

Effects of strength and endurance training on thigh and leg muscle mass and composition in elderly women

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Sipilä, Sarianna, and Harri Suominen. Effects of strength and endurance training on thigh and leg muscle mass and composition in elderly women. *J. Appl. Physiol.* 78(1): 334–340, 1995.—The effects of 18 wk of intensive strength and endurance training on knee extensor, knee flexor, and lower leg muscle mass and composition were studied in 76- to 78-yr-old women. Muscle cross-sectional area (CSA), lean tissue CSA, and relative proportion of fat were determined using computed tomography. The strength-trained women increased their total muscle lean tissue CSA of the thigh (1.5%; $P = 0.035$), quadriceps CSA (4.5%; $P = 0.021$), quadriceps lean tissue CSA (5.8%, $P = 0.009$), and mean Hounsfield unit of the lower leg muscles (11.2%; $P = 0.035$) compared with the changes that occurred in the control group during the experiment. The change in quadriceps lean tissue CSA because of the strength training was also significant compared with that in the endurance group. The relative proportion of fat within the quadriceps muscle decreased due to the strength training compared with the changes that occurred in the endurance group. The results show that intensive strength training can induce skeletal muscle hypertrophy in elderly women and thereby also reduce the relative amount of intramuscular fat, whereas the effects of endurance training are negligible.

aging; computed tomography; exercise; hamstrings; quadriceps

AGE-RELATED MUSCLE ATROPHY is one of the major reasons for impaired muscle performance in elderly people. To what extent these age-induced changes can be counteracted by external factors, such as by increasing the level of physical activity, remains an open question.

Previous cross-sectional studies have shown that elderly athletes who have been training for years have a larger quadriceps cross-sectional area (CSA) than do sedentary controls (7, 15). Klitgaard et al. (7) showed that strength-trained male athletes (mean age 68 yr) had larger muscle CSA compared with controls of the same age. No difference was found between the endurance athletes and sedentary controls. In our previous study of 70- to 81-yr-old male athletes (14), we found no significant differences between power athletes, endurance athletes, and untrained controls in quadriceps CSA measured using ultrasonography. However, the muscle echogenicity pattern reflected a lower relative proportion of fat in both groups of athletes compared with the controls. In a further study of 66- to 85-yr-old female athletes (power and endurance athletes combined) and controls, the athletes had a larger lean tissue CSA (16) and smaller area of fat (15) inside the quadriceps compartment.

The results of the experimental studies investigating training effects on muscle mass and structure in elderly subjects show little agreement because of differences in the study design, training protocol, age of subjects,

muscle under investigation, and methods used. Most such trials have been conducted in men. Twelve weeks of resistance training in elderly men resulted in a significant increase in the CSA of the quadriceps (1, 4), knee (1), and elbow flexors (1, 13). In elderly women, 12 wk of resistance training resulted in a 20% increase in type II fiber area (2). After only 8 wk of resistance training, a group of 86- to 96-yr-old men and women increased their computed tomography (CT)-measured quadriceps CSA by an average of 10.9% (3). On the other hand, 8 wk of strength training produced only a 2.8% increase in a group of 78- to 84-yr-old men (5). Moritani and deVries (10) failed to show any changes whatsoever in quadriceps CSA estimated from anthropometric measurements after 8 wk of resistance training in elderly male volunteers. Even 24 wk of strength training did not bring about significant changes in arm girth corrected by skinfold measurements in 65- to 78-yr-old men (12).

Endurance training has not been shown to induce muscle hypertrophy in elderly people. In an animal experiment swim-trained 29-mo-old rats had smaller muscle fiber areas than did their strength-trained counterparts but had larger fiber areas than age-matched controls (6). After 2 yr of endurance training in Wistar rats, the mean CSA of type I fibers in the soleus muscle was smaller than that of age-matched controls (8).

The purpose of this study was to investigate, using CT, the effects of progressive, intensive strength and endurance training on the quadriceps, hamstrings, knee flexor compartment, and lower leg muscle mass and composition in 76- to 78-yr-old women.

METHODS

Subjects. A postal questionnaire concerning health status, medication and functional capacity was mailed to a random sample of 76- to 78-yr-old women ($n = 240$) drawn from the population register of the city of Jyväskylä. One hundred fifty-seven women responded to the questionnaire, of whom 65 who had reported no severe diseases or functional impairments were invited for clinical and laboratory examinations. Fifty-four women agreed to participate, and after the clinical examinations and a symptom-limited progressive multistage exercise test on a bicycle ergometer with electrocardiograph monitoring and blood pressure measurement, 42 women with no contraindications for intensive physical exercise were randomly assigned to strength ($n = 16$), endurance ($n = 15$), and control ($n = 11$) groups.

Twelve subjects from the strength, 12 from the endurance, and 11 from the control group completed the study. Of the seven women who withdrew from the study, six were excluded because of disease and illness and one was unwilling to continue because of the lack of time in her daily schedule.

The study was approved by the ethical committees of the Central Hospital of Central Finland and of the University

TABLE 1. *Physical characteristics in 76- to 78-year-old women before and after 18 wks of intensive strength and endurance training*

Variable	Strength		Endurance		Control		ANOVA Significance (P value)			
	Baseline	18 wk	Baseline	18 wk	Baseline	18 wk	Interaction	Group	Time	Contrasts
Body height, cm	159.5±1.0	159.9±1.0	156.7±1.6	156.9±1.6	158.7±1.7	159.1±1.7	0.768	0.337	<0.001	
Body mass, kg	66.9±2.7	65.3±2.7	67.3±2.8	65.9±2.6	67.6±3.9	66.7±4.0	0.519	0.972	<0.001	
Lean body mass, kg	45.3±1.1	45.8±0.9	44.4±0.8	44.2±0.8	45.0±1.5	45.0±1.5	0.477	0.728	0.706	
Body fat, %	31.9±1.9	29.2±2.3	34.4±1.9	32.9±1.7	32.2±2.4	31.2±2.4	0.078	0.572	<0.001	S-C 0.031 E-C 0.570 S-E 0.105

Values are means ± SE. S, strength; E, endurance; C, control; ANOVA, analysis of variance.

of Jyväskylä. A written informed consent was obtained in advance from all the subjects.

The physical characteristics of the subjects who completed the study are shown in Table 1.

Training. Both experimental groups participated in an 18-wk progressive physical training program, which was divided into a 2-wk orientation phase and a 16-wk training phase. The subjects had their supervised 1-h training sessions twice a week during the orientation phase and three times a week during the training phase. Training sessions were not arranged during the holidays. In the beginning of each training session, both groups had a warm-up period of 10 min including brisk walking and stretching. At the end of the session, stretching exercises to include the major muscle groups were performed.

The strength group trained on equipment using compressed air as a resistance (HUR, Kokkola, Finland). The function of these machines resembles the function of the variable resistance machines, in which the force distribution throughout the range of motion will accommodate to the maximum force produced by the muscles. The dynamic training was specifically directed at increasing the mass and strength of the quadriceps femoris by means of leg press and leg extension curl, the hamstrings through the leg flexion curl on standing position, and the calf muscles using the calf raise. Principally, each training session included all the above-mentioned exercises except the calf raise, which was included in the training program after the 1st wk of orientation, and the leg extension curl, which was added in the program after 9 wk of training. The resistance was individually adjusted according to the one-repetition maximum test (1 RM) measured at 2-wk intervals. To obtain 1 RM, the initial resistance was set close to the previous 1 RM result. Resistance increment was 0.25 bar. One RM was defined as the heaviest load the subject could move in an acceptable way throughout the complete range of motion. During the first 2 wk, 1 RM increased on the average 19%, and during the last 2 wk it increased only on the average 2%. The coefficient of variation between the last 1 RM measurements was on the average 2%. The intensity of the training was gradually increased so that during the orientation phase and during the 1st wk of training phase the load corresponded to 60% of the 1 RM, during the next 11 wk it corresponded to 70% of the 1 RM, and for the last 4 wk it corresponded to 75% of the 1 RM. The subjects performed three to four sets of 8–10 repetitions with a 30-s pause between sets. The leg extension curl was used with caution because it produced discomfort in the knee area in several subjects.

The training of the endurance group included track walking twice a week and step aerobics once a week. The training heart rate was individually adjusted on the basis of a progressive multistage exercise test on a bicycle ergometer. Training

intensity was gradually increased so that during the first 5 wk the training heart rate corresponded to 50%, during the next 10 wk from 60 to 70%, and during the last 4 wk to 80% of the initial maximal heart rate reserve. The training heart rates were controlled by heart rate monitors during the training sessions. Step aerobics was not arranged during the first and the last week of training.

The actual number of training sessions attended by both the strength- and endurance-trained women is shown in Table 2. The main reasons for nonparticipation in a training session were a trip abroad and influenza. Two women in the strength-training group did not perform calf press training during the training weeks 15 and 16 because of a mild muscle soreness in the calf area. No training-related injuries were sustained by any of the subjects.

The controls were instructed to continue their daily routines and not to change their physical activity levels.

To determine the actual physical activity level of the subjects and possible changes in it during the experiment, all subjects were instructed to keep a diary concerning their daily physical activities. The subjects were asked to record the type and duration of physical activity performed and also the kilometers for walking, cycling, and swimming. Beyond the training included in the trial, walking was the principal activity reported by the subjects in every study group. Weekly walking performed by the subjects ranged from 14 to 19 km in the strength-training group, from 11 to 18 km in the endurance group, and from 10 to 16 km in the control group. The mean duration of total physical activity (walking, home gymnastics, cycling, swimming, etc.) ranged weekly from 4.5 to 7.0 h in the strength group, from 3.2 to 5.8 h in the endurance group, and from 3.4 to 5.1 h in the control group.

Anthropometry. Body height, body mass, and lean body mass together with body fat measured using bioelectrical impedance (Spectrum II, RJL Systems, Detroit, MI) (9) were

TABLE 2. *Number of strength- and endurance-training sessions arranged and actual participation among the 76- to 78-yr-old women*

	Sessions	Participation	
		Mean	Range
Strength training			
Leg press	50	43	30-50
Leg extension curl	24	17	6-24
Leg flexion curl	50	42	30-50
Calf press	48	40	27-46
Endurance training			
Track walking	31	27	21-29
Step aerobics	14	12	9-14

determined. In our laboratory, the coefficient of variation between two consecutive measurements has been <2% for lean body mass and <3% for percent body fat. The bioelectrical impedance results of one woman were discarded because of a technical failure.

CT. The CT examinations were obtained from the thigh and lower leg muscles before and after training using a Siemens Somatom CR scanner (Siemens, Erlangen, Germany). Midthigh was defined as a midpoint between the great trochanter and lateral joint line of the knee. Lower leg length was defined as the distance between the condyles lateralis of the tibia and malleolus lateralis of the fibula. Leg length was then multiplied by 0.33, and the distance obtained was measured downward from the tuberositas of the tibia (18). The scanning sites were located with a flexible tape. Midthigh was marked with an indelible ink for the needle muscle biopsy. The scar was then used as a marker for the posttraining measurements. The scanning site of the lower leg was remeasured for the posttraining measurements. During scanning, the subjects lay supine with the leg extended and relaxed on the examination table. The slice thickness was 2 mm, and the scanning time was 7 s.

Scan analysis. The scans (256×256 pixels in the calculation matrix) were stored for future analysis on diskettes. A pen cursor was used to trace manually the outline of the whole thigh and more specifically quadriceps femoris, hamstrings, knee flexor compartment (i.e., hamstrings, gracilis, sartorius, and adductors), and lower leg muscles (i.e., ankle flexors and extensors). The CSA of the encircled area was measured by the scanner's own computer. The mean radiological density (Hounsfield unit; HU) (17) and specific HU ranges (0–200 HU for lean and –1 to –200 HU for fat tissue) were also recorded for the different areas studied. The HU ranges were based on the literature and personal experimentation adjusted for the CT scanner used in this study. The scans were evaluated twice by the same person, and the mean values were recorded as a result, even though the differences between the two evaluations were minimal.

The coefficient of variation between two consecutive measurements varied between 1.3 (lower leg) and 2.9% (hamstrings) for the CSA, between 1.9 (knee flexor compartment) and 2.9% (hamstrings) for the mean HU, between 0.9 (lower leg) and 2.1% (hamstrings) for the muscle lean tissue CSA, between 0.2 (lower leg) and 0.3% (quadriceps) for the mean HU of the muscle lean tissue, and between 4.2% (knee flexor compartment) and 9.3% (quadriceps) for the relative propor-

tion of fat. Of the controls, one woman failed to attend the posttraining CT measurements and another from the strength-training group failed to attend the pretraining CT measurements of the lower leg. We also failed to obtain acceptable scans for the muscle density analysis of the thigh area from eight women because of the reconstruction algorithm (convolution kernel S) used. The kernel S has a high-contrast resolution, which affects the mean HU values, especially when scanning a thigh of large circumference.

Statistical methods. Standard procedures were used to calculate means, standard errors, and correlation coefficients (Pearson r). The differences between the study groups in the baseline measurements were assessed using one-way analysis of variance (ANOVA). The effects of the training programs were assessed using ANOVA for repeated measures. If the significance of the interaction was $P < 0.10$, the training effect was localized utilizing simple contrasts. The level of statistical significance chosen for the contrasts was $P < 0.05$. Within-group differences from the baseline to the posttraining measurements were also assessed using Student's t -test (2-tailed) for repeated measures. The level of significance was set at $P < 0.05$.

RESULTS

In the baseline measurements, the study groups did not differ with respect to any physical characteristic or muscle group under investigation.

The strength-trained women decreased the body fat compared with the change observed in the control women during the experiment (Table 1). When the posttraining measurements were compared with the baseline measurements of physical characteristics within the study groups, there was also a significant decrease in body fat in the endurance group ($P = 0.015$) and in the control group ($P = 0.008$) and in body mass in both the strength- ($P = 0.009$) and the endurance-trained women ($P = 0.008$).

The strength-trained women increased significantly their total muscle lean tissue CSA of the thigh (from 96.8 ± 4.0 to 98.3 ± 4.3 cm²) compared with the change observed in the controls (from 92.9 ± 3.5 to 90.5 ± 4.0 cm²; interaction $P = 0.064$, contrast $P = 0.035$). Strength training also tended to increase the muscle

TABLE 3. Effects of intensive strength and endurance training on muscle mass and composition of quadriceps in 76- to 78-yr-old women

Variable	Strength		Endurance		Control		ANOVA Significance (P value)			
	Baseline	18 wk	Baseline	18 wk	Baseline	18 wk	Interaction	Group	Time	Contrasts
CSA, cm ²	44.9 \pm 2.4	46.9 \pm 2.1	44.1 \pm 1.8	45.0 \pm 1.8	42.4 \pm 1.3	42.5 \pm 1.5	0.062	0.449	0.03	S-C 0.021 E-C 0.309 S-E 0.150
Mean HU	65.3 \pm 0.9	65.6 \pm 1.5	64.0 \pm 2.9	63.3 \pm 2.2	63.2 \pm 2.2	60.7 \pm 3.3	0.679	0.495	0.450	
Lean CSA, cm ²	39.4 \pm 1.4	41.7 \pm 1.2	39.2 \pm 1.2	39.8 \pm 1.4	38.1 \pm 1.0	38.0 \pm 1.3	0.023	0.391	0.010	S-C 0.009 E-C 0.394 S-E 0.050
Lean HU	74.2 \pm 1.1	73.5 \pm 1.3	74.4 \pm 2.4	74.4 \pm 1.5	72.8 \pm 1.8	70.4 \pm 3.1	0.632	0.517	0.300	
Proportion of fat, %	10.3 \pm 1.4	9.4 \pm 1.6	9.7 \pm 0.9	10.4 \pm 1.1	9.6 \pm 1.0	10.0 \pm 1.0	0.098	0.986	0.888	S-C 0.101 E-C 0.759 S-E 0.044

Values are means \pm SE. CSA, cross-sectional area; HU, Hounsfield unit.

TABLE 4. *Effects of intensive strength and endurance training on muscle mass and composition of hamstrings in 76- to 78-yr-old women*

Variable	Strength		Endurance		Control		ANOVA Significance (<i>P</i> value)		
	Baseline	18 wk	Baseline	18 wk	Baseline	18 wk	Interaction	Group	Time
CSA, cm ²	26.2±1.2	26.5±1.2	27.4±1.8	27.8±1.8	24.3±1.5	25.0±1.6	0.875	0.385	0.222
Mean HU	58.1±2.8	59.8±2.5	58.8±3.1	59.5±2.8	60.2±3.7	60.6±4.0	0.917	0.934	0.437
Lean CSA, cm ²	21.7±1.1	22.3±1.1	22.7±1.2	23.1±1.2	20.6±1.0	21.4±0.9	0.895	0.504	0.036
Lean HU	76.5±1.8	76.2±2.0	78.0±2.3	77.8±1.8	75.6±2.2	74.6±3.1	0.924	0.645	0.598
Proportion of fat, %	16.0±1.5	14.5±1.4	15.4±1.5	15.1±1.5	14.0±1.6	13.6±1.5	0.351	0.726	0.063

Values are means ± SE.

lean tissue CSA of the thigh compared with the change in the endurance-trained women (from 98.9 ± 5.1 to 96.3 ± 4.8 cm²; $P = 0.054$).

The effects of strength and endurance training on the quadriceps, hamstrings, knee flexor compartment, and lower leg muscles are shown in Tables 3, 4, 5, and 6, respectively. The strength-trained women increased quadriceps CSA, quadriceps lean tissue CSA, and mean HU of the lower leg muscles compared with the control women during the experiment. The increase in quadriceps lean tissue CSA due to the strength training was also significant compared with that of the endurance group. The relative proportion of fat within the quadriceps muscle decreased in the strength-training group compared with the endurance-training group.

The mean changes in quadriceps CSA and lean tissue CSA were 4.9 and 6.1% for the strength-trained, 2.2 and 1.5% for the endurance-trained, and 0.1 and -0.4% for the control women, respectively (Figs. 1 and 2). When the posttraining measurements are compared with the baseline measurements within the study groups, the strength-trained women showed a significant increase in quadriceps CSA ($P = 0.012$) and lean tissue CSA ($P = 0.008$). Strength training also increased the mean HU ($P = 0.006$), lean tissue CSA ($P = 0.042$), and the mean HU of the lean tissue ($P = 0.011$) in the lower leg muscles, and it decreased the relative proportion of fat in the knee flexor compartment ($P = 0.003$). Strength training also tended to decrease the relative proportion of fat in the hamstrings ($P = 0.055$). Endurance training decreased the total muscle lean tissue CSA of the thigh ($P = 0.033$). The control group showed an increase in the muscle lean tissue CSA of the hamstrings ($P = 0.034$) and a de-

crease in the total lean tissue CSA of the thigh ($P = 0.025$) during the experiment.

Regardless of the variation in the number of actual training sessions, the above-mentioned changes that occurred in the muscles during the experiment were not related to the number of training sessions. However, in the endurance group the number of training sessions was related to the change in the CSA ($r = 0.940$) and lean tissue CSA ($r = 0.928$) of the hamstrings.

DISCUSSION

Compliance with the protocol was very good in the 34 women who completed the study. Beyond the training included in the trial, the study groups did not differ with respect to the level of physical activity, which remained constant throughout the experiment.

Several reports concerning the adaptation of skeletal muscle mass to intensive strength training in elderly people have recently been published by different research groups. The majority of those studies have been conducted on men with only a few reports concerning the training effects on muscle mass in elderly women. Moreover, surprisingly few studies investigating training effects on muscle mass in elderly people have included control groups in their study design. In experimental studies, the use of a control group is necessary to separate, for example, seasonal variation from true training effects.

In this study the total muscle lean tissue CSA of the thigh increased significantly (1.5%) in the strength-trained women compared with the decrease (2.6%) that occurred in the controls. Frontera et al. (4) found an

TABLE 5. *Effects of intensive strength and endurance training on muscle mass and composition of knee flexor compartment in 76- to 78-yr-old women*

Variable	Strength		Endurance		Control		ANOVA Significance (<i>P</i> value)		
	Baseline	18 wk	Baseline	18 wk	Baseline	18 wk	Interaction	Group	Time
CSA, cm ²	55.7±1.8	55.2±2.3	57.8±2.5	56.7±2.8	55.3±2.5	54.7±3.0	0.915	0.786	0.226
Mean HU	57.6±2.5	59.6±2.6	58.1±4.1	58.5±3.1	57.9±3.3	57.8±4.1	0.795	0.986	0.566
Lean CSA, cm ²	45.1±1.7	45.5±1.7	47.5±1.9	46.6±1.8	46.1±1.8	45.6±2.0	0.501	0.767	0.421
Lean HU	76.2±2.0	75.8±2.2	77.8±2.6	77.3±2.1	75.5±2.3	73.9±3.4	0.869	0.680	0.401
Proportion of fat, %	16.7±1.3	15.0±1.5	15.8±1.5	15.8±1.3	15.6±1.3	15.4±1.5	0.178	0.981	0.142

Values are means ± SE.

TABLE 6. *Effects of intensive strength and endurance training on lower leg muscle mass and composition in 76- to 78-yr-old women*

Variable	Strength		Endurance		Control		ANOVA Significance (P value)			
	Baseline	18 wk	Baseline	18 wk	Baseline	18 wk	Interaction	Group	Time	Contrasts
CSA, cm ²	53.5±2.5	56.1±2.5	52.7±2.9	54.2±2.7	49.8±3.0	50.6±3.0	0.479	0.500	0.012	S-C 0.035 E-C 0.612 S-E 0.084
Mean HU	58.7±1.2	65.3±2.8	54.7±4.6	56.6±5.2	55.7±3.5	56.6±5.8	0.080	0.334	0.100	
Lean CSA, cm ²	50.1±2.3	53.0±2.4	48.1±3.3	49.4±3.2	45.8±3.0	46.6±3.0	0.344	0.443	0.008	
Lean HU	64.5±1.2	70.4±2.5	63.7±2.3	65.3±2.6	63.1±2.2	64.0±2.6	0.125	0.317	0.012	
Proportion of fat, %	6.2±0.6	5.3±0.6	9.5±2.8	9.4±2.9	8.1±1.6	7.8±1.7	0.346	0.432	0.105	

Values are means ± SE.

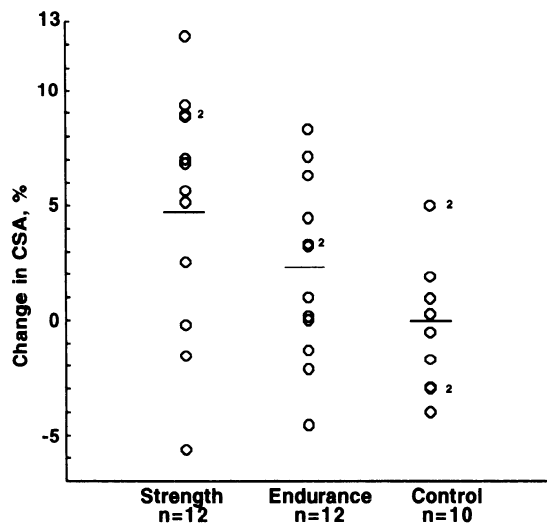


FIG. 1. Individual changes in quadriceps muscle cross-sectional area (CSA) in 76- to 78-yr-old strength-trained, endurance-trained, and control women. *n*, no. of women. —, Means.

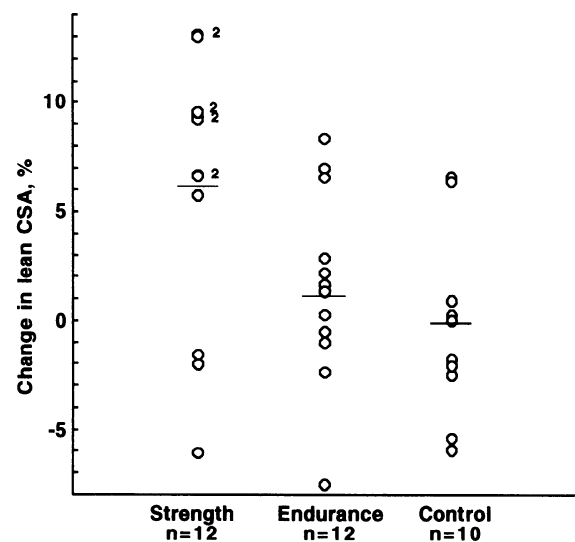


FIG. 2. Individual changes in quadriceps muscle lean CSA in 76- to 78-yr-old strength-trained, endurance-trained, and control women. *n*, no. of women. —, Means.

11.4% increase in the total muscle area of the thigh in elderly men, and Fiatarone et al. (3) found an increase of 9.0% in a group of 86- to 96-yr-old men and women after strength training. On the other hand, Grimby et al. (5) failed to observe any change in the mid-thigh muscle area after ~8 wk of strength training in elderly men.

The increase in quadriceps CSA (Fig. 1) and lean tissue CSA (Fig. 2) due to strength training in this study was within the range of results of the earlier studies. Grimby et al. (5) reported a significant increase of 2.8% in quadriceps CSA after 8 wk of strength training in voluntary 78- to 84-yr-old men. Frontera et al. (4) found a 9.3% increase and Brown et al. (1) found a 6.9% increase in quadriceps CSA after 12 wk of strength training in voluntary 60- to 70-yr-old men. Fiatarone et al. (3) showed an increase of 10.9% in quadriceps CSA after 8 wk of strength training in a study in which men and women were pooled. In the latter study, however, there was considerable individual variation, and the results were significant only at the level of $P = 0.09$ (1-tailed test).

In the elderly, training effects on the muscle mass of the quadriceps muscle group have been studied more frequently than on the other muscles of the lower ex-

tremity. To our knowledge, there are no other studies engaged in the specific training and measuring of hamstrings and lower leg muscles in elderly people. Hamstrings are quite difficult to separate from adductors, and ankle extensors and flexors are impossible to separate from each other even when modern imaging techniques are used. In this study, the hamstrings, the knee flexor compartment, and the total muscle mass of the lower leg were analyzed. There were no training-induced changes in the knee flexors even though the training of the knee flexors was quite specific. Brown et al. (1) reported an increase of 3.6% in the knee flexor compartment after 12 wk of strength training in elderly men, although the only exercise for the lower extremities was the bilateral leg press. In the study by Frontera et al. (4), a strength-training program for both knee flexors and extensors was conducted in 60- to 72-yr-old men. The subjects increased their dynamic knee flexor strength by over 200% and extensor strength by over 100%, as measured using the 1-RM technique. However, it seems that only the CT-measured total muscle area and quadriceps area increased significantly and was not accompanied by any increase in the knee flexor compartment.

The high correlation between the number of training sessions and the change in CSA and lean CSA in the hamstrings in the endurance group was partly due to the woman with the lowest participation rate showing, at the same time, an exceptionally high decrease in CSA. If her values are excluded, the correlation coefficients remain lower ($r = 0.731$ – 0.667 and $P = 0.011$ – 0.025 , respectively). Furthermore, there would be a significant 4.1–4.8% increase in these variables by training.

In the present study, there was a 4.6% increase in muscle CSA and 5.5% increase in lean tissue CSA in the lower leg muscles after the strength-training program. The changes were not significant compared with the changes that occurred in the endurance or control groups. However, if the posttraining measurements are compared with the baseline measurements within the study groups, the increase in lean tissue CSA becomes significant.

In this study the effect of strength training on the quadriceps muscle group and on the lower leg muscles was rather similar. The training effect on the hamstrings and knee flexor compartment was clearly smaller. One possible explanation for this may be the difference in the actual training stimulus. The leg press and knee extension curl were supposed to stress the quadriceps muscle group, whereas the lower leg muscles are activated by both the leg press and calf raise. For the knee flexors there was only one exercise, the knee flexion curl. On the other hand, the leg press might also have some effect, although not very specific, on knee flexors. This is supported by the above-mentioned results of Brown et al. (1).

Studies investigating strength-training effects on skeletal muscles in both young (11) and elderly subjects (10) have shown that in the early stages of training other structural as well as functional adaptations take place than simply the increase in muscle CSA. Neural factors and the muscle architecture are probably the first to undergo changes, at least in the early phase of strength training in the elderly. However, Yarasheski et al. (19) have shown that there is a marked increase in the protein synthesis of the quadriceps already during the first 2 wk of strength training in both elderly men and women.

As expected, endurance training did not increase the CSA of the muscles under investigation. A small increase in the lean CSA of the hamstrings was observed in the control group. However, this increase was close to the precision of the measurement and was not significant compared with the change observed in the other study groups during the experiment.

Grimby et al. (5) did not find any significant changes in the intramuscular adipose tissue concentration after 2–3 mo of strength training in elderly men. However, they suggested that a longer training period may hinder the age-related infiltration of fat into the muscle tissue. It seems that the 18 wk of strength training used in this study may have decreased the relative proportion of fat in the muscles under investigation. The decrease in the proportion of fat in the quadriceps, which was mainly due to the increase in the lean CSA

of the muscle, was significant compared with the increase in the endurance group. Within the strength-training group, the relative proportion of fat in the knee flexor compartment decreased and there was also a trend toward a smaller proportion of fat in the hamstrings. Body fat also decreased in the strength-trained women. The endurance training did not affect the relative proportion of fat in the lower extremities or the body fat.

In conclusion, this study indicates that in elderly women the adaptation of skeletal muscle mass to intensive training is specific to the type of training used. The results show that strength training can induce skeletal muscle hypertrophy in elderly women and thereby also reduce the relative amount of intramuscular fat, whereas the effects of endurance training are negligible.

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REFERENCES

1. Brown, A. B., N. McCartney, and D. G. Sale. Positive adaptation to weight-lifting in the elderly. *J. Appl. Physiol.* 69: 1725–1733, 1990.
2. Charette, S. L., L. McEvoy, G. Pyka, C. Snow-Harter, D. Guido, R. A. Wiswell, and R. Marcus. Muscle hypertrophy response to resistance training in older women. *J. Appl. Physiol.* 70: 1912–1916, 1991.
3. Fiatarone, M. A., E. C. Marks, N. D. Ryan, C. N. Meredith, L. A. Lipsitz, and W. J. Evans. High-intensity strength training in nonagenarians. Effects on skeletal muscle. *J. Am. Med. Assoc.* 263: 3029–3034, 1990.
4. Frontera, W. R., C. N. Meredith, K. P. O'Reilly, H. G. Knuttgen, and W. J. Evans. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. *J. Appl. Physiol.* 64: 1038–1044, 1988.
5. Grimby, G., A. Aniansson, M. Hedberg, G.-B. Henning, U. Grangård, and H. Kvist. Training can improve muscle strength and endurance in 78- to 84-yr-old men. *J. Appl. Physiol.* 73: 2517–2523, 1992.
6. Klitgaard, H., A. Brunet, B. Maton, C. Lamaziere, C. Lesty, and H. Monod. Morphological and biomechanical changes in old rat muscles: effect of increased use. *J. Appl. Physiol.* 67: 1409–1417, 1989.
7. Klitgaard, H., M. Mantoni, S. Schiaffino, S. Ausoni, L. Gorza, C. Laurent-Winter, P. Schnohr, and B. Saltin. Function, morphology and protein expression of ageing skeletal muscle: a cross-sectional study of elderly men with different training backgrounds. *Acta Physiol. Scand.* 140: 41–54, 1990.
8. Kovanen, V., and H. Suominen. Effects of age and life-time physical training on fibre composition of slow and fast skeletal muscle in rats. *Pfluegers Arch.* 408: 543–551, 1987.
9. Lukaski, H. C., and W. W. Bolonchuk. Theory and validation of the tetrapolar bioelectrical impedance method to assess human body composition. In: *In-Vivo Body Composition Studies*, edited by K. J. Ellis, S. Wasumura, and W. D. Morgan. London: Inst. Phys. Sci. Med., 1987, p. 410–414.
10. Moritani, T., and H. A. DeVries. Potential for gross muscle hypertrophy in older men. *J. Gerontol.* 35: 672–682, 1980.
11. Narici, M. V., G. S. Roi, L. Landoni, A. E. Minetti, and P. Cerretelli. Changes in force, cross-sectional area and neural

- activation during strength training and detraining of the human quadriceps. *Eur. J. Appl. Physiol. Occup. Physiol.* 59: 310–319, 1989.
12. **Rice, C. L., D. A. Cunningham, D. H. Paterson, and J. R. Dickinson.** Strength training alters contractile properties of the triceps brachii in men aged 65–78 yrs. *Eur. J. Appl. Physiol. Occup. Physiol.* 66: 275–280, 1993.
 13. **Roman, W. J., J. Fleckenstein, J. Stray-Gundersen, S. E. Alway, R. Peshock, and W. J. Gonyea.** Adaptations in the elbow flexors of elderly males after heavy-resistance training. *J. Appl. Physiol.* 74: 750–754, 1993.
 14. **Sipilä, S., and H. Suominen.** Ultrasound imaging of the quadriceps muscle in elderly athletes and untrained men. *Muscle Nerve* 14: 527–533, 1991.
 15. **Sipilä, S., and H. Suominen.** Muscle ultrasonography and computed tomography in elderly trained and untrained women. *Muscle Nerve* 16: 294–300, 1993.
 16. **Sipilä, S., and H. Suominen.** Knee extension strength and walking speed in relation to quadriceps muscle composition and training in elderly women. *Clin. Physiol. Oxf.* 14: 433–442, 1994.
 17. **Stytz, M. R., and O. Frieden.** Three-dimensional medical imaging modalities: an overview. *Biomed. Eng.* 18: 1–26, 1990.
 18. **Sulin, C., J. Timonen, and H. Suominen.** Elastic wave propagation in bone in vivo: methodology. *J. Biomech.* In press.
 19. **Yarasheski, K. E., J. J. Zachwieja, and D. M. Bier.** Acute effects of resistance exercise on muscle protein synthesis rate in young and elderly men and women. *Am. J. Physiol.* 265 (Endocrinol. Metab. 28): E210–E214, 1993.

