

Effects of strength training on total and regional body composition in older men

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Treuth, M. S., A. S. Ryan, R. E. Pratley, M. A. Rubin, J. P. Miller, B. J. Nicklas, J. Sorkin, S. M. Harman, A. P. Goldberg, and B. F. Hurley. Effects of strength training on total and regional body composition in older men. *J. Appl. Physiol.* 77(2): 614–620, 1994.—The effects of a 16-wk strength-training program on total and regional body composition were assessed by dual-energy X-ray absorptiometry (DEXA), magnetic resonance imaging (MRI), and hydrodensitometry in 13 untrained healthy men [60 ± 4 (SD) yr]. Nine additional men (62 ± 6 yr) served as inactive controls. The strength-training program resulted in substantial increases in both upper ($39 \pm 8\%$; $P < 0.001$) and lower ($42 \pm 14\%$; $P < 0.001$) body strength. Total fat-free mass (FFM) increased by 2 kg (62.0 ± 7.1 to 64.0 ± 7.2 kg; $P < 0.001$), and total fat mass decreased by the same amount (23.8 ± 6.7 to 21.8 ± 6.0 kg; $P < 0.001$) when measured by DEXA. When measured by hydrodensitometry, similar increases in FFM (61.3 ± 7.8 to 63.0 ± 7.6 kg; $P < 0.01$) and decreases in fat mass (23.8 ± 7.9 to 22.1 ± 7.7 kg; $P < 0.001$) were observed. When measured by DEXA, FFM was increased in the arms (6.045 ± 0.860 to 6.418 ± 0.803 kg; $P < 0.01$), legs (19.416 ± 2.228 to 20.131 ± 2.303 kg; $P < 0.001$), and trunk (29.229 ± 4.108 to 30.134 ± 4.184 kg; $P < 0.01$), whereas fat mass was reduced in the arms (2.383 ± 0.830 to 2.128 ± 0.714 kg; $P < 0.01$), legs (7.583 ± 1.675 to 6.945 ± 1.551 kg; $P < 0.001$), and trunk (12.216 ± 4.143 to 11.281 ± 3.653 kg; $P < 0.01$) as a result of training. MRI analysis revealed significant increases in midhigh muscle cross-sectional area (161 ± 19 to 172 ± 18 cm²; $P < 0.01$) and significant reductions in midhigh subcutaneous fat (65 ± 19 to 59 ± 17 cm²; $P < 0.05$). These changes in body composition were not associated with changes in serum concentration of growth hormone, insulin-like growth factor I, or testosterone. None of the measured variables changed significantly in the control subjects. Thus, strength training increases regional and total lean mass and decreases regional and total fat mass in middle-aged and older men. The mechanisms for these changes will require further study.

aging; resistance training; weight training

AGING IS ASSOCIATED with the loss of fat-free mass (FFM) and an increase in body fat (9). This loss of FFM is due to decreases in bone mass (20), skeletal muscle mass (31), and body water (18). The age-related decline in muscle mass may be related to changes in glucose metabolism (3), which may increase the risk for diabetes and atherosclerosis (32). This reduction in muscle mass also may be related to the decrease in basal metabolic rate (34), maximal oxygen uptake ($\text{VO}_{2\text{max}}$; Ref. 16), and anabolic hormones and growth factors (10) observed with aging. Therefore, maintenance of muscle mass in the older population may have important health implications.

Aging is also associated with the preferential deposition of body fat in the trunk region (4). Longitudinal studies have shown that this type of regional distribution of body fat is independently associated with coronary heart disease (CHD) and related mortality (13). In contrast, fat deposition in the periphery does not appear to result in an increased risk for CHD (12). Because of these important health implications, there is a need for reliable determinations of body composition in specific regions as well as in the total body. In addition, intervention strategies are needed to prevent the loss of FFM and the deposition of body fat, particularly in the trunk region, with aging.

Increases in FFM are not always observed when hydrodensitometry is used to assess the effects of strength training (21, 30), perhaps due to the low sensitivity of this method (24). However, when sensitive measurements of regional body composition are used, increases in the cross-sectional area (CSA) of muscle are demonstrated in older individuals after strength-training programs (5, 15, 17, 22). We have recently reported that strength training can decrease limb fat mass, as measured by magnetic resonance imaging (MRI), even when the circumference of the limb is unchanged (22). Therefore, we hypothesized that strength training alters the total and regional body composition in older individuals, but techniques more sensitive than anthropometry and hydrodensitometry may be required to detect these changes.

Dual-energy X-ray absorptiometry (DEXA) and MRI can provide accurate and precise information on changes in lean tissue, fat tissue, and bone mineral content (BMC) in specific regions (27, 29, 33). If these changes can be derived from a strength-training program in older individuals, it may have a direct relevance to health status. Thus, this study was designed to determine the effects of strength training on total and regional body composition measured by MRI, DEXA, hydrodensitometry, and anthropometry and to ascertain whether these effects are associated with alterations in testosterone, growth hormone (GH), and insulin-like growth factor I (IGF-I) levels.

METHODS

Subjects

Twenty-two healthy untrained men (60 ± 4 yr, range 51–71 yr) volunteered for the study. They had not participated in a regular exercise program for ≥ 6 mo before the start of the study. Thirteen of these subjects volunteered to undergo a strength-training program for 16 wk. The remaining nine volun-

teered to serve as controls and remain inactive during this time period. The methods and procedures used in this investigation were approved by the Institutional Review Board at the University of Maryland. All participants provided informed consent before testing. Subjects were screened by medical history questionnaire, physical examination, and a graded treadmill exercise test (7). Only those subjects who were nonsmokers, were free of disease and use of medications that affect body composition, and showed no abnormalities indicative of CHD were admitted to the study.

$\dot{V}O_{2\max}$

Subjects in the training group performed a progressive exercise test on a treadmill to measure $\dot{V}O_{2\max}$ before training to verify that they were indeed untrained before entering the training program. This test was administered again after the training program to verify that they had not engaged in an aerobic exercise training program during the study. Expired air was collected each minute in neoprene meteorological balloons and analyzed by a mass spectrometer system (model 2000, Airspec, Kent, UK). The volume of expired air was measured with a Collins 120-liter chain spirometer. $\dot{V}O_{2\max}$ was considered to be achieved when two of the following three criteria were met: 1) a leveling off of oxygen uptake ($<2 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ with increasing workload), 2) a respiratory exchange ratio >1.10 , or 3) a heart rate within 10 beats of their age-predicted maximal heart rate. All subjects met these criteria during their initial and final treadmill exercise tests. The $\dot{V}O_{2\max}$ test was not administered to the control group.

Standardized Diet

In an attempt to keep dietary intake as constant as possible throughout the training program, all subjects (including control subjects) were instructed on the American Heart Association (AHA) step I diet by a qualified nutritionist and maintained this diet throughout the study, starting 4 wk before the beginning of the study. Two subjects were already following this diet before enrolling in this study, and six subjects in the training group only had to make minor changes to conform to the AHA diet. Four weeks was chosen to allow weight and metabolic stability before the study began. Subjects were counseled weekly, and 3-day food records were reviewed and analyzed every 3 wk to verify maintenance of this diet throughout the study. Any subject found to deviate from the AHA diet was counseled by the nutritionist on ways to comply. In addition, a 7-day food record was obtained from each subject before training and again just before the end of training before final testing. Subjects were asked to replicate their pretraining 7-day diets and record any deviations from their records during the post-training 7-day time period. The complete food records, including any deviations from the pretraining records, were analyzed for total calories and percentage of calories from fat, protein, and carbohydrates. They were also given the same diet from a metabolic kitchen for 5 days before both the initial testing and the final testing after training.

Body Composition Assessment

Body composition was measured by anthropometry, hydrodensitometry, DEXA, and MRI. All assessments were conducted in the morning at approximately the same time of day after an overnight fast.

Anthropometry. Body weight was measured to the nearest 0.1 kg using a medical beam scale with the subject clothed only in a dry bathing suit. Height was measured to the nearest 0.5 cm. Skinfold measurements at the triceps, subscapular, abdominal, and suprailliac sites were taken with a Lange caliper using

specific anatomic landmarks (25). These measurements were repeated until no more than a 1-mm difference existed between duplicate measurements and then were averaged. Circumferences at the waist, abdomen, and hip were assessed to the nearest 0.1 cm with a flexible tape at specified locations (25). These measurements were repeated until no more than a 0.5-cm difference existed between duplicate measurements and then were averaged.

Hydrodensitometry. Residual volume (RV) was assessed by the closed-circuit oxygen-dilution method (37) utilizing the Airspec model 2000 mass spectrometer system calibrated according to the manufacturer's specifications. After a practice trial, the average of two trials within a 75-ml range was used as the RV. Body composition was assessed immediately after RV determination. After four practice trials, the underwater weight was recorded as the average of the three highest of six trial weights obtained within a 150-g range and then was corrected for RV. Percent body fat was estimated from body density using the formula of Brozek et al. (6). It is thought that this procedure can cause inaccurate estimates in the elderly due to losses in BMC. However, this factor should not affect the relative changes in percent body fat over the short time frame of this study.

DEXA. A total body scan was performed using DEXA (model DPX-L, LUNAR Radiation, Madison, WI), and all scans were analyzed by one investigator using the LUNAR Radiation version 1.2i DPX-L program for body composition analyses (26). Fat mass of soft tissue (FTM), lean mass of soft tissue (LTM), and BMC were determined for the total body as well as for regional measures of the arms, legs, and trunk. The sum of LTM and BMC is referred to as FFM in this paper. Before data collection, reliability was assessed from five total body scans performed on one 73-year-old healthy subject who weighed 78.6 kg, was 175 cm tall, had 24.6% body fat, and had 3.2 kg of BMC. He was repositioned before each repeat scan. The coefficients of variation (CV) for total body percent fat, FTM, LTM, and BMC were 1.4, 1.4, 0.7, and 0.4%, respectively. The CVs for regional measures of the arms, legs, and trunk were $<2.9\%$ for all regions of FTM, $<1.2\%$ for LTM, and $<1.8\%$ for BMC. The DPX-L precision for the soft tissue attenuation ratio (R_{st}) and percent fat measurements was assessed with aluminum spine phantom scans in which the phantom was placed in a plastic container filled with 12 cm of water and 3 cm of 100% vegetable oil each time to simulate 20% fat. Five scans before the start of the study and five scans after the training period yielded identical values for R_{st} (CV = 0.3%) and percent fat (CV = 0.7%). In addition, the phantom was scanned on the testing days for R_{st} and percent fat before training (CV = 0.03 and 1.38%, respectively) and after training (CV = 0.07 and 2.6%, respectively). All of the scans were combined as an index of long-term precision and subsequently gave CV values of 0.056 and 1.98% for R_{st} and percent fat, respectively.

MRI. The CSAs of muscle and subcutaneous fat at the midhigh were measured before and after training by MRI using a Siemens 1.5-T magnetom. The magnetom was calibrated for the signal-to-noise ratio before each test using a phantom. Because of the high cost, this procedure was performed only on the first 10 subjects in the training group and the first 5 control subjects who volunteered. All subjects fasted and were tested at the same time of day during both testing conditions. Images were obtained using a spin-lattice relaxation time weighted sequence.

To ensure that midhigh transaxial images were obtained from exactly the same anatomic location, one-half the distance between the head of the femur and the medial condyle was measured from a sagittal image in both legs. A grid was placed over the sagittal image with horizontal lines running 10 mm apart. After the correct slice position was obtained, a transaxial

image was displayed and muscle CSA was obtained using a pixel counting program (Image Analysis 1.41). Each image was measured repeatedly until a variation of <1% was obtained between trials. All scans were analyzed without knowledge of subject name, testing conditions (before or after training), group (training or control), or testing order. To assess the reliability of the MRI scanner, one of the investigators (*BFH*) was scanned twice on 1 day and once on a different day during the study at the midhigh. The average midhigh muscle CSAs were 170.4 and 160.6 cm² for the two performed on the same day and 170.8 cm² on the scan performed on a different day. This suggests that the variation between scans is not greater than the variation between measurements of the same scan.

Anabolic Hormones and IGF-I

Blood samples were drawn before and after 16 wk of strength training in the training group and at approximately the same time periods in the control group. Samples drawn after training were taken 24 and 48 h after the last training session. All blood samples were drawn after an overnight fast at a similar time of morning. Samples were allowed to clot at room temperature for 20 min and then centrifuged. After separation, 1-ml aliquots of serum were pipetted into culture tubes. The blood was stored at -70°C until the samples were assayed. Serum concentrations of testosterone, GH, and IGF-I were measured by radioimmunoassay methods. To eliminate interassay variation, all samples were analyzed (in duplicate) in the same assay. Testosterone was quantified using reagents supplied by ICN Biomedicals (Carson, CA). The intra-assay CV was 5% at 1 ng/ml and 6% at 10 ng/ml, and sensitivity was 0.05 ng/ml. GH was measured using Allegro hGH Immuno radiometric assay (Nichols Laboratories, San Juan Capistrano, CA). The intra-assay CV was 12% at a dose of 0.5 ng/ml. Sensitivity was on the order of 0.05 to 0.1 ng/ml. Serum IGF-I was determined by double antibody radioimmunoassay after acid ethanol extraction at Endocrine Sciences Laboratories (Tarzana, CA). Intra-assay CV for the IGF-I assay was 6.4% at 250 ng/ml and 10.0% at 125 ng/ml. The assay sensitivity was ± 10 ng/ml.

Strength Assessment and Training Program

Four training sessions were conducted before strength testing in the training group so the subjects could become familiar with the equipment and proper exercise techniques. This helps control for large gains in strength measurements during the initial training session due to motor learning and also helps to prevent injuries. Upper and lower body strength were assessed on Keiser K-300 exercise machines before and after training with a three-repetition maximum (3-RM) test. The 3 RM was defined as the maximal resistance that could be moved through the full range of motion for three repetitions. We chose 3 RM because one-repetition maximum has been shown to lead to injuries and substantially higher numbers, which might become a measure of muscle endurance rather than strength. Subjects were allowed three warm-up repetitions before testing. Approximately the same number of trials (4-6 on average) and the same rest period between trials (~60 s) were used to reach the 3-RM weight after training as before training. The strength measures were completed on the leg press, leg extension, chest press, latissimus pull down, military press, and upper back row exercise machines for both the training and control groups. Testing procedures were standardized on the basis of specific seat adjustments and body positions, depending on the exercise.

The strength-training program consisted of 14 exercises using Keiser K-300 variable resistance machines, dumbbells, and floor exercises. Each subject trained on nonconsecutive days, three times per week for 16 wk using Keiser K-300 equipment.

Exercise sessions were supervised by a registered nurse and at least two exercise specialists. Subjects warmed up on a Schwinn Airdyne exercise bike or Concept II rowing machine for 3 min at a low intensity. This warm-up period was followed by 10 min of static stretching. After the accommodation period the starting weight for all exercises was set at 90% of the 3RM resistance for the first four repetitions. We found that most subjects could only complete about five repetitions at this resistance level. After the fourth repetition, resistance was reduced just enough on each repetition to prevent failure until 15 repetitions were completed. This was accomplished without having to disrupt the normal cadence of each repetition so that 15 continuous repetitions were completed while using a resistance that required near maximal effort on every repetition. Starting and finishing resistances were recorded for each exercise. The resistance level was checked once a week and adjusted to accommodate strength gains for each individual. Upper and lower body exercises were alternated to minimize fatigue, with a rest interval of ~90 s between exercises. The following exercises were performed in order: leg press, chest press, leg curl, latissimus pull down, leg extension, military press, abductor, adductor, upper back row, seated triceps, trunk extensions (lower back), abdominal curls, seated dumbbell curls, and supine abdominal crunches. After one set of each exercise was completed, the lower body exercises were repeated for a second set. Blood pressure and heart rate were taken before exercise, after the military press, after the second circuit on the leg machines, and before departure. All heart rates, blood pressures, and initial and final resistances for each machine were recorded during every exercise session, and subjects were weighed before every third exercise session.

Statistical Analyses

A two-factor repeated measures analysis of variance was used to test for overall differences in main effects and time by group interactions. When the *F* ratio for time by group interactions was significant, paired *t* tests were used to test planned within-group comparisons in both the training and control groups and nonpaired *t* tests were used to test planned comparisons between groups. Significance was initially set at the 0.05 level. Bonferonni adjustments were made for all significant findings. All data were analyzed by the Statview 512⁺ (Brain Power) and Super ANAOVA statistical packages (Abacus Concepts) for the Macintosh personal computer. Data are reported as means \pm SD.

RESULTS

Physical Characteristics

At baseline, the training and control groups did not differ significantly in age (60 ± 4 and 62 ± 6 yr, respectively), height (176 ± 5 and 175 ± 7 cm, respectively), or total body mass (85.1 ± 12.7 and 75.3 ± 8.7 kg, respectively). The strength training program did not result in any significant changes between the initial and final measurements in body mass (85.1 ± 12.7 and 85.1 ± 11.7 kg, respectively) or $\dot{V}O_{2\max}$ (28.5 ± 4.2 and 29.1 ± 3.4 ml \cdot kg⁻¹ \cdot min⁻¹, respectively). Body mass was also unchanged between the initial and final measurements in the control group.

Dietary Analysis

When comparing the 7-day food records before and after training, there were no significant changes in the total caloric intake ($2,261 \pm 216$ and $2,346 \pm 158$ kcal,

TABLE 1. 3-RM strength values for training and control groups

	Training Group		Control Group	
	Before	After	Initial	Final
Upper body, kg	179±34	249±46*	182±31	195±33
Lower body, kg	385±85	542±120*	377±50	397±48
Total body, kg	565±112	791±157*	560±80	591±73

Values are means ± SD; $n = 13$ training and 9 control subjects. 3-RM, three-repetition maximum; upper body strength, sum of values for chest press, military press, latissimus pull down, and upper back row; lower body strength, sum of values for leg press and bilateral leg extension; total body strength, sum of upper and lower body values. * Significantly different from before training, $P < 0.001$.

TABLE 2. Total body composition for training and control groups

	Training Group		Control Group	
	Before	After	Initial	Final
	<i>Fat, %</i>			
Hydrodensitometry	26.6±6.0	24.8±6.3*	21.4±3.7	22.8±3.6
DEXA	27.2±5.0	25.0±4.8*	24.4±5.5	25.1±5.3
	<i>Fat mass, kg</i>			
Hydrodensitometry	23.8±7.9	22.1±7.7*	16.5±4.0	17.9±4.1
DEXA	23.8±6.7	21.8±6.0*	18.7±5.2	19.3±5.2
	<i>Fat-free mass, kg</i>			
Hydrodensitometry	61.3±7.8	63.0±7.6†	58.8±6.9	58.4±6.4
DEXA	62.0±7.1	64.0±7.2*	57.1±6.8	57.1±6.4

Values are means ± SD; $n = 13$ training and 9 control subjects. DEXA, dual-energy X-ray absorptiometry. Significantly different from before training; * $P < 0.001$; † $P < 0.01$.

respectively) and percentage of total calories from fat (31 ± 1 and $31 \pm 1\%$, respectively), protein (19 ± 2 and $19 \pm 2\%$, respectively), or carbohydrate (51 ± 3 and $51 \pm 3\%$, respectively) in the training group. Similarly, no significant differences were observed between the initial and final values for total caloric intake ($2,012 \pm 510$ and $1,928 \pm 609$ kcal, respectively) and percentage of total calories from fat (27 ± 9 and $30 \pm 10\%$, respectively), protein (15 ± 3 and $14 \pm 3\%$, respectively), or carbohydrate (55 ± 14 and $54 \pm 11\%$, respectively) in the control group.

Muscular Strength

The training program resulted in a $39 \pm 8\%$ increase in upper body strength ($P < 0.001$) and a $42 \pm 14\%$ increase in lower body strength ($P < 0.001$) (Table 1). No significant changes occurred between the initial and final values for the control group for any of the 3-RM strength tests.

Total Body Composition

Percent body fat decreased by approximately the same amount whether measured by hydrodensitometry or DEXA (both $P < 0.001$) (Table 2, Fig. 1). Increases in FFM assessed by hydrodensitometry were also comparable to the increases assessed by DEXA (both $P < 0.001$). There were no changes in total BMC after training. No significant changes in percent fat or FFM were found

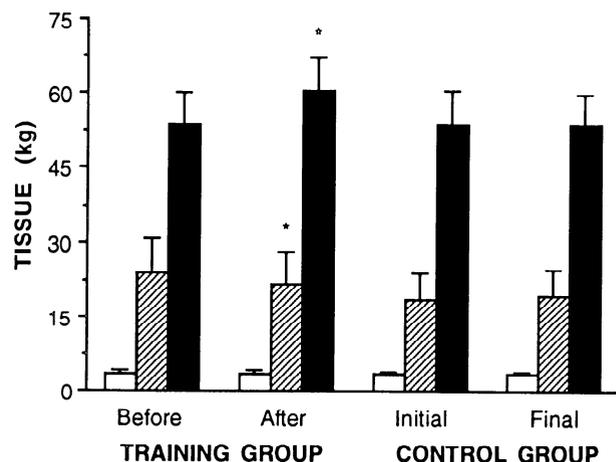


FIG. 1. Bone mineral content (BMC; open bars), fat (hatched bars), and nonosseous lean (solid bars) tissue values of total body by dual-energy X-ray absorptiometry (DEXA) in strength-trained and control groups. Values are means ± SD. * Significantly different compared with before training, $P < 0.001$.

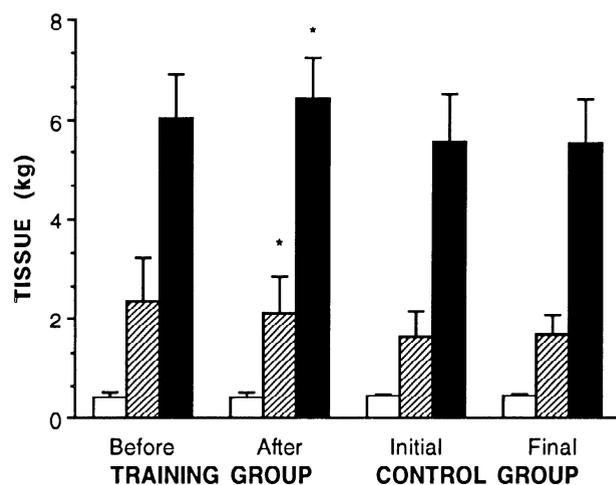


FIG. 2. BMC (open bars), fat (hatched bars), and nonosseous lean (solid bars) tissue values of arms by DEXA in strength-trained and control groups. Values are means ± SD. * Significantly different compared with before training, $P < 0.01$.

when determined by either hydrodensitometry or DEXA in the control group.

Regional Body Composition

In addition to changes observed in total body composition, regional changes in the arms, legs, and trunk were evident when measured by DEXA. Fat mass in the arms decreased significantly after training (2.383 ± 0.830 to 2.128 ± 0.714 kg; $P < 0.01$; Fig. 2), whereas arm FFM increased significantly (6.045 ± 0.860 to 6.418 ± 0.803 kg; $P < 0.01$). Leg fat mass also decreased (7.583 ± 1.675 to 6.945 ± 1.551 kg; $P < 0.01$; Fig. 3), whereas FFM in the legs increased (19.416 ± 2.228 to 20.131 ± 2.303 kg; $P < 0.001$). Furthermore, fat mass in the trunk decreased (12.216 ± 4.143 to 11.281 ± 3.653 kg; $P < 0.01$; Fig. 4), whereas FFM in the trunk increased (29.229 ± 4.108 to 30.134 ± 4.184 kg; $P < 0.01$) with training. These changes correspond to mean decreases in fat mass of $9.5 \pm 8.6\%$ in the arms, $8.5 \pm 5.4\%$ in the legs, and $7.4 \pm 5.0\%$ in the trunk region when calculating the average percent

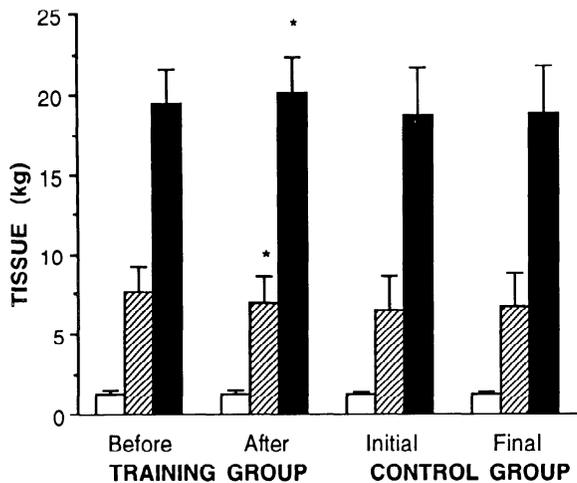


FIG. 3. BMC (open bars), fat (hatched bars), and nonosseous lean (solid bars) tissue values of legs by DEXA in strength-trained and control groups. Values are means \pm SD. * Significantly different compared with before training, $P < 0.001$.

changes based on individual values. For FFM, the increases for the arms, legs, and trunk region are $6.5 \pm 3.8\%$, $3.7 \pm 2.0\%$, and $3.0 \pm 2.7\%$, respectively. There were no significant differences observed in BMC in any of these regions with training. No significant changes in arms, legs, or trunk for fat mass, FFM, or BMC were observed in the control group. There were no significant changes in triceps, abdominal, subscapular, or suprailiac skinfold values before vs. after the training program (Table 3). Similarly, no significant differences in waist and hip circumferences or waist-to-hip ratios were observed after training (Table 4). Although there was a small but significant decrease in abdominal circumference after training ($P < 0.01$), this change was not significantly different from that of the control group. Skinfold and circumference values did not change significantly in the control group.

Midthigh muscle CSA increased in all subjects with an average gain of 6.6% (161 ± 19 to 172 ± 18 cm², $P < 0.01$),

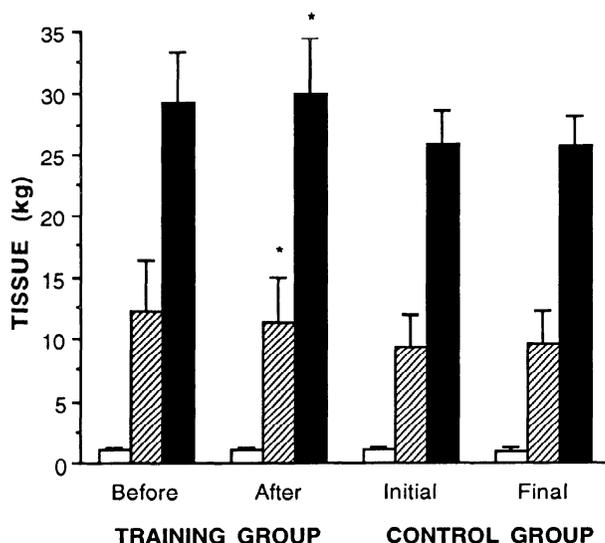


FIG. 4. BMC (open bars), fat (hatched bars), and nonosseous lean (solid bars) tissue values of the trunk by DEXA in strength-trained and control groups. Values are means \pm SD. * Significantly different compared with before training, $P < 0.01$.

TABLE 3. Skinfold measurements for training and control groups

	Training Group		Control Group	
	Before	After	Initial	Final
Triceps, mm	14.4 \pm 4.6	13.5 \pm 3.7	13.8 \pm 5.1	13.9 \pm 5.1
Abdominal, mm	24.5 \pm 5.1	25.2 \pm 7.9	27.6 \pm 4.0	28.6 \pm 4.7
Subscapular, mm	18.2 \pm 6.0	20.6 \pm 6.7	16.0 \pm 5.9	19.7 \pm 6.8
Suprailiac, mm	22.9 \pm 7.0	21.6 \pm 8.5	22.3 \pm 6.5	19.7 \pm 7.0

Values are means \pm SD; $n = 13$ training and 9 control subjects. None of the differences was significant.

whereas midthigh subcutaneous fat decreased by 9% (66 ± 13 to 60 ± 14 cm², $P < 0.05$). No changes in any of these areas were observed with MRI analyses in the controls.

Anabolic Hormones and IGF-I

There were no significant changes in serum testosterone, GH, and IGF-I after the training program (Table 5). Similarly, there were no significant differences between the initial and final values for the control group. The final values for the training group represent the mean of the values obtained 24 and 48 h after the last training session, since there were no significant differences between these time points. Initial baseline values for testosterone, GH, and IGF-I for both groups are also based on the mean of two samples taken on two separate occasions.

DISCUSSION

The results of the present study show that strength training can increase total body FFM and decrease total body fat mass in older men when measured by either DEXA or hydrodensitometry. The findings assessed by DEXA also reveal, for the first time, that strength training can increase FFM and decrease fat mass in the legs, arms, and trunk region in older men. MRI analyses provide further support that the increases in FFM in the leg region represent muscle hypertrophy. On the basis of our previous findings in younger men (21, 30), it was hypothesized that hydrodensitometry and anthropometry would not be sensitive enough to detect the subtle changes in body composition that occur with strength training in older individuals. The lack of changes in skinfolds supported this hypothesis, but the decreased percent body fat values observed with hydrodensitometry did not support the hypothesis, since the results using

TABLE 4. Circumference measurements for training and control groups

	Training Group		Control Group	
	Before	After	Initial	Final
Abdomen, cm	100.4 \pm 9.8	98.9 \pm 9.5*	94.0 \pm 6.2	95.6 \pm 6.3
Waist, cm	96.0 \pm 11.2	95.2 \pm 10.9	88.8 \pm 5.9	89.8 \pm 5.8
Hip, cm	103.9 \pm 6.4	102.9 \pm 6.0	97.7 \pm 5.4	98.5 \pm 5.6
Waist-Hip Ratio	0.92 \pm 0.06	0.92 \pm 0.06	0.91 \pm 0.04	0.91 \pm 0.04

Values are means \pm SD; $n = 13$ training and 9 control subjects. None of the differences between groups was significant. * Significantly different from before training, $P < 0.01$.

TABLE 5. Anabolic hormone and IGF-I values for training and control groups

	Training Group		Control Group	
	Before	After	Initial	Final
Growth hormone, ng/ml	0.34±0.45	0.38±0.43	0.59±0.44	0.75±0.83
IGF-I, ng/ml	192±30	191±47	171±45	183±53
Testosterone, ng/ml	7.16±2.17	6.84±1.76	8.63±1.86	8.84±1.78

Values are means ± SD; *n* = 12 training and 9 control subjects. IGF-I, insulin-like growth factor I. None of the differences was significant.

hydrodensitometry were similar to those of DEXA. In addition, the data did not support our hypothesis that these body composition changes would be accompanied by serum alterations in anabolic hormones and IGF-I. Nevertheless, the findings of an increase in muscular strength and FFM in the present study, along with those from other recent investigations (5, 15, 17, 22) and our finding of a 2-kg decrease in total body fat with about one-half of this loss coming from the trunk region, may have important implications for preventing the deterioration of functional capacity (16) and health status (31) with age. The observed reduction of fat mass in the trunk region was of particular interest due to the relationship of fat deposition in this region to the risk of CHD and diabetes (12).

Significant decreases in percent body fat are often not found with strength training (21, 30, 35). This might be expected because of the relatively low caloric expenditure of many strength-training programs (1, 36) and the low sensitivity of hydrodensitometry (24). Our finding of significant decreases in both total and regional fat mass cannot be explained on the basis of energy expenditure from the training program. The estimated energy expenditure for the entire training program in the present study (~7,200 kcal above resting levels) is far below the amount that would be required to account for the 2 kg of fat loss measured by DEXA. Although possible, it is not likely that this discrepancy in energy balance could be explained by either a decrease in caloric intake during the study or an increase in energy expenditure outside of the exercise sessions. There are limitations in the use of food records for reliably assessing habitual energy intake. However, several methods and a separate control group were used in this study to help control some of these limitations. Dietary factors were closely monitored by a nutritionist who analyzed 3-day food records approximately every 3 wk throughout training. Seven-day food records were also analyzed and found not to differ between pre- and posttraining. In addition, subjects were given food both before and after training for 5 days before testing. All subjects were also reminded on a frequent basis not to change their outside activity levels.

Other possible explanations for this discrepancy include shifts in substrate utilization and increased levels of protein synthesis. It is generally believed that the duration of resistive exercise is too low and the intensity is too high to account for fat utilization. However, Essén-Gustavsson and Tesch (14) demonstrated increases in

free fatty acids and glycerol, as well as triglyceride utilization, with heavy-resistance exercise. It is not known whether there is a shift toward greater fat utilization as the individual progresses from the untrained to the trained state during a strength-training program. Substantial increases in protein synthesis after resistive exercise have been documented (8) and could account for a relatively large amount of energy not measured during exercise. Similar discrepancies between calculated caloric expenditure and actual fat loss have been observed previously (2, 19).

Although the mechanism for changes in body composition with strength training or an explanation for the energy balance discrepancy cannot be determined from the data obtained in this study, we recently observed an increase in resting metabolic rate with the same training program used in the present study (28). It is conceivable that an increase in resting metabolic rate throughout a large portion of the training program could help to explain the discrepancy between the caloric expenditure of the exercise and the actual fat loss.

Our finding of a 6.6% increase in midhigh muscle CSA with a total body strength-training program is slightly lower than reported in those studies that used a single exercise in their training program (15, 17). For example, Fiatarone et al. (15) found a 9% increase in older men and women after single-limb training. However, this difference can probably be explained on the basis of differences in initial values. Their subjects were older and frail and had much lower initial midhigh muscle CSAs. The absolute magnitude of change in muscle tissue was greater in the present study.

Our finding of no significant changes in skinfold thickness despite decreases in fat mass when measured by DEXA supports our preliminary observation (22) of no changes in thigh skinfold thickness despite a decrease in thigh subcutaneous fat when measured by MRI. These results reinforce the need to use sensitive techniques such as DEXA and MRI for assessing the effects of exercise training on body composition.

Training-induced alterations in body composition might be related to alterations in endogenous anabolic hormones and growth factors (10, 11, 23). For this reason, we hypothesized that training-induced changes in body composition would be accompanied by alterations in serum levels of testosterone, GH, and IGF-I. However, such changes were not evident in the present study. Nevertheless, the failure of serum levels to change does not rule out an important role of these anabolic factors, particularly locally produced IGF-I. Measurements of IGF-I receptor density or mRNA for IGF-I in muscle tissue are needed to clarify this issue because circulating IGF-I is released mainly from the liver.

In conclusion, these results provide evidence that strength training increases both total and regional lean tissue mass and decreases both total and regional fat tissue mass. The changes in total body composition are observed whether assessed by DEXA or hydrodensitometry. Further studies are needed to help explain these results. Regardless of the mechanism(s), these results suggest that strength training may play an important role in the prevention of age-associated losses of strength

and muscle mass, as well as the deposition of body fat, which may be related to declines in functional abilities and health status in the elderly.

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