triangle, and trochanter BMD (Table 3). The spine BMD were 94% ± 4% (HL), 96% ± 4% (HR), and 96% ± 3% (C) compared with the mean of the young-adult reference population. The total hip BMD were 96% ± 5% (HL), 94% ± 6% (HR), and 95% ± 5% (C) compared with the young-adult mean.

Neither of the resistance training groups experienced a significant change in BMD for the spine, total hip, femoral neck, trochanter, and Ward’s triangle sites from pre- to post-testing assessments (Table 3). There were no significant \((P > 0.05)\) group differences in absolute changes or in percent changes from pre- to post-training for any BMD site. However, there was a trend \((P = 0.054)\) for the HL total body BMD to decrease \((-1.1\% ± 0.4)\) after the 6 months of training.

Figure 3 shows the relative changes in spine, total hip, and total body BMD for individual subjects within each group. When examining the individual responses, 35% (6/ 17); 53% (9/17), and 47% (8/17) of the training subjects maintained or increased their spine, total hip, and total body BMD, respectively. Generally, relative changes in BMD variables were not significantly related \((P > 0.05)\) to the initial BMD levels. % change in Ward’s triangle was positively associated \((r = 0.57\ P < 0.05)\) with presupplemented baseline calcium intakes in the training subjects.
There were no significant group, trial, or group \times trial\) effects for CTx (Fig. 4). There was a trend \((P = 0.08)\) for serum osteocalcin levels to increase after the training period for all three groups. Also, the C group tended to have higher posttest serum osteocalcin levels than HR \((P = 0.08)\). There were two subjects who had much higher increases in CTx and one subject who exhibited a much greater \% change in osteocalcin compared to the rest of the sample. When these outliers were omitted, \% change in CTx was negatively related \((r = -0.53, P = 0.013)\) to \% change in the total hip BMD in the entire sample. \% Change in osteocalcin was positively related to \% changes in the total hip \((r = 0.41, P = 0.048)\) and the trochanter \((r = 0.42, P = 0.04)\) sites.

**Relationships between BMD, body composition, and strength variables.** Zero-order correlation coefficients between the baseline body composition and BMD variables showed that LBM and BMI were positively related \((P < 0.05)\) to the trochanter \((r = 0.51, r = 0.52, respectively)\) and total hip \((r = 0.42, r = 0.49)\) BMD sites. There were no significant correlations between FM and any of the BMD sites. At baseline, significant \((P < 0.05)\) positive correlations were found for spine BMD and upper body strength \((r = 0.44–0.58)\). Hip BMD sites (femoral neck, Ward’s triangle, trochanter, total hip) were positively related \((P < 0.05)\) to hip strength (abduction, extension, and flexion) \((r = 0.49–0.70)\) and leg strength \((leg\ press,\ hamstrings)\) \((r = 0.47–0.72)\). When the postraining BMD and strength data were collapsed over the two training groups, similar significant relationships were observed for the hip, with hip adduction strength \((r = 0.60–0.73)\) and hip extension strength \((r = 0.53–0.74)\) showing the strongest correlations with the hip BMD sites. In addition, \% change in total hip BMD was positively related \((r = 0.44, P < 0.05)\) to the \% change in hip adduction strength for the entire sample.

**DISCUSSION**

This study compared the effects of a high-intensity—low-repetition resistance training protocol and a high-repetition—low-intensity resistance training protocol, both designed to produce similar volumes of work \((sets \times reps \times load)\) on the BMD and muscular strength in estrogen-deficient, early postmenopausal women. In contrast to previous training studies \((12,17,23)\), our subjects were homogenous with respect to age, number of years postmenopausal, and they were consuming levels of calcium adequate to support bone formation. We documented that both resistance training programs produced similar overall improvements in muscular strength, particularly for the lower body exercises. The increases in upper body strength for both programs were less than for the leg or hip, which may be explained in part by the fact that both training programs involved more lower body than upper body exercises. Similar findings for high- and low-intensity resistance training programs have been reported in late postmenopausal women \((12)\) and in women using hormone replacement therapy \((23)\). In contrast to those studies, hip abduction strength did not improve with either training protocol, suggesting a single set may not have been a sufficient stimulus for this exercise. We also documented that both training protocols resulted in muscle hypertrophy for the biceps brachii \((28–33\% increase)\) and rectus femoris \((20\% increase)\) muscle groups in these early postmenopausal women. Significant increases in whole muscle \((16)\) or muscle fiber \((7)\) cross-sectional areas from resistance training interventions have been previously reported in elderly men and women.

Although it is generally accepted that heavier loads result in greater strength development \((3,9)\), our results indicate that a low intensity program of sufficient training volume can produce relative strength gains similar to a higher intensity program in sedentary postmenopausal women. It has been reported previously that both high and low volume resistance training programs performed at the same high intensity were equally effective in improving isometric strength and muscle size \((31)\). Therefore, it is not clear whether the similar strength responses to the two training programs in our study can be attributed to the modest differences in training volumes that occurred in the latter part of the program. There are some important implications for resistance training prescription for older populations. A lower-intensity program may be more easily tolerated by older individuals while having similar health and fitness benefits. For example, we noted that the subjects in the high repetition group adapted to the workloads more quickly; thus, they tended to progress at a faster rate than the high-load training subjects. This type of program also would be beneficial for women with osteopenia and/or osteoporosis whose weakened bones might not be able to withstand the stress of high-intensity resistance training.

Although spine and hip BMD were positively related to strength measures before and after training, significant group BMD changes were not observed with either training protocol. Some training subjects maintained or increased

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**TABLE 3. Pre- and post-training bone mineral density (BMD) values.**

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<thead>
<tr>
<th>BMD ((g/cm^2))</th>
<th>HL ((N = 10))</th>
<th>HR ((N = 7))</th>
<th>C ((N = 8))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spine L2–L4</td>
<td>1.125 ± 0.044</td>
<td>1.160 ± 0.047</td>
<td>1.152 ± 0.037</td>
</tr>
<tr>
<td>Total hip</td>
<td>0.962 ± 0.050</td>
<td>0.944 ± 0.061</td>
<td>0.947 ± 0.060</td>
</tr>
<tr>
<td>Neck</td>
<td>0.910 ± 0.048</td>
<td>0.922 ± 0.060</td>
<td>0.921 ± 0.062</td>
</tr>
<tr>
<td>Ward’s triangle</td>
<td>0.745 ± 0.059</td>
<td>0.792 ± 0.060</td>
<td>0.810 ± 0.065</td>
</tr>
<tr>
<td>Trochanter</td>
<td>0.760 ± 0.045</td>
<td>0.731 ± 0.049</td>
<td>0.731 ± 0.058</td>
</tr>
<tr>
<td>Total body</td>
<td>1.154 ± 0.027</td>
<td>1.170 ± 0.020</td>
<td>1.171 ± 0.021</td>
</tr>
</tbody>
</table>

Values are means ± SE. HL, high load resistance training group; HR, high repetition resistance training group; C, control group. No significant group effect, trial effect, or group \times trial interaction \((P > 0.05)\).
their BMD at the spine (6/17), total hip (9/17), and total body (8/17) sites during the study. The maintenance of bone mass may be clinically significant when considering that bone loss during the early postmenopausal phase can be as much as 5% per year (25). One training subject, in particular, had substantial losses in her spine (−3.8%) and total hip (−2.6%) BMD, indicating she was undergoing rapid bone loss requiring anti-resorptive drug therapy.

The 6-month duration of this training intervention was a limitation of our study, as previous training studies documenting a significant improvement (1–1.6%) in bone density in postmenopausal women utilized programs 9–12 months in duration (13,17,22). Duration is important because the bone remodeling cycle is 4–6 months long; therefore, some subjects may have been in the resorption phase when their BMD was measured at 6 months. Although areal bone density may not show adaptations in 6 months, it is possible that there are beneficial structural and/or geometric changes within bone which can be detected by techniques such as peripheral quantitative computer tomography (pQCT). Recently, Adami et al. (1) reported that 6 months of strength training for the wrist resulted in increased CSA and density of the cortical component of the ultradistal radius assessed by pQCT. Therefore, exercise reshaped the structure and geometry of the bone without increasing its areal density.

Few human studies have directly compared the effects of different resistance training programs on the adaptive response of bone in this population. Pruitt et al. (23) examined the effects of 1 yr of high-intensity (80% 1-RM) versus low-intensity (40% 1-RM) resistance training on BMD and found that neither training program significantly increased BMD of the lumbar spine or proximal femur compared with the control group. This study was confounded by the estrogen use by 15 of 26 subjects, because estrogen has a strong influence on the bone remodeling process by decreasing bone resorption (6). Kerr et al. (12) addressed the question of whether the load magnitude (intensity) or the number of load cycles (repetitions) is more important for increasing BMD in postmenopausal women. Estrogen-deficient subjects participated in either a high-load—low-repetition program (8-RM) or a low-load—high-repetition program (20-RM) for 1 yr. Although both training groups had similar increases in strength, only the high load program provided significant increases in BMD.

Figure 3—Relative (%) changes in spine, total hip, and total body BMD for individual subjects.

Figure 4—Pre- and post-test serum osteocalcin (top panel) and urinary CTX (bottom panel). Levels for high-load (HL, N = 10), high-repetition (HR, N = 7), and control (C, N = 8) groups. No significant group, trial or group × trial effects, P > 0.05.
significantly increased BMD at the trochanter (+1.7%) and Ward’s triangle (+2.3%) sites. This finding supported the results of previous animal studies (27,28) that documented that the maximum load of the mechanical stimulus was more important than the number of load cycles for eliciting bone adaptations.

Biochemical markers of bone remodeling may be useful for providing information about mechanisms of bone loss and for monitoring the efficacy of treatments on bone (26). An advantage of using these markers of bone turnover is their rapid response to treatments, as shown by increases in bone formation markers in the first month of a 4-month resistance training program in young men (11). We measured serum osteocalcin as an indicator of bone formation and urinary C-telopeptide (CTx) as a marker of bone resorption. Estrogen deficiency is associated with elevated levels of both osteocalcin and CTx, corresponding to high rates of bone turnover, and accelerated bone loss (19). All groups tended to have increased osteocalcin levels after the training period, although the control group had higher post-training levels than the low intensity group. Because CTx tended to decrease in the training groups and to increase in the control group, it could be speculated that the rates of bone formation were enhanced in the training groups, whereas rates of both formation and resorption, and thus bone turnover, were increased in the control group. The effects of exercise on osteocalcin levels in postmenopausal women have been quite variable, with reports of increases (17), decreases (22,23) and no changes (14,29) occurring with training. Our osteocalcin findings are similar to those of Nelson et al. (17), who reported a 14% increase in osteocalcin in the osteoporosis resistance training group. It is interesting to note that a negative relationship was found between % changes in CTx and in the total hip BMD, suggesting that increases in CTx were associated with decreases in BMD. Conversely, relative increases in osteocalcin were related to increases in the hip BMD. It is unlikely that these bone marker responses could be attributed to the increased calcium intake by some subjects as long-term calcium supplementation has been reported to suppress both bone formation (osteocalcin) and bone resorption markers (24).

The results of this study indicated that the high-intensity—low-repetition and high-repetition—low-intensity resistance training protocols were both effective in improving muscular strength and size in early postmenopausal women. Neither resistance training protocol elicited statistically significant increases in the BMD of the spine, proximal femur, and total body. There were, however, BMD increases exhibited by some individuals, which may be clinically significant. The primary reason for the significant gains in strength without concomitant increases in areal BMD is likely the 6-month duration of the study. The menopausal status of the subjects also may have affected the results in that all the women were 1–7 yr postmenopausal and could have been undergoing accelerated bone loss due to estrogen deficiency. An important implication of this study is that older women can have dramatic improvements in muscular strength with low-intensity, high-repetition resistance training. This information is especially useful when prescribing exercise for osteopenic and osteoporotic women for whom high-intensity exercise is contraindicated.

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