

Resistance Training in Postmenopausal Women with and without Hormone Therapy

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ABSTRACT

TEIXEIRA, P. J., S. B. GOING, L. B. HOUTKOOPER, L. L. METCALFE, R. M. BLEW, H. G. FLINT-WAGNER, E. C. CUSSLER, L. B. SARDINHA, and T. G. LOHMAN. Resistance Training in Postmenopausal Women with and without Hormone Therapy. *Med. Sci. Sports Exerc.*, Vol. 35, No. 4, pp. 555–562, 2003. **Purpose:** The main purpose of this study was to analyze the impact of a 1-yr resistance-training program on body composition and muscle strength in postmenopausal women, and to describe the impact of hormone replacement therapy (HRT) on body composition changes, with and without exercise. Secondly, we wanted to study dose-response relationships between measures of program compliance and changes in primary outcomes. **Methods:** Subjects were postmenopausal women (40–66 yr) randomly assigned to an exercise (EX) group ($N = 117$) and a nonexercise group ($N = 116$). The EX group participated in a 1 yr trainer-supervised resistance-training program, 60–75 min·d⁻¹, 3 d·wk⁻¹. Lean soft tissue (LST) and fat tissue (FT) changes were measured by dual-energy x-ray absorptiometry and strength by one-repetition maximum testing. **Results:** Significant ($P < 0.001$) gains in LST were observed for women who exercised, regardless of HRT status, whereas women who did not exercise lost LST ($P < 0.05$) if they were not taking HRT, and gained LST ($P = 0.08$) if they were on HRT. The only significant FT losses were observed for women who exercised while on HRT ($P < 0.05$). Strength increases were observed at all sites ($P < 0.001$). Total weight lifted by subjects in their training sessions was a significant predictor of changes in LST ($P < 0.001$) and strength ($P < 0.01$). **Conclusions:** Resistance and weight-bearing exercise significantly changed total and regional body composition in postmenopausal women by increasing LST in all women and decreasing FT in women on HRT. Hormone therapy showed no independent effects on body composition, but it protected nonexercising women from losses in LST. The lean and muscle strength changes observed were partially dependent on the volume of training, as expressed by attendance and total weight lifted in 1 yr of training. **Key Words:** STRENGTH TRAINING, BODY COMPOSITION, VOLUME, FREQUENCY, WEIGHT LIFTED, ATTENDANCE, DOSE-RESPONSE

Strength training is recommended by the American College of Sports Medicine as a key component of an overall fitness program (3). For older adults, this is particularly important given the loss of muscle mass and strength that occurs from middle to old age. Sarcopenia, or the loss of lean tissue, especially muscle, has been shown to predict self-reported physical disability, independent of age, morbidity, obesity, ethnicity, income, and health behaviors among older men and women (6). In addition to increasing muscle mass and improving function (11), strength training has been shown to increase resting and total energy expenditure (15) and lipid oxidation (31), and to induce decreases in total and abdominal fat (7,23,30). In women, important

changes in body composition occur around the time of menopause, including increases in total body fat mass, marked increases in abdominal fat, and a progressive reduction in lean tissue (18,26,29) that may be countered with exercise. The tendency for a shift in fat distribution toward an increased central-/upper-body fat pattern, together with overall weight gain, contributes for the higher risk of heart disease and metabolic disorders suffered by postmenopausal women.

Hormone replacement therapy (HRT) seems to counteract the trend for an accumulation of total fat, abdominal fat, and the loss of lean tissue that occurs after menopause though controversy remains whether HRT alone can induce significant changes in total body composition over time (7,10,13,14,16). A recent review suggests that HRT protects against strength losses with age and could potentially be used in the future as a strategy to facilitate maintenance of muscle strength in postmenopausal women (20). When used together with weight-bearing aerobic exercise, HRT was beneficial for reducing adiposity and increasing fat-free mass in older women (16). Earlier results from the same research group had shown that gains in fat-free mass and strength with weight-bearing exercise and HRT were not additive compared with the effects of exercise alone (7). The

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impact of resistance (i.e., with added weights) plus weight-bearing exercise on body composition and strength has not been compared for postmenopausal women who are either using or not using HRT in a randomized clinical trial.

A dose-response effect of exercise on body composition changes has not been established. To our knowledge, no study has examined the association between measures of compliance with the training routine (volume, frequency) and body composition changes in exercising postmenopausal women. This controlled study was designed to analyze the impact of a vigorous 1-yr strength training and weight-bearing exercise program on whole-body and regional lean and fat tissue in postmenopausal women, and to describe the impact of HRT on body composition changes, with and without exercise. In addition, the relationships among changes in soft tissue mass, changes in strength, attendance to the program, and weight lifted were investigated to better understand the influence of dose on the desired response.

METHODS

Subjects. Subjects were 233 healthy, sedentary postmenopausal women participating in a study investigating the effects of progressive resistance and weight-bearing exercise training on bone mineral density. The study was approved by the University of Arizona's Human Subjects Institutional Review Board, and all participants gave written informed consent before participation in the study. The women were on average 5.8 yr postmenopausal, nonsmokers, and were either using HRT for longer than 1 yr but no more than 6 yr or were not using HRT and had not done so in the year before the study. Women who used HRT followed regimens prescribed by their primary care providers. Consequently, a variety of regimens were used, although most women took oral estrogen (32%) or estrogen and progesterone (48%). Another 14% received estrogen and/or progesterone by patch. Subjects did not take any other medications known to affect body composition and had not used exercise or energy reduction diets for 1 yr before entering study. All participants received 800 mg·d⁻¹ of calcium citrate (Citracal[®], Mission Pharmacal, San Antonio, TX). Subjects were instructed to take two tablets (200-mg elemental calcium/tablet), twice a day, without food, with a minimum of 4 h between doses. Within categories of HRT status, subjects were randomly assigned to 1 yr of weightlifting and weight-bearing exercise or to a group with no exercise. Participants were instructed to maintain their usual diets and to avoid weight changes for the duration of the study. Furthermore, controls were instructed to maintain the same level of physical activity, or inactivity, as the case may be, as upon entering the study. If subjects gained or lost weight, they were not excluded from the study nor was there any intervention employed to return them to their stable weight.

For controls, a medical history questionnaire was administered every 6 months addressing any adverse events or medication changes that may have occurred in the preceding

6 months. Exercisers completed this same questionnaire but were also instructed to inform their personal trainers of any such events, and this information was then noted in the subject file. There were no adverse events reported. Among exercisers, only subjects who completed at least the first 10 months of the program were included for analysis purposes. A baseline comparison of completers with the 25 exercisers who did not complete at least 10 months showed no significant differences.

Dual-energy x-ray absorptiometry. Lean soft tissue (LST), fat tissue (FT), and body fat percentage (%BF) were measured by dual-energy x-ray absorptiometry (DXA) using a total-body scanner (model DPX-L; Lunar Radiation Corp., Madison, WI). The scanner was calibrated daily against a standard calibration block supplied by the manufacturer. Subject position for the total body scan was standardized and identical to that described by Mazess and colleagues (19). All total body scans were completed in medium scan mode to ensure appropriate image resolution. To decrease measurement error, subjects were scanned twice within approximately 2 wk, at all assessment periods. DXA technicians were blind to the participants' group assignments. Coefficients of variation from duplicate measurements for all subjects were 1.21% for total LST mass and 1.72% for total FT. The mean of the two scans was used in all statistical analyses. Initial scan analysis, including the placement of baselines distinguishing bone and soft tissue, edge detection, and regional demarcations, was done by standard computer algorithms (version 1.3y, Lunar Corp.). Subsequently, one certified technician visually inspected all scans, and adjustments were made as necessary.

Anthropometry. Standing height (HT) and weight (WT) were measured with subjects wearing lightweight clothing without shoes. HT was measured to the nearest 0.1 cm during a maximal inhalation using a Schorr (Olney, MD) measuring board. WT (kg) was measured on a calibrated digital scale (SECA, model 770; Hamburg, Germany) accurate to 0.1 kg. The average of two measurements for both HT and WT were used as the criterion measurement. Body mass index in kilograms per squared meter was calculated from WT (kg) and HT (m²).

Strength assessment. Muscle strength in exercising subjects was estimated from assessments of a one-repetition maximum (1-RM), measured in exercise facilities every 6–8 wk to set training loads. The 1-RM was defined as the maximal weight that could be lifted with proper body alignment and correct lifting technique. Exercises used were the leg press, hack squats or smith squats, lat pulldowns, lateral rows, back extensions, right- and left-arm dumbbell presses, and rotary torso. The 1-RM were measured in the same exercise facility, using the same equipment for every subject at all assessment time points.

Exercise intervention. Subjects in the exercise group trained 3 d·wk⁻¹ on nonconsecutive days in community facilities with constant supervision by study trainers. Each session lasted 60–75 min and included a warm-up (stretching, balance, and weight-bearing activity), weightlifting period, a weight-bearing circuit of moderate impact activities

(e.g., walk/jog, skipping, and hopping), and stair-climbing/step boxes with weighted vests. Exercise class attendance, weightlifting loads, sets and repetitions, steps with weighted vests, and minutes in aerobic activity were all monitored with logs that were checked regularly by study trainers.

The weightlifting component of the exercise session was done using free weights and machines. Core exercises were selected to target major muscle groups and included leg press, hack squats or smith squats, lat pulldowns, lateral rows, back extensions, right- and left-arm dumbbell presses, and rotary torso. Each session included two sets of 6–8 repetitions done at 70% ($2 \text{ d}\cdot\text{wk}^{-1}$) and 80% ($1 \text{ d}\cdot\text{wk}^{-1}$) of the 1-RM. Strength (1-RM) was measured every 6–8 wk, and the load increased to maintain loads at 70–80% 1-RM.

Weight-bearing activity was done for approximately 10 min during warm-up before weightlifting (walking on a treadmill or track), and for another 20–25 min during the circuit and stair climbing/step boxes. The weight-bearing circuit progressed from walking to increasing time spent in jogging, skipping, hopping, and similar activities with greater ground reaction forces than walking. Intensity was maintained at approximately 60% of maximal heart rate. Stair-climbing/steps boxes (8 inches) began with 120 stairs/steps per session and increased progressively to 300 stairs/steps while wearing vests weighing 10–30 lb. Loads during stairs/steps were increased incrementally by 1–3 lb, as the participants were able to tolerate greater loads.

Statistical analysis. Statistical analyses were completed using the Statistical Package for the Social Sciences (SPSS, version 10.0.5). Measures of central tendency and distribution were examined to describe the sample, to test for normality and homoscedasticity, and to describe outcomes. The baseline physical characteristics of women who completed the study were compared with women who stopped the exercise program before completing 10 months using independent *t*-tests. Possible baseline mean differences in body composition and other characteristics between women randomized to exercise and no exercise groups were tested using independent *t*-tests within HRT and no HRT groups. Paired *t*-tests were used to test for significant changes in body composition within groups (exercise and HRT status) from baseline to follow-up. Independent *t*-tests were used to compare 1-yr changes between exercisers and nonexercisers. The general linear model (ANCOVA) was used to study the effects of exercise, HRT, and interaction (exercise \times HRT) in body composition outcomes, using age and baseline body composition as covariates.

For exercisers only, attendance was calculated as the ratio of sessions attended to the total possible sessions that each subject could have attended, given start and end dates. The average maximum number of sessions subjects could have attended was 148 ± 4 and varied between 12 and 232 with a mean attendance of 105 ± 4 . The weight lifted in 1 yr for a specific exercise was calculated by adding weight lifted for all sets across all sessions (*n*) as follows:

$$\text{Exercise Dose (kg)} = \sum_{\text{session}=1}^n ([\text{Reps} * \text{Weight}]_{(\text{set}1)} + [\text{Reps} * \text{Weight}]_{(\text{set}2)})$$

Total weight lifted was calculated from the sum of all weights lifted from eight individual exercises. For weight lifted, legs value was equal to the sum of weight lifted performing leg-press exercises, arms value was calculated as the sum of weight lifted in military press, lat pulldown, and row exercises, and trunk value was calculated as sum of weight lifted in lat pulldown, row, and back extension exercises. The average of 1-RM percent change for the same combination of exercises was used to calculate the corresponding strength value (legs, arms, and trunk strength). For all calculations using total weight lifted and strength changes, all analyses were adjusted by cohort number and facility. Not all subjects used the same facility for their training, and facility was found to have a significant effect on weight lifted and strength changes values.

Analysis of covariance was used to assess the impact of HRT on strength changes among exercisers, controlling for age, baseline body composition, cohort, and facility. To examine changes in LST and strength across quartiles of total weight lifted and quartiles of attendance, these variables (weight lifted and attendance) were adjusted for cohort and facility (plus age, HRT status, and baseline body composition) using regression residuals. Two regression models were developed with these variables as independent variables and compliance measures (total weight lifted and attendance) as dependent variables. Residuals from these regression models (added to mean value) were then used to build the adjusted quartiles. Analysis of variance (ANOVA) was used to study changes in LST and strength across adjusted quartiles of compliance measures. Finally, multiple linear regression was used to study the relationship between outcomes measures (LST and strength used a dependent and independent variables) and compliance measures (weight lifted and attendance used as independent variables). Type 1 error was set at $\alpha = 0.05$ (two-tailed) for all tests.

RESULTS

Baseline descriptive statistics for subjects who completed baseline and follow-up measurements are shown in Table 1 by HRT status. Women taking HRT were approximately 1.5 yr younger and had been postmenopausal for approximately 1.6 yr less, compared with women not taking HRT ($P < 0.05$). There were no other significant differences observed between women taking HRT or not taking HRT at baseline. There were no baseline significant differences between women assigned to exercise ($N = 117$) or no exercise ($N = 116$) groups.

Figure 1 shows 1-yr changes in LST and FT for women taking HRT (exercise and no exercise) and not taking HRT (exercise and no exercise). Significant gains in LST were observed for women who exercised, both taking and not taking HRT. Women who did not exercise significantly lost

TABLE 1. Baseline descriptive statistics by HRT status ($N = 233$).

	HRT	No HRT
	($N = 119$)	($N = 114$)
	Mean \pm SD	Mean \pm SD
Age (yr)	54.5 \pm 4.4	56.0 \pm 5.1*
Years postmenopausal	5.0 \pm 2.7	6.6 \pm 3.1***
Weight (kg)	68.2 \pm 11.9	66.9 \pm 10.1
BMI ($\text{kg}\cdot\text{m}^{-2}$)	25.5 \pm 4.1	25.1 \pm 3.3
Waist (cm)	80.8 \pm 9.9	80.2 \pm 9.6
WHR	0.78 \pm 0.05	0.78 \pm 0.07
Body fat (%)	38.2 \pm 6.9	38.2 \pm 6.6
Total LST (kg)	38.6 \pm 4.5	38.1 \pm 4.1
Total FT (kg)	26.3 \pm 8.7	25.7 \pm 7.6

LST, lean soft tissue; FT, fat tissue; WHR, waist-to-hip ratio.

* $P < 0.05$, *** $P < 0.001$ for independent t -test comparing HRT and no-HRT two groups.

LST if they were not taking HRT and showed a trend toward LST gains ($P = 0.08$) if they were on hormone therapy. The only significant FT losses were observed for women who exercised while on HRT.

One-year changes for exercisers and controls, within HRT category, are shown in Table 2. Among subjects on HRT, exercise had a significant impact on weight, body mass index, %BF, LST (except trunk LST), and FT (except trunk FT). Among women not on HRT, changes in %BF and LST in exercisers were different than in nonexercising controls. The overall impact of exercise was significant for LST, FT, and %BF, although effects were much stronger for LST (and %BF) than for FT. The effects of HRT were generally not significant, although there was a weak, significant interaction effect between HRT and exercise in augmenting/preserving LST. Given the small impact of HRT, results are henceforth reported without discriminating HRT status.

Among exercisers, changes in whole-body LST ($P < 0.001$) and FT ($P = 0.029$) were both significantly different than changes in controls ($P < 0.05$ for intergroup comparison). Total lean and fat changes among controls were nonsignificant ($P > 0.36$). Despite significant average changes in total and regional body composition among exercisers, the intersubject variability was very high. For total LST, the range for individual changes was 6.7 kg (min = -3.0 kg; max = $+3.7$ kg), whereas for FT changes the range was 14.2 kg (min = -8.3 kg; max = 5.9 kg). Positive changes in 1-RM were significant for all exercises ($P < 0.001$) and ranged from $+28\%$ (seated row) to $+77\%$ (leg press). ANCOVA showed that HRT did not significantly affect total and regional strength gains ($P > 0.161$). Muscle strength by 1-RM was not measured in controls.

Individual changes in LST and strength among women in the training group may be related to the volume (total weight lifted) and frequency (number of sessions attended) of training. Total weight lifted during 1 yr of training was measured for six primary exercises and ranged between 563,314 kg and 2,619,290 kg; mean was 1,312,770 kg (sum of six exercises). Mean attendance to the exercise sessions was 77% and ranged from 26% and 100%. Attendance was strongly correlated with weight lifted. Partial correlation coefficient (adjusting for age, HRT status, baseline body composition, cohort, and facility) between percent atten-

dance and sum of weight lifted for all exercises was 0.67 ($P < 0.001$).

To better assess the relationship between changes in outcomes (LST and strength) and measures of compliance (weight lifted and attendance), we divided 1-yr changes in outcomes into quartiles. Figure 2 shows LST and strength changes by adjusted quartiles of weight lifted and attendance. Analysis of variance showed a significant dose-response for LST and strength changes across categories of weight lifted. For attendance, a similar, albeit nonsignificant, dose-response trend was observed, particularly for strength. For changes in LST, a more linear association was observed toward the right side of the distribution (third and fourth quartiles) in total weight lifted, whereas for strength changes the association seemed linear across the four weight-lifted quartiles.

DISCUSSION

This randomized controlled trial investigated the impact of 1 yr of resistance and weight-bearing exercise on whole-body and regional body composition in postmenopausal women who were either using HRT or not using HRT. Previous studies with postmenopausal women that analyzed the effects of resistance and/or weight-bearing training on body composition used either small samples sizes (15,22,28), relatively short training periods (30,31), training protocols without added weights (7,16,17), and/or did not analyze the relative impact of HRT with resistance training (21,23). Furthermore, few studies have used controlled designs. Although the present study did not randomize subjects by HRT, it is, to our knowledge, the only study that has investigated the interaction of strength training and HRT effects in postmenopausal women. Recently, we have published the bone density results on this cohort of women (8) and have submitted for publication the results for body composition changes in a subsample (12).

In the present study, we performed *post hoc* analyses to study the dose-response effects of strength training on LST changes and strength gains, using weight lifted during 1 yr and attendance rates as independent variables. These variables were carefully monitored by the study's staff and recorded after each exercise session.

Exercise effects on body composition. We found resistance and weight-bearing training to have a significant and positive effect on LST changes (whole-body and regional areas of interest) and a significant negative effect on leg FT changes in women who exercised. All measured changes in body composition variables within the exercise group, except for trunk FT changes, were significantly different than what was found for nonexercising controls, who showed a tendency for LST losses and FT gains after 1 yr. Moreover, the main effects of HRT were found to have a nonsignificant impact on body composition changes.

One-year gains in LST among exercisers were close to 0.9 kg, a result that can be considered typical. Using a training protocol identical to ours, Taaffe et al. (27) observed a mean increase of 0.7 kg in DXA-measured LST,

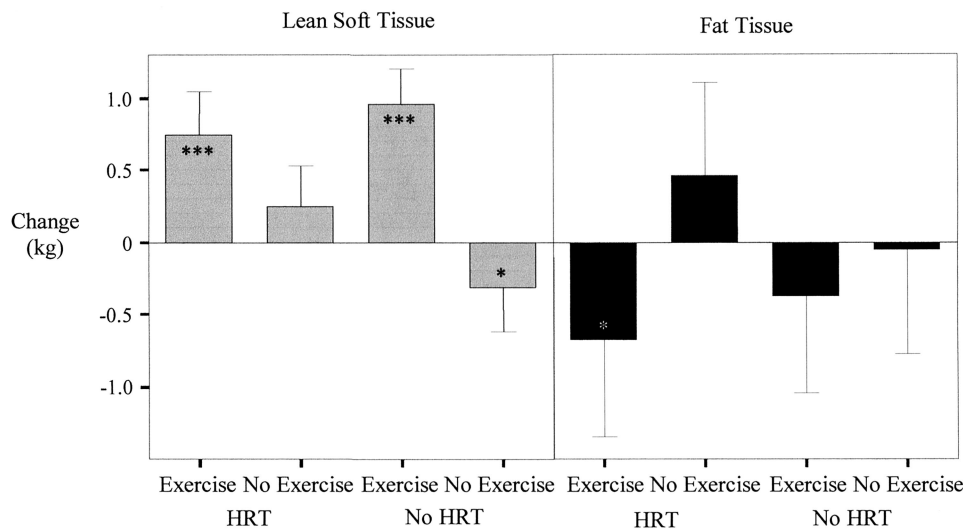


FIGURE 1—* $P < 0.05$, *** $P < 0.001$ for paired t -test within group from baseline to 1 yr.

whereas Nelson et al. (21) observed a mean muscle mass gain of 1.2 kg (assessed by creatinine excretion) with a twice-a-week protocol, in both cases after 1 yr of resistance training with postmenopausal women. These average changes are relatively modest and, if considered in isolation, may be interpreted as clinically insignificant. Nevertheless, our study and others (21) observed that subjects not participating in resistance training show a noticeable trend toward lean mass losses, reconfirming the fact that after menopause, women are at higher risk for sarcopenia (11). If continued for several years, strength training may override this trend, protecting women from progressive lean tissue losses and the accompanying decrease in function and quality of life (6).

The effects of resistance training on FT appear to be smaller in magnitude than those observed for LST. Collectively, previous studies have shown nonsignificant mean FT losses ranging from 0.2 and 0.7 kg in women after various resistance-training programs, of 4–12 months in duration (15,23,28,30,31). This supports the common understanding that strength training *per se* will not typically cause enough

energy expenditure to induce substantial changes in energy balance and adiposity (2). However, longer-term strength training studies may show cumulative beneficial effects on women's adiposity when compared with sedentary controls. It is also important to note that strength training has been shown to significantly impact intra-abdominal fat in postmenopausal women, even in the absence of whole-body weight, fat, and fat-free mass changes (30), suggesting that important health benefits from strength training may go unnoticed when less precise measures of regional adiposity are used.

HRT and exercise effects. We found virtually no independent effects of HRT on body composition after 1 yr. Previously, HRT has been shown to contribute to the preservation of fat-free mass (16) or to have no effects on lean tissue (1,13). Results on fat and weight have also been variable (4,13). The relative impact of HRT and exercise on the body composition and/or strength of exercising postmenopausal women has been studied both cross-sectionally (14) and longitudinally (7,10,16). Three studies using body weight-bearing aerobic exercises in older women (60 and 84

TABLE 2. One-year changes for fat and lean soft tissue for exercise and nonexercise groups within HRT status.

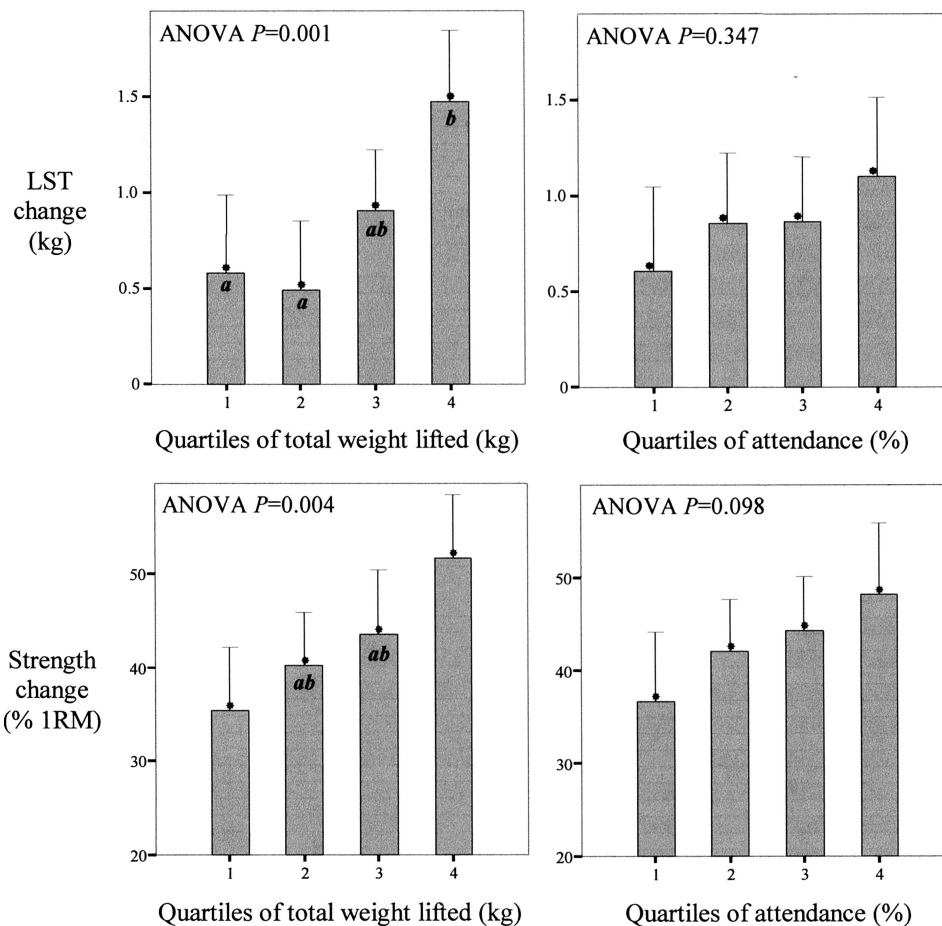
	HRT		No HRT		Exercise P^a	HRT P^a	Exercise \times HRT P^a
	Exercise (N = 58) Mean \pm SD	No Exercise (N = 61) Mean \pm SD	Exercise (N = 59) Mean \pm SD	No Exercise (N = 55) Mean \pm SD			
Weight (kg)	-0.2 \pm 2.6	0.8 \pm 2.7*	0.34 \pm 2.5	-0.4 \pm 3.3	0.439	0.671	0.024
BMI (kg·m ⁻²)	-0.02 \pm 1.03	0.38 \pm 1.11*	0.17 \pm 1.06	-0.03 \pm 1.23	0.213	0.669	0.049
Waist (cm)	-0.45 \pm 2.39	0.04 \pm 3.44	-0.44 \pm 2.80	-1.14 \pm 3.02	0.898	0.269	0.173
WHR	0.001 \pm 0.018	-0.004 \pm 0.026	0.002 \pm 0.021	-0.005 \pm 0.033	0.105	0.552	0.552
Body fat (%)	-1.14 \pm 2.74	0.23 \pm 2.18**	-0.99 \pm 2.63	0.11 \pm 2.31*	<0.001	0.772	0.772
Total LST (kg)	0.9 \pm 0.1	0.3 \pm 1.1*	1.0 \pm 0.9	-0.3 \pm 1.1***	<0.001	0.244	0.008
Legs LST (kg)	0.1 \pm 0.5	0.0 \pm 0.5**	0.3 \pm 0.5	-0.2 \pm 0.5***	<0.001	0.353	0.030
Arms LST (kg)	0.1 \pm 0.2	0.0 \pm 0.2*	0.1 \pm 0.2	0.0 \pm 0.2***	<0.001	0.747	0.549
Trunk LST (kg)	0.5 \pm 0.7	0.3 \pm 0.8	0.5 \pm 0.6	-0.1 \pm 0.7***	<0.001	0.018	0.020
Total FT (kg)	-0.7 \pm 2.5	0.5 \pm 2.5*	-0.4 \pm 2.6	-0.1 \pm 2.7	0.015	0.949	0.236
Legs FT (kg)	-0.5 \pm 0.9	0.0 \pm 1.0*	-0.3 \pm 1.0	-0.2 \pm 1.2	0.021	0.834	0.156
Arms FT (kg)	-0.1 \pm 0.7	0.1 \pm 0.4*	0.0 \pm 0.4	0.0 \pm 0.4	0.030	0.634	0.117
Trunk FT (kg)	-0.1 \pm 1.4	0.3 \pm 1.3	-0.1 \pm 1.4	0.1 \pm 1.3	0.030	0.871	0.543

LST, lean soft tissue; FT, fat tissue; WHR, waist-to-hip ratio.

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$ for independent t -test comparing exercise and no exercise groups within HRT status.

^a P values for analysis of covariance (ANCOVA) with age, baseline LST, and baseline FT as covariates.

FIGURE 2—Tukey-HSD test for multiple comparisons (significant differences are indicated by different letters, $P < 0.05$); to build quartiles, total weight lifted and attendance were adjusted for age, HRT status, baseline body composition, cohort, and facility; error bars indicate 95% confidence intervals; adjusted means for quartiles of total weight lifted in 1 yr were 826, 1194, 1412, and 1822 (kg/100) and for attendance were 57.9, 75.8, 83.6, and 89.6% (percentage of sessions attended), respectively, for quartiles 1 through 4.



yr old) have analyzed the independent and exercise-related effects of HRT on body composition and/or strength changes, showing that HRT has a positive and additive (in relation to exercise alone) effects on FT but that it does not significantly add to the impact of exercise on fat-free mass or strength (7,10,16).

Differences in sample age and size, and especially in the type of exercise training limit comparisons between these studies and ours. The presence of added weights in the exercise program we used may solicit a different response in LST than that which is caused by the impact forces induced by the weight of the body alone. In our study, HRT did not enhance the exercise effects on LST changes, but instead it worked to prevent LST losses in the nonexercising controls. Unlike previously reported data [e.g., (10)], we did not notice an interaction between the effects of exercise and HRT on FT or fat distribution changes.

The established knowledge that muscle cells in other species have estrogen receptors (9,24) may explain the potentially anabolic effects of HRT on LST in humans. Because estrogens promote fluid retention in postmenopausal women (25), it is hypothesized that estrogens improve LST at least partially by increasing the water content in muscle, an adaptation that is also induced by exercise. Because DXA does not discriminate between protein and water content in LST, this study cannot elucidate the mechanisms behind the relative effects of HRT on LST in sedentary controls. Also,

the assessment of abdominal adiposity by DXA may be insufficiently precise to detect significant changes in that depot, particularly if they occurred preferentially in the abdominal region, where HRT and exercise may have a selective impact (16,30).

Strength changes and dose-response effects.

The importance of preserving or even increasing LST in women after menopause and in later years is associated with the need to maintain an adequate level of muscular functioning, allowing independent and effective physical work in daily tasks. However, it is not clear whether muscle mass is an ideal surrogate measure of muscular function. In fact, although some evidence has shown muscle mass to be correlated with physical performance (6,32), muscle strength is a more consistent predictor of performance and physical ability (11) and has been shown to mediate the association between muscle mass and performance in daily tasks (32). Given the wide variability of responses for strength and LST changes, we investigated the source of this variation and hypothesized that the level of attendance to the exercise sessions and/or the amount of weight women lifted in those sessions throughout the year could account for some of the total variance in outcome measures. Weight lifted during the year-long program significantly predicted changes in LST and, with the exception of legs, changes in strength, whereas percentage of sessions attended did not predict LST changes but it was correlated with some

strength improvements. Importantly, a dose-response relationship was observed between the total weight that was lifted during 1 yr and improvements in both lean mass and strength, adjusting for baseline body composition. Although total weight lifted values in this study are difficult to translate into practical recommendations given differences in equipment between ours and other training settings, the observation of a increasing improvement in LST and strength with increasing amount of weight lifted across a wide range of values suggests that postmenopausal women will continue to benefit from protocols that ask for continuously higher training loads, within safe limits. This is the first study to report dose-response analysis for changes in body composition and strength in postmenopausal women, as a result of resistance training.

This study has limitations that should be acknowledged. First, subjects were not randomly assigned to HRT and no-HRT groups. Although a completely randomized design is preferable, many women are not willing or able to undergo HRT, and randomizing women to HRT requires extensive surveillance that was beyond the scope of this study. Also, the study was originally designed to study exercise effects on bone. Therefore, the training program was not conceived to specifically promote muscle and strength changes but to maximize external weights' and weight-bearing impact on the skeleton. Finally, the fact that subjects exercised on four different facilities with different equip-

ment (though performing identical exercises in all facilities) may have influenced results beyond what we could statistically control. These limitations notwithstanding, this is the largest exercise randomized controlled trial (RCT) reporting the effects of resistance training on postmenopausal women's body composition and strength and the only RCT to study the independent and interactive impact of HRT using added and weight-bearing resistance training, in this age group.

In conclusion, we found that resistance and weight-bearing exercise had a significant and positive impact on the total and regional body composition of postmenopausal women, independent of HRT. In the absence of exercise, HRT protected women from LST losses occurring in non-HRT treated controls. The overall positive impact of exercise on body composition in postmenopausal women was clearly superior to that of HRT. Frequent and vigorous resistance exercises were safely performed by a large number of postmenopausal participants, many of whom lifted a considerable amount of weight during the 1-yr training program. These are very encouraging results, particularly in light of recent reports that have cast a shadow of doubt on the health effects of the most popular form of HRT in healthy postmenopausal women (5).

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