Reduction in intra-abdominal adipose tissue after strength training in older women

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TREUTH, Margarita S., Gary R. Hunter, Tamas Kekes-Szabo, Roland L. Weinsier, Michael I. Goran, and Lincoln Berland. Reduction in intra-abdominal adipose tissue after strength training in older women. J. Appl. Physiol. 78(4): 1425-1431, 1995. — The purpose of this study was to examine the effects of a total body strength-training program on changes in total and regional body composition, in particular intra-abdominal adipose tissue (IAAT), in older women. Fourteen healthy older women (mean age 67 ± 1 yr) exercised 3 times/wk for 16 wk. Strength was assessed by one-repetition maximum tests, with training intensity gradually increased to ~67% of one repetition maximum. Body composition was measured by hydrodensitometry and regional body composition was measured by computed tomography. Strength was significantly increased in the upper (51%) and lower body (65%). There was no significant change in body weight (64.4 ± 2.7 vs. 64.2 ± 2.7 kg), total body fat (38.7 ± 1.4 vs. 38.0 ± 1.6%) or fat-free mass (39.7 ± 1.0 vs. 40.0 ± 0.9 kg). However, after ST, there were significant reductions in IAAT (143.9 ± 13.3 vs. 130.0 ± 12.4 cm²), the IAAT-to-subcutaneous adipose tissue ratio (0.48 ± 0.04 vs. 0.44 ± 0.04), and midthigh subcutaneous adipose tissue (141.7 ± 11.5 vs. 133.6 ± 10.8 cm²) and an increase in midthigh muscle (62.9 ± 2.6 vs. 68.0 ± 2.0 cm²) (all P < 0.05). In conclusion, significant reductions in IAAT and an increase in strength and muscle area were observed after a strength-training program in healthy older women. These changes may be important in preventing the negative health outcomes associated with the age-related increase in intra-abdominal obesity.

body composition; exercise; aging

AGING IS GENERALLY ASSOCIATED with a fall in energy expenditure and energy intake (27) and an inability to maintain whole body energy balance, leading to dynamic alterations in body composition that have negative health consequences. Specifically, aging is associated with an accumulation of excess body fat (8), leading to an increased risk of cardiovascular disease and non-insulin dependent diabetes mellitus (12, 13, 15, 19), and a loss of fat-free mass (31), leading to a loss of functional dependence (a dependent lifestyle). Excess body fat, particularly when accrued in the upper body region, is considered an independent risk factor for cardiovascular disease in men (12, 13) and women (15, 19). In contrast, fat deposition in the periphery does not appear to increase the risk for cardiovascular disease (10). It is likely that the intra-abdominal adipose tissue is the compartment associated with cardiovascular disease (20). Although excess deposition of body fat in the abdominal region occurs more frequently in males of all ages (2), it is more prevalent in postmenopausal than in premenopausal women (25). Thus, identification of an effective intervention to reverse the age-associated accretion of body fat in the abdominal region may have widespread implications for preventing cardiovascular disease in the older adult population.

The use of aerobic exercise as an intervention to improve the distribution of fat in the abdominal region has been previously examined (9, 11, 29). These studies reported decreases in total abdominal fat in obese premenopausal women (11) and young men (9) and a decrease in intra-abdominal adipose tissue in older men (29) after endurance training. Strength training (ST) is known to improve muscle mass (7, 14, 17, 34), even in the very old (14). Treuth et al. (34) recently reported a decrease in trunk fat after a 16-wk ST program in older men with the use of dual-energy X-ray absorptiometry. However, the effects of ST on intra-abdominal adipose tissue has not been explored in older women. Thus we were interested in examining whether ST also had any additional effects on intra-abdominal fat stores.

Maintenance of muscle mass in the older population also has many important health implications. The loss in muscle mass has been linked to changes in glucose regulation (38), which may then lead to an increased risk for diabetes and atherosclerosis (32). Another benefit of increasing muscle with ST is that metabolic activity and oxidative potential are improved, which may also be very important in the prevention of diabetes and atherosclerosis. In addition, the loss of muscle mass causes the strength losses seen with age (16) and contributes to the disability evident in the elderly (22). Increases in both strength and cross-sectional area of muscles by computed tomography (CT) in older individuals have been demonstrated after ST (7, 14, 17). Treuth et al. (34) reported increases in the lean mass of the arms, legs, and trunk in older men after a high-intensity ST program using dual-energy X-ray absorptiometry. These studies have focused on males, whereas little information is available on females. In one study of older women, increased strength and muscle size were reported after a combined aerobic and ST program (7).

Due to the potential adverse health effects of increased abdominal obesity and loss of muscle with advancing age, we designed an intervention study to examine the effects of ST on total and regional body composition and muscle mass in healthy older women.

METHODS

Subjects

Potential subjects were screened by history and physical exam and by treadmill testing by a physician. All subjects...
then completed a demographic form and physical activity questionnaire to exclude subjects who exercised more than two 30-min sessions/wk. Subjects were excluded from the study if they had evidence of cardiovascular disease (defined as anginal symptoms or myocardial infarction within the last 3 mo and electrocardiographic evidence of ischemia), hypertension (defined as resting systolic blood pressure > 140 mmHg and resting diastolic blood pressure > 90 mmHg), medications known to affect cardiovascular performance (such as \( \beta \)-blockers), anemia, diabetes, elevated plasma glucose, significant renal or hepatic disease, hypothyroidism, or musculoskeletal problems that would hinder participation. Smokers and those who plan to move before the termination of the study were also excluded. Estrogen replacement therapy was not an exclusion factor, and three women on estrogen (which was continued throughout the study) participated in the study. These women were all on Premarin (0.625 mg/day) for at least 4 yr. The mean number of years postmenopause was 19. All methods and procedures for the study were approved by the Institutional Review Board of the University of Alabama at Birmingham. All subjects signed appropriate informed consent forms.

Lipid Profile

Blood samples were drawn before and after 16 wk of ST, after an overnight fast. The blood was drawn at least 24 h after the last training session for the postraining measures. All samples were sent to a local laboratory (National Health Laboratories) for standard analysis of total cholesterol, high-density lipoprotein (HDL), low-density lipoprotein (LDL; calculated), triglycerides, and glucose. These samples were analyzed as they were received and were not completed in the same assay. The between-run precision or coefficient of variation of the low and high standards are 5.0 and 3.5% for HDL, 1.2 and 1.3% for cholesterol, 1.6 and 1.3% for triglycerides, and 1.6 and 1.8% for glucose, respectively.

Maximal \( O_2 \) Consumption (\( \dot{V}O_2^{\text{max}} \))

\( \dot{V}O_2^{\text{max}} \) was determined by collecting expired gases during a progressive treadmill exercise test to voluntary exhaustion. The Weber treadmill protocol (36), which involved increases in either grade or speed every 2 min, was utilized. \( \dot{V}O_2^{\text{max}} \) was reached when two of the three following criteria were met: 1) leveling off of \( O_2 \) consumption (<2 ml·kg\(^{-1}\)·min\(^{-1}\)) with increasing workload, 2) a respiratory quotient > 1.10, and 3) a heart rate 10 beats above or below age-predicted maximal heart rate. Repeat analysis, 6 mo apart, of the same four adults for \( \dot{V}O_2^{\text{max}} \) gave an intraclass correlation coefficient of 0.96.

Dietary Analysis

To monitor dietary intake throughout the study, 3-day dietary food records (including one weekend day) were completed before and after the study. One limitation of food records is that older women are known to underreport energy intake by 20–30% (18). All food records were analyzed by the Minnesota Nutrition Data System, version 2.4 (Nutrition Coordinating Center, Univ. of Minnesota, Minneapolis).

Body Composition

Total body composition. Total body composition was assessed by hydrodensitometry. Total body density was measured by hydrostatic weight to the nearest 50 g in a stainless steel tank in which the subject was suspended from a LCL, 20 shear beam load cell (Omega Engineering, Stanford, CT).

Residual lung volume was measured simultaneously by the closed-circuit oxygen-dilution technique (37). Percent body fat was determined using the Brozek formula (4), and fat-free mass was calculated from body mass minus fat mass. The standard deviation for repeated measures of percent fat by hydrodensitometry for consecutive days in our laboratory is 0.6%, with an intraclass correlation coefficient of 0.98 for nine subjects.

Regional body composition. Regional body composition was assessed by CT with a GE IIILight/Advantage Scanner with a single 5-mm scan at the abdominal (L4–L5) and midthigh regions while the subject was supine with the arms stretched above the head. A fat tissue-highlighting technique was used to determine the various tissues with different densities. Subcutaneous abdominal adipose tissue and intra-abdominal adipose tissue were measured for the abdomen, with muscle and subcutaneous adipose tissues measured for the thigh. CT data were expressed as cross-sectional area in square centimeters of tissue. The ratios of intra-abdominal to subcutaneous abdominal adipose tissue, intra-abdominal to thigh subcutaneous adipose tissue, abdominal subcutaneous to thigh subcutaneous adipose tissue, and total abdominal to thigh subcutaneous adipose tissue were calculated. These ratios were used to determine whether the intra-abdominal vs. the subcutaneous or the abdomen vs. the thigh had greater changes in adipose tissue. The Hounsfield units for adipose tissue and muscle were –190 to –30 and +30 to +80, respectively. To ensure that the same anatomic sites were scanned, the scans were taken midway between the inguinal crease and the top of the patella and at the level of the umbilicus for the thigh and abdomen, respectively. The coefficient of variation for repeat analysis of abdominal scans, analyzed by one investigator, in our laboratory is <2% for 44 adults, with an intraclass correlation coefficient of 0.99.

Skinfold thickness measurements were taken at the midaxillary, triceps, biceps, abdominal, suprailliac, subscapular, and thigh sites by using skinfold calipers. Circumference measurements were taken at the biceps, waist, hip, abdomen, and thigh by using a standard measuring tape. Measurements were taken by using standard procedures (26) until no more than 1 mm (skinfolds) or 1 cm (circumferences) difference existed between measurements. The average of these two trials was used in the statistical analyses. Sagittal diameter was measured by using a spreading caliper while the subject was standing.

Strength Assessment

Before the strength assessment, subjects were allowed two sessions to become familiar with the equipment and exer- cise techniques. Upper body and lower body strengths were assessed by the one repetition maximum (1-RM) test, defined as the maximum amount of weight that could be lifted successfully one time. Starting with a weight used in the preliminary sessions, the subjects attempted lifts with gradually increasing weights (~10% at first, decreasing to 5 and 2.5% as difficulty became evident). Successful attempts were made with a 90-s rest period between attempts until failure occurred. The 1 RM was defined as the maximum weight lifted successfully. Test-retest reliability in our laboratory of 1-RM testing varies from 0.95 to 0.99 depending on the type of 1-RM test (<5% variation in all tests). Approximately three to five trials were needed to reach the 1 RM both before and after training. Strength was assessed for both the upper and lower body by using six exercise machines: elbow flexion, latissimus pull down, chest press, leg press, leg extension, and leg curl.
STRENGTH TRAINING AND INTRA-ABDOMINAL ADIPOSE TISSUE

TABLE 1. Subject characteristics before and after strength training

<table>
<thead>
<tr>
<th>Clinical characteristics</th>
<th>Before</th>
<th>After</th>
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<tbody>
<tr>
<td>Age, yr</td>
<td>67±1</td>
<td></td>
</tr>
<tr>
<td>Weight, kg</td>
<td>65.5±2.7</td>
<td>65.4±2.8</td>
</tr>
<tr>
<td>RM1, kg/m²</td>
<td>25.1±1.0</td>
<td>25.2±1.0</td>
</tr>
<tr>
<td>VO2max, ml·kg⁻¹·min⁻¹</td>
<td>18.6±0.7</td>
<td>18.2±0.7</td>
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</table>

1-RM strength values

| Upper body, kg           | 49±2   | 74±9* |
| Lower body, kg           | 105±8  | 173±11* |
| Total body, kg           | 151±11 | 246±14* |

Values are means ± SE. BMI, body mass index; VO2max, maximal O₂ consumption; 1-RM, 1-repetition maximum; upper body, sum of elbow flexion, chest press, and latissimus pull down; lower body, sum of leg press, leg extension, and leg curl; total body, sum of upper and lower body values. * Significantly different from before training, P < 0.001.

ST Program

ST took place for 1-h sessions, 3 times/wk, for 16 wk. In addition to a warm-up and cool-down, the session included a whole body ST program with the subjects completing seven upper and five lower body exercises. The exercises included the leg press, chest press, latissimus pull down, elbow flexion, and elbow extension (Shape XXI); leg extension, leg curl, upper back row, and military press (Keiser K-300 pneumatic variable resistance machines); and hip abductor, hip adductor, and abdominal curls (Cybex). All the subjects started the exercise program at 50% of 1 RM for a given exercise. After three sessions, the weight was gradually increased in the smallest increments until the subjects could comfortably perform two sets of 12 repetitions for a given exercise. To maintain the appropriate intensity for 12 repetitions, adjustments in weights were made approximately every 2 wk throughout the duration of the study to continue to promote increases in strength. Training intensity was gradually increased to ~67% of 1 RM. Subjects alternated between upper and lower body exercises to minimize fatigue, with ~2-min rest periods allowed between exercises. Attendance was taken at each exercise session to monitor compliance to the program. Subjects were contacted if an exercise session was missed. All sessions were monitored by an exercise physiologist and at least one exercise leader, both of which were certified in cardiopulmonary resuscitation. Body weight was recorded every week throughout the study at the training sessions.

Statistical Analyses

t-Tests were conducted between before and after training measures on all dependent variables. Statistical significance was set at P < 0.05 for all tests. All data were analyzed by SPSS statistical software. All values are expressed as means ± SE.

RESULTS

Subject Characteristics

Fifteen women completed the ST protocol with over 90% compliance for the exercise sessions. Data for the CT scans from one individual were lost; therefore, data for all variables are presented with a sample size of 14.

The clinical characteristics and strength results are presented in Table 1. The subjects ranged in age from 60 to 70 yr (mean age 67 ± 1 yr). Neither body weight, body mass index, nor VO2max changed with training. Upper body strength was significantly increased by 51% and lower body strength was significantly increased by 65%, as assessed by the 1-RM tests.

Body Composition

Total body composition, as measured by hydrodensitometry, was not significantly changed after ST (Table 2). There was no significant change in total body percentage fat, fat mass, or fat-free mass. The CT measurements of the abdomen and thigh revealed alterations in regional body composition (Table 3). Intra-abdominal adipose tissue decreased significantly by 9.7% (P < 0.05), with no significant change in the abdominal subcutaneous adipose tissue. Total abdominal fat and total area of the abdomen also decreased by 7.1 and 6.3%, respectively (P < 0.05). Thigh subcutaneous adipose tissue decreased by 5.8% and muscle cross-sectional area in the thigh increased by 9.7% (both P < 0.05).

The intra-abdominal-to-subcutaneous abdominal adipose tissue ratio was significantly decreased (P < 0.05) after training (Table 3). There were no significant differences before and after training in the intra-abdominal-to-thigh subcutaneous adipose tissue, abdominal subcutaneous-to-thigh subcutaneous adipose tissue, and total abdominal-to-thigh subcutaneous adipose tissue.

TABLE 2. Total body composition by hydrodensitometry before and after strength training

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
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<tbody>
<tr>
<td>Body fat, %</td>
<td>38.7±1.4</td>
<td>38.0±1.6</td>
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<tr>
<td>Fat mass, kg</td>
<td>25.8±1.9</td>
<td>25.4±2.0</td>
</tr>
<tr>
<td>Fat-free mass, kg</td>
<td>39.7±1.0</td>
<td>40.0±0.9</td>
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Values are means ± SE.

TABLE 3. CT-measured adipose tissue and muscle areas before and after strength training

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
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<tbody>
<tr>
<td>Intra-abdominal adipose tissue</td>
<td>143.9±13.3</td>
<td>130.0±12.4*</td>
</tr>
<tr>
<td>Abdominal subcutaneous adipose tissue</td>
<td>299.2±25.3</td>
<td>281.8±27.1</td>
</tr>
<tr>
<td>Total abdominal adipose tissue</td>
<td>443.1±34.0</td>
<td>411.8±34.7*</td>
</tr>
<tr>
<td>Abdominal area</td>
<td>647.8±36.0</td>
<td>607.0±39.7*</td>
</tr>
<tr>
<td>Thigh area, cm²</td>
<td>141.7±11.5</td>
<td>133.6±10.8*</td>
</tr>
<tr>
<td>Thigh muscle</td>
<td>52.9±2.6</td>
<td>58.0±2.9*</td>
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Ratios

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
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<tbody>
<tr>
<td>Intra-abdominal/subcutaneous abdominal adipose tissue</td>
<td>0.48±0.04</td>
<td>0.44±0.04*</td>
</tr>
<tr>
<td>Intra-abdominal/thigh subcutaneous adipose tissue</td>
<td>1.01±0.08</td>
<td>0.97±0.07</td>
</tr>
<tr>
<td>Abdominal subcutaneous/thigh subcutaneous adipose tissue</td>
<td>2.09±0.13</td>
<td>2.04±0.13</td>
</tr>
<tr>
<td>Total abdominal/thigh subcutaneous adipose tissue</td>
<td>3.11±0.17</td>
<td>3.01±0.16</td>
</tr>
</tbody>
</table>

Values are means ± SE. CT, computed tomography. * Significantly different from before training, P < 0.05.
TABLE 4. Regional body composition by anthropometry before and after strength training

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
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<tbody>
<tr>
<td><strong>Skinfolds, mm</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Midaxillary</td>
<td>25±1</td>
<td>26±2</td>
</tr>
<tr>
<td>Triceps</td>
<td>25±1</td>
<td>24±1</td>
</tr>
<tr>
<td>Biceps</td>
<td>15±1</td>
<td>14±1</td>
</tr>
<tr>
<td>Abdominal</td>
<td>37±3</td>
<td>42±2</td>
</tr>
<tr>
<td>Thigh</td>
<td>34±2</td>
<td>33±2</td>
</tr>
<tr>
<td><strong>Circumferences, cm</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biceps</td>
<td>31±1</td>
<td>32±1</td>
</tr>
<tr>
<td>Waist</td>
<td>79±2</td>
<td>81±2</td>
</tr>
<tr>
<td>Hip</td>
<td>99±5</td>
<td>103±2</td>
</tr>
<tr>
<td>Abdomen</td>
<td>89±4</td>
<td>92±2</td>
</tr>
<tr>
<td>Thigh</td>
<td>52±1</td>
<td>52±1</td>
</tr>
<tr>
<td>WHR</td>
<td>0.82±0.04</td>
<td>0.79±0.01</td>
</tr>
</tbody>
</table>

Values are means ± SE. WHR, waist-to-hip ratio.

Dietary Intake

There were no significant changes in the daily caloric intake by 3-day food records (1,449 ± 81 vs. 1,461 ± 63 kcal/day) or in the percentage of calories from protein (16 ± 1% vs. 16 ± 1%), carbohydrate (54 ± 2% vs. 56 ± 2%), and fat (29 ± 1% vs. 30 ± 2%) from before to after training.

Lipid Profile

There were no significant changes in serum levels of total cholesterol, HDL, LDL, total cholesterol-to-HDL ratio, or triglycerides (Table 5). In addition, basal glucose remained unchanged. Removing the three women on hormone replacement therapy from the data does not affect any of the coronary heart disease risk factor variables. In other words, there were still no significant differences from before to after training in HDL, LDL, total cholesterol, total cholesterol-to-HDL ratio, triglycerides, or glucose.

Changes in HDL were significantly associated with decreases in subcutaneous abdominal fat (r = -0.57; P = 0.014) and in total body percent fat (r = -0.8; P = 0.001). Smaller and nonsignificant correlations were observed between changes in HDL and changes in intra-abdominal adipose tissue (r = -0.2; P = 0.2) and thigh subcutaneous fat (r = 0.35; P = 0.1). There was a nonsignificant correlation between changes in triglycerides and changes in intra-abdominal adipose tissue (r = 0.4; P = 0.07) and a significant negative correlation between changes in LDL and thigh subcutaneous fat (r = -0.56; P = 0.018). Changes in fasting plasma glucose were not significantly associated with changes in total and regional fat.

DISCUSSION

This study demonstrates for the first time that reductions in body fat from the intra-abdominal region are observed after ST in postmenopausal women. The decrease in the intra-abdominal-to-subcutaneous abdominal adipose tissue ratio provides evidence that a greater proportion of the fat loss in the abdominal region is from the intra-abdominal area rather than from the subcutaneous area. This is a clinically significant finding because ST not only increases muscle mass but fat is decreased from the abdominal region, which is linked to a risk for cardiovascular disease in men (10, 12, 13) and women (15, 19).

The best exercise modality to promote changes in abdominal body fat is unknown. Although ST utilizes less energy than aerobic exercise and did not change blood lipid levels in this study, ST has the added benefit of increasing strength and muscle mass that may be important in improving functional abilities and health status in the elderly. With ST, Treuth et al. (34) recently reported a significant 8% decrease in trunk fat tissue in older men by using dual-energy X-ray absorptiometry. In these same men, there was a trend toward a decrease in intra-abdominal adipose tissue measured by magnetic resonance imaging (30). However, the use of ST as an intervention in healthy older women has not been previously examined; thus our finding of a decreased intra-abdominal adipose tissue after ST is new. Other investigators have examined the effects of aerobic exercise on intra-abdominal adipose tissue; however, none have utilized ST as an intervention.

The effects of aerobic exercise training on the loss of abdominal body fat are well established. In male subjects, aerobic exercise training induced greater reductions in trunk skinfold thickness than in the extremities (9). In obese women undergoing aerobic exercise, there was a significant reduction in adipose tissue area in the abdominal region (11). In addition, Despres et al. (11) observed a significant reduction in the ratio...
of subcutaneous abdominal fat to thigh fat, indicating that subcutaneous fat was lost preferentially from the abdominal region. A preferential loss of fat (>20%) from the subcutaneous and intra-abdominal adipose tissue depots after aerobic training has also been reported in older men, who displayed a central adiposity at baseline (29). Another study demonstrated a preferential loss of abdominal fat with endurance training in older men and women (24). Thus, with aerobic exercise training, there is a reduction in abdominal fat, but this loss is not necessarily greater for intra-abdominal fat vs. subcutaneous abdominal fat.

Although we found a decrease in intra-abdominal adipose tissue by CT, there was no significant change in total body percent fat or fat mass by hydrodensitometry. Conflicting evidence exists concerning the ability of hydrodensitometry to detect changes in body composition with ST, as some studies have found reduced body fat with this technique (34), whereas other studies have not (21). Two factors may explain this: 1) hydrodensitometry may not be a sensitive enough technique and 2) the inherent assumptions of the hydrodensitometry technique may change (i.e., the density of fat-free mass) with training, and failure to take these into account may "mask" real changes. The application of the Brozek et al. (4) equation before and after training assumes that the densities of fat and fat-free mass are unaltered by ST. A small change in the density of fat-free mass would cause large errors in body fat.

Anthropometry may be limited in determining the changes in regional body composition with ST in older adults. The waist-to-hip ratio may have rather limited value for evaluating body fat distribution (35) and may not be related to cardiovascular risk factors after adjusting for intra-abdominal adipose tissue (20). The waist-to-hip ratio also has been reported to be an inaccurate index of intra-abdominal adipose tissue cross section in obese women (5). We did not observe any significant change in waist-to-hip ratio in our postmenopausal women, which is in agreement with the study of older males (34). For these reasons, we feel that the CT scans, rather than anthropometry, gave a better indication of regional body composition changes after ST in these older women.

One factor that may have confounded the findings is that three subjects were on estrogen replacement therapy for >4 yr. When these three subjects were removed from the sample, the mean change in intra-abdominal adipose tissue was 10.5 cm² and the significance level was P = 0.065. All three women on estrogen lost intra-abdominal adipose tissue (14, 16, and 57 cm²). This suggests that older women with or without estrogen replacement therapy lose intra-abdominal adipose tissue after ST. Further research is warranted to establish the effects of very long-term estrogen replacement therapy on changes in intra-abdominal adipose tissue with ST.

The mechanism for the loss of intra-abdominal adipose tissue is unclear. One issue is whether the subjects were in energy balance, i.e., whether energy intake and energy expenditure of the training session played some role. Although the 5-day food records give only an estimate of food and energy intake, no changes were observed from before to after training in total caloric intake or in the percentage of calories from fat, carbohydrate, or protein. Food records have been shown to underestimate intake by 20–30% in older women (18). However, the underreporting of food intake would have occurred both at baseline and at the end of the study; therefore, the relative difference (which was not statistically significant) would be the same regardless of whether the diets were recorded correctly. There is also no reason to believe that this bias would be affected by the exercise training. In addition, there was no change in body weight from before to after training. Thus, although it cannot be ruled out for certain that the change in adipose tissue distribution observed in the present study was independent of potential changes in dietary intake, this probably played little role. Second, the energy expenditure associated with ST programs similar to the one used in the present study has been reported to be very low, on the order of 150 kcal/session (34). It is therefore unlikely that the changes in regional adipose tissue were due solely to changes in energy expenditure during the training session itself. We did, however, find a significant increase in resting energy expenditure and fat oxidation measured in an indirect calorimeter in these women after the training program (33a). Yet, there was no change in the 24-h energy expenditure in the metabolic chamber.

Another possible explanation for the observed changes in body composition is the effect of hormones, i.e., cortisol, growth hormone, testosterone, and sex hormone-binding globulin. These affect body composition in the following ways: 1) glucocorticoids increase site-specific lipid accumulation, and women with elevated cortisol have increased fat storage in the abdominal region (27); 2) women with abdominal obesity have higher testosterone and lower sex hormone-binding globulin (3); 3) both growth hormone and insulin-like growth factor I are inversely related to abdominal obesity (1, 27); and 4) abdominal adiposity is associated with a relatively more androgenic sex hormone profile in postmenopausal women (23). After ST, cortisol increased by 19% in older men and women (6). Growth hormone, insulin-like growth factor I, and testosterone did not change in older men after ST (28). None of these hormones was measured in the present study, and it is unknown whether postmenopausal women would respond differently than older men with training. Therefore, we cannot say whether hormones played a role in altering regional body composition.

Prior studies (10, 12, 13, 15, 19) have demonstrated a relationship between cardiovascular disease and abdominal adiposity utilizing anthropometrics. We are not aware of any studies that demonstrate that the loss of intra-abdominal adipose tissue reduces the risk for cardiovascular disease in postmenopausal women. The correlations between changes in body composition and changes in blood lipids support findings from aerobic exercise studies that changes in body composition are accompanied by changes in metabolic cardiovascular risk factors. Although none of the intra-abdominal adipose tissue correlations was significant, several were of similar magnitude to correlations observed in other
studies that have examined the cardiovascular risk factors and intra-abdominal adipose tissue. Because of the magnitude and direction of these correlations, we cannot discount that the lack of significant correlations was not due to the small sample size. We did observe a significant correlation between changes in HDL and total body fat. Overall, it is difficult to explain why changes in subcutaneous abdominal and thigh adipose tissues but not intra-abdominal adipose tissue were correlated with changes in lipoprotein cholesterol concentrations. It is interesting that decreases in thigh subcutaneous fat were associated with increases in LDL, indicating that thigh fat may be protective. This is consistent with the concept that larger thigh and smaller abdominal fat depots are associated with a more favorable metabolic profile in women (38). No significant correlations were observed between plasma glucose and changes in total and regional body fat. We have used fasting plasma glucose only as a descriptor and therefore have not attempted to make any interpretations as to insulin resistance. Our lipid analyses may also have been limited because we did not measure any lipoprotein subspecies (i.e., HDL₂ subfraction, apoprotein subfractions, LDL subfractions) and so cannot discount that other cardiovascular risk factors did not change. Future studies would need to address this issue.

The present investigation also found an increase in muscle cross-sectional area of the mid thigh region, which is consistent with several other studies (14, 17, 34). The present report of a 9.7% increase in thigh muscle area is similar to the 9% increase in 86- to 96-year-old men and women (14), the 11% increase observed in 60- to 72-year-old men (17), and the 6.6% increase reported in 51- to 71-year-old men (34). Treuth et al. (34) reported a 5.8% decrease in subcutaneous fat of the thigh with no change in thigh circumference that also agrees with a 9% decrease in subcutaneous fat with no change in thigh circumference after ST. Thus, the observed muscle hypertrophy and fat loss in the thigh are consistent with the literature of ST in primarily older men and demonstrate that women can also undergo similar beneficial changes in body composition after ST.

In conclusion, significant reductions in intra-abdominal adipose tissue and increases in strength were observed after ST in healthy older women. The loss of intra-abdominal adipose tissue is also accompanied by a decrease in thigh subcutaneous adipose tissue and an increase in thigh muscle. Thus, ST may be a useful intervention to improve body composition and fat distribution in the older population.

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