

# Effect of Age on Muscle Hypertrophy Induced by Resistance Training

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**Background.** Previous research has shown that resistance training induces muscle hypertrophy in older subjects, but has not clarified whether the degree of hypertrophy is affected by age. The present study was done to test the hypothesis that men and women over 60 years old have a smaller hypertrophic response to resistance training than young adults.

**Methods.** Cross-sectional areas (CSA) of muscle in the thigh and upper arm were determined before and after 3 months of progressive resistance training by magnetic resonance imaging (MRI) in 9 young (22–31 yr, 5 male and 4 female) and 8 old (62–72 yr, 4 male and 4 female) subjects. Strength was determined by 3-repetition-maximum (3RM) testing. The amount of weight lifted during the training program was proportional to baseline strength.

**Results.** Mean pretraining 3RM strength, per cm<sup>2</sup> CSA, was less in the older group for all muscle groups examined ( $16 \pm 6\%$  for elbow flexors,  $p < .02$ ;  $40 \pm 7\%$  for knee flexors,  $p < .001$ ;  $19 \pm 9\%$  for knee extensors,  $p < .05$ ). Mean training-induced increases in muscle CSA were less in the older group for elbow flexors ( $22 \pm 4\%$  in young,  $9 \pm 4\%$  in old,  $p < .05$ ) and knee flexors ( $8 \pm 2\%$  in young,  $1 \pm 2\%$  in old,  $p < .01$ ), but not for knee extensors ( $4 \pm 1\%$  in young,  $6 \pm 2\%$  in old). Mean training-induced increases in specific tension (ratio of 3RM strength to CSA) were similar in young and old groups for elbow flexors ( $21 \pm 5\%$  in young,  $19 \pm 5\%$  in old) and knee extensors ( $38 \pm 6\%$  in young,  $32 \pm 14\%$  in old), but were greater in the older group for knee flexors ( $28 \pm 5\%$  in young,  $64 \pm 13\%$  in old,  $p < .02$ ).

**Conclusions.** Aging can attenuate the hypertrophic response of muscle groups to resistance training, when the training load is proportional to baseline strength. However, aging does not impair training-induced increases in specific tension.

THERE has been much interest in recent years in the potential of resistance exercise to improve strength and increase muscle mass in older people, as a way to minimize frailty and enhance the ability to function independently. Several studies have demonstrated that progressive resistance exercises produce strength gains and muscle hypertrophy in older people (1–13). However, it is not clear whether or not aging influences the ability of muscle to respond to resistance training. Moritani and deVries (14) reported that gains in strength in young subjects after an 8-week progressive resistance training program resulted from both hypertrophy and neural factors, whereas strength gains in older subjects in the same type of exercise program occurred without muscle hypertrophy. In that study, muscle hypertrophy was assessed by imprecise anthropometric measurements. Subsequent studies using more precise methods have demonstrated muscle hypertrophy after resistance training in older people (1–10). However, these studies have not directly compared the responses of older subjects to those of young subjects who participated in the same exercise program. Thus, it is possible that older subjects must train harder to achieve the same level of muscle hypertrophy as young subjects. To test the hypothesis that older subjects have a diminished exercise-induced muscle hypertrophy, we used magnetic resonance imaging (MRI) to determine the cross-sectional areas (CSA) of the thigh and upper arm muscles before and after a 3-month progressive resistance exercise program in young and old men and women.

## METHODS

**Subjects.** — Nine young (22–31 years old) and eight old (62–72 years old) volunteers had MRI studies before and after the resistance training program. There were four women included in each age group. All were normotensive nonsmokers who were healthy as judged by medical history, physical examination, resting electrocardiogram, chest X-ray, and laboratory tests (glucose tolerance test, TSH, T4, creatinine, electrolytes, liver enzymes, creatine kinase, hematocrit, complete blood count, albumin, and total protein). The young and old groups were similar in mean height ( $172 \pm 3$  cm in young group,  $172 \pm 4$  cm in old group) and body weight ( $69.1 \pm 4.5$  kg in young group,  $71.6 \pm 5.6$  kg in old group).

All procedures and risks were explained to the subjects, verbally and in a written consent form, before any procedures were done. Written consent was obtained from all subjects. The research was approved by the University of Rochester Research Subjects Review Board.

**Protocol.** — Subjects were admitted to the University of Rochester Clinical Research Center (CRC) for various baseline tests of body composition, protein metabolism, and strength. Data on total lean body mass, protein metabolism, and 3RM strength (not adjusted for muscle CSA) have been presented in a separate paper (15). The baseline MRI study was done during this CRC admission, which was about two

weeks ( $16 \pm 2$  days in young group,  $14 \pm 1$  day in old group) before the baseline 3RM testing. The exercise program started within 3 days of the baseline 3RM testing, and lasted for 3 months. The second MRI study was done within 1–2 days after the final exercise session. The final 3RM testing was done  $12 \pm 3$  days before the second MRI study in the young group, and  $12 \pm 1$  day before the second MRI study in the old group.

**Resistance training program.** — Before starting the exercise program, subjects had tests of 3RM strength for evaluation of strength gains and for the determination of the initial training load. Testing was done on four Universal (Cedar Rapids, IA) weight machines: elbow flexion, knee extension, knee flexion, and lateral pulldown. Baseline 3RM tests were done on two occasions separated by at least two days, and subsequent tests were done once each month. After instruction about proper breathing and lifting techniques, subjects warmed up with a small load on each machine. They were then asked to lift the weights on each machine three times without resting between lifts. Subjects were instructed to lift the weight smoothly and slowly over the full range of motion, over a 2- to 3-second period, and to lower the weight slowly. They were allowed to rest as desired between sets. Weights were added to each machine until a subject could not complete the three lifts with good form. The highest weight achieved with good form on either baseline day was recorded as the initial 3RM. Small weights (1.1 and 2.3 kg) that could be added to the standard weight stacks were used to enhance resolution in the weaker subjects, but 4.5 kg increments were used for the stronger subjects.

Subjects exercised every Monday, Wednesday, and Friday for 3 months. Each session was supervised by one of the investigators. After stretching and warming up with small loads, they performed 3 sets of 8 repetitions on each of the machines used for 3RM testing. Subjects did one set on each machine before repeating a set. The initial load was the available weight nearest to 80% of the 3RM. Every week the load was increased by 5–10% for the first set. If the subject could perform 8 lifts in the first set with the new weight, this heavier load was used for training for the entire week even if the subject could not complete 8 lifts in the second and third sets. Subjects were instructed to not change their usual activities, except for the resistance training, and to maintain their usual eating habits.

**Muscle CSA and specific tension.** — Images of the right upper arm and thigh were acquired with a 1.5 Tesla clinical imager (GE Signa, Milwaukee, WI) using a body coil as the transmitter and a specially designed surface coil as the receiver. True axial images of the upper arm were acquired from the level of the humeral head to the level of the humeral condyle using TR/TE of 800ms/20ms,  $256 \times 192$  matrix, variable field of view depending on the size of the subject, 5 mm slice thickness, 5 mm interslice cap, and one excitation. True axial images of the thigh were obtained from the level of the femoral head to the level of the femoral condyle using the parameters listed above for the upper arm. Areas were determined by digitizing the MRI and manually outlining the

muscles on the image appearing on the video terminal of the computer system (Microcomputer Imaging Device, Imaging Research, St. Catharines, Ontario, Canada). The same investigator performed all of the muscle traces. Bone, visible blood vessels, and fat deposits were excluded, but fat deposits that were too small to accurately trace with the imaging software were included in the muscle areas. For each muscle group we used the image that represented the maximal CSA. The elbow flexor compartment included the biceps brachii and the brachialis muscles (6). The knee flexor compartment included the biceps femoris (long and short heads), the semitendinosus, and the semimembranosus muscles (16). The knee extensor compartment included the vastus lateralis, vastus intermedius, vastus medialis, and rectus femoris muscles.

Specific tension was defined as the ratio of 3RM strength to maximum CSA of the relevant muscle group. The 3RM strength was determined by the weight lifted with both right and left arms or legs, whereas CSA was measured only on the right side. For the purpose of calculating the specific tension, we assumed that half of the weight was lifted by the right side. Although this procedure would have caused an underestimation of true specific tension if the right side was dominant, it should not have caused any bias with respect to the relative effect of age on specific tension.

**Statistical analysis.** — Analysis of variance was performed using the general linear model procedure of the SAS/STAT software package (SAS Institute, Cary, NC). Between-subjects factors were age (entered as a discontinuous variable, i.e., young or old) and gender. Gender was used in the model to account for the variance associated with the large differences in muscle mass and strength between men and women, but the effects of gender were expected and are not reported in the results. Resistance training (pretraining vs posttraining) was a repeated-measures (within-subject) factor. Using this model, a difference in the response to training between young and old groups yielded a significant Age  $\times$  Training interaction. The effects of training on muscle CSA and specific tension (the ratio of 3RM strength to muscle CSA) also were expressed as percentage changes, in which case a difference in response to training between young and old groups yielded a significant main effect of age group. The data are presented as the mean and standard error. A *p*-value of  $< .05$  was considered to be statistically significant.

## RESULTS

Before training, there were no significant differences between age groups in the mean CSA of the elbow or knee flexors (Table 1). However, the mean knee extensor CSA was 22% less in the older group (Table 1). The baseline specific tension was significantly less in the older group for all muscle groups (Table 2).

Attendance at the training sessions was 97% in the young group and 94% in the old group. During the sessions that were attended, young subjects completed an average of  $92 \pm 1\%$  of the scheduled repetitions on the elbow flexion machine,  $98 \pm 1\%$  on the knee extension machine, and  $92 \pm 1\%$  on the knee flexion machine. Older subjects com-

Table 1. Muscle Cross-sectional Area

		Pretraining	Posttraining
Knee extensors	Young	69.5 ± 4.9	72.0 ± 4.8
	Old	54.0 ± 6.4	57.9 ± 7.5
Knee flexors	Young	35.4 ± 1.8	38.2 ± 2.0
	Old	35.8 ± 4.4	35.8 ± 4.0
Elbow flexors	Young	17.6 ± 1.7	21.5 ± 2.2
	Old	17.1 ± 2.4	18.4 ± 2.4

Notes: Values are cm<sup>2</sup>, mean ± one standard error. Significant ( $p < .05$ ) age effects by ANOVA: pre- and posttraining knee extensors, posttraining elbow flexors. Significant ( $p < .005$ ) training effects by ANOVA: all muscle groups. Significant ( $p < .05$ ) Age × Training interaction: elbow and knee flexors.

Table 2. Specific Tension

		Pretraining	Posttraining
Knee extensors	Young	.63 ± .03	.87 ± .03
	Old	.51 ± .06	.63 ± .04
Knee flexors	Young	.46 ± .02	.59 ± .04
	Old	.28 ± .03	.43 ± .03
Elbow flexors	Young	.61 ± .03	.73 ± .03
	Old	.51 ± .02	.60 ± .02

Notes: Values are one half of 3RM (kg) per cm<sup>2</sup> CSA, mean ± one standard error. 3RM was divided by 2 to estimate specific tension because both right and left muscle groups were involved in lifting weight. Significant ( $p < .05$ ) age effects by ANOVA: all muscle groups pretraining and posttraining. Significant ( $p < .001$ ) training effects by ANOVA: all muscle groups. Significant ( $p < .05$ ) Age × Training interaction: knee extensors.

pleted an average of  $95 \pm 1\%$  of the scheduled repetitions on the elbow flexion machine ( $p < .05$  vs young),  $99 \pm 1\%$  on the knee extension machine ( $p < .10$  vs young), and  $98 \pm 1\%$  on the knee flexion machine ( $p < .01$  vs young). As illustrated in Figure 1, the training load as a percentage of the 3RM (which progressively increased during training) was similar in young and old groups throughout the study. Because of the reduced strength per cm<sup>2</sup> CSA in the older subjects, their mean absolute training load (defined as the total amount of weight lifted over 3 months of training divided by CSA [mean of initial and final]) was less than that of the younger group (Table 3).

The mean increases in the CSAs of the elbow and knee flexors after 3 months of training were significantly less in the older group than in the younger group, whether expressed as the total increase in cm<sup>2</sup> (Table 1) or as a percentage increase (Figure 2). Elbow flexor CSA increased  $22 \pm 4\%$  in the young group and  $9 \pm 4\%$  in the old group ( $p < .05$ ). Knee flexor CSA increased  $8 \pm 2\%$  in the young group and  $1 \pm 2\%$  in the old group ( $p < .01$ ). However, there was not a significant effect of age on the hypertrophic response of the knee extensors (Table 1, Figure 2). Knee extensor CSA increased  $4 \pm 1\%$  in the young group and  $6 \pm 2\%$  in the old group ( $p = .29$ ).

The training-induced increase in the specific tension of the elbow flexors was not affected by age, whether data were analyzed as unadjusted changes (Table 2) or as percent

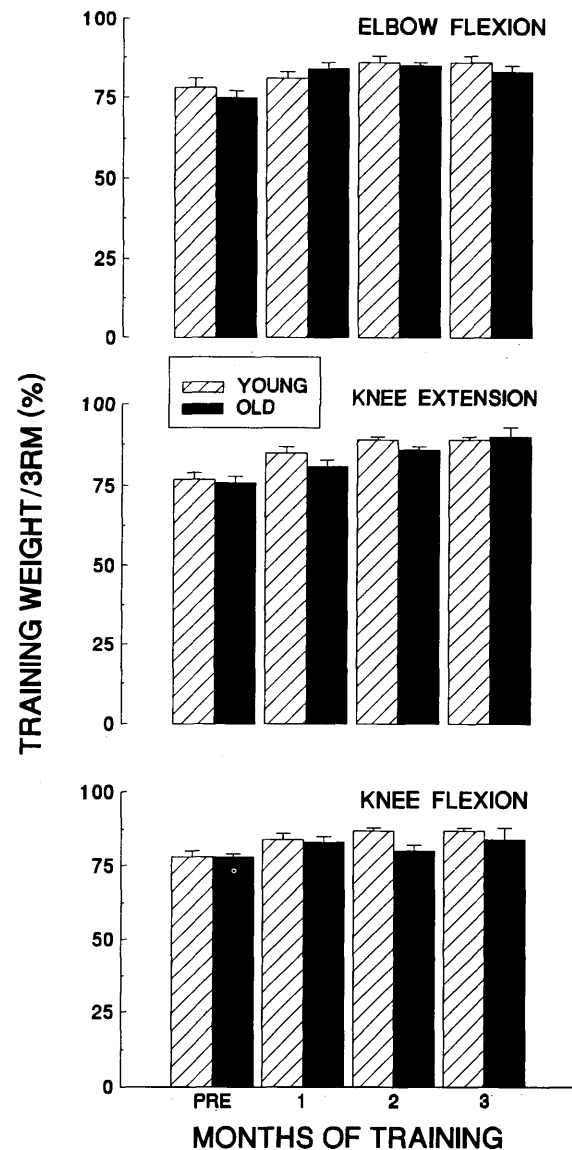


Figure 1. Mean ratio of training weight to 3RM strength of elbow flexors, knee extensors, and knee flexors at the beginning of the training program (PRE), and after 1, 2, and 3 months of training in 9 young and 8 old subjects. Error bars are one standard error of the mean.

changes (Figure 3). Elbow flexor specific tension increased  $21 \pm 5\%$  in the young group and  $19 \pm 5\%$  in the old group. Conclusions about the effect of age on the training-induced increase in the specific tension of the knee extensors and flexors depended on whether the data were analyzed as unadjusted changes or percent changes. The increase in knee flexor specific tension was similar in young and old groups ( $p = .38$  for Age × Training interaction, Table 2). However, because the older group had a substantially reduced specific tension before training, the percent increase in knee flexor specific tension was greater ( $p < .02$ ) in the older group ( $64 \pm 13\%$ ) than in the younger group ( $28 \pm 5\%$ , Figure 3). The unadjusted increase in knee extensor specific tension was greater in the younger group ( $p < .05$  for Age ×

Table 3. Training Load

	Young	Old
Knee extensors	595 ± 22	468 ± 40
Knee flexors	421 ± 31	288 ± 23
Elbow flexors	521 ± 22	420 ± 21

Notes: Values are total kg of weight lifted during the 3-month training period, per cm<sup>2</sup> CSA (mean of initial and final CSA), assuming right muscle group lifted one half of the weight. Significant age effects by ANOVA ( $p < .01$ ): all muscle groups.

Training interaction, Table 2), but there was no significant age effect ( $38 \pm 6\%$  in young,  $32 \pm 14\%$  in old,  $p = .68$ ) when data were expressed as the percent increase (Figure 3).

#### DISCUSSION

There is general agreement that strength declines with aging (16–23). However, there is some debate regarding whether or not the loss of strength can be explained exclusively by the reduction in muscle mass. Although most studies have indicated that the decrease in strength in older subjects is greater than what would be expected from the decrease in muscle mass (16–21), this finding is not universal (22,23). In the present study the ratio of 3RM strength to muscle CSA was significantly less in older subjects than in young adults. This finding was consistent for all three muscle groups that were examined. These data indicate that rejuvenating muscle function in older people requires not only increasing the muscle mass, but also increasing the specific tension of the muscle.

Several studies have demonstrated that resistance exercise can induce muscle hypertrophy in older people (1–10), but did not directly determine whether old muscles hypertrophy as much as young muscles when challenged with the same training regimen. One previous study had indicated that the elbow flexor muscles of older men have a diminished hypertrophic response to resistance training than elbow flexors of young men, but only an imprecise anthropometric method was used to estimate muscle CSA (14). We also observed smaller hypertrophic responses in the elbow and knee flexor muscles of older subjects in the present study. However, there was no reduction in the hypertrophic response of the knee extensor muscles of the older subjects. These results emphasize that the effect of age on responses to exercise in one muscle group cannot be generalized to all muscle groups.

The reason that knee extensor hypertrophy was not affected by age, whereas elbow and knee flexor hypertrophy was diminished in older subjects, is not clear. All of these muscle groups had a diminished specific tension in older subjects before training started, but only the knee extensors had a smaller CSA in the older group. The difference in the training load between young and old groups was similar for elbow flexors and knee extensors (Table 3), so that this factor seems to be an unlikely explanation for the different results obtained in these muscle groups. One possible explanation is that the younger subjects lifted the weights on the elbow and knee flexion machines to momentary fatigue more often than the older subjects, as reflected by the lower

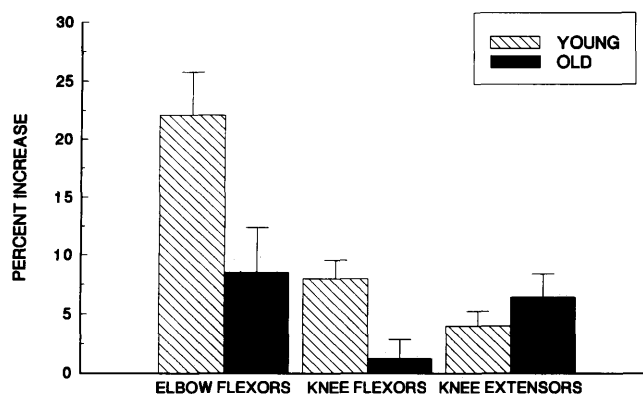


Figure 2. Mean percent increase in CSA of elbow flexor, knee extensor, and knee flexor muscles after a 3-month resistance training program in 9 young and 8 old subjects. Error bars are one standard error of the mean.

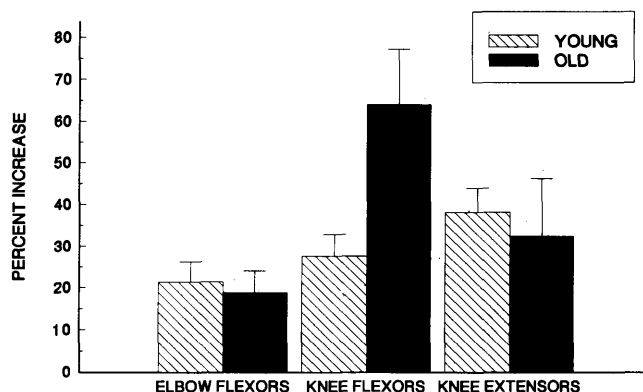


Figure 3. Mean percent increase in the specific tension (ratio of 3RM strength to muscle CSA) of elbow flexor, knee extensor, and knee flexor muscles after a 3-month resistance training program in 9 young and 8 old subjects. Error bars are one standard error of the mean.

percentage of scheduled lifts that were completed by younger subjects. In contrast, lifting to momentary fatigue on the knee extension machine was relatively infrequent in both age groups. In other words, the degree of effort exerted on the elbow and knee flexion machine might have been greater in the younger group. The fact that the ratio of training weight to 3RM (Figure 1) was not different in young and old groups does not prove that there was no difference in the degree of exertion, because it is conceivable that the older subjects tended to exert less effort than young subjects during the 3RM tests. Relative exertion is difficult to evaluate and could be influenced by a number of factors, including motivation and fear of injury or pain.

It is not clear whether the diminished hypertrophic response of the elbow and knee flexors of the older subjects represents a true difference in the capacity for muscle hypertrophy. It is possible that the degree of muscle hypertrophy would have been the same in the young and old groups if the absolute training load, i.e., the amount of weight lifted per unit of CSA, had been the same in both groups. The average training load was less in the older group because the training load was proportional to baseline strength, which is the usual

method for determining how much weight should be lifted during resistance training. The difference in the total training load, as defined in the present report, may underestimate the true difference in the stimulus for hypertrophy, because undoubtedly there is a threshold for the amount of weight that must be lifted before any hypertrophy is induced (24). It is not possible to precisely calculate the age-related difference in the actual stimulus for muscle hypertrophy, because this threshold is unknown and could be different in the young and old groups. In order to determine whether aging diminishes the capacity for muscle hypertrophy, studies are required in which the amount of weight lifted per cm<sup>2</sup> CSA is the same in young and old groups.

The observation that elbow flexor hypertrophy was greater than knee extensor hypertrophy, particularly in young subjects, is consistent with previous reports. Using computed tomography (CT), Cureton et al. (25) found a 16–23% increase in upper arm muscle CSA after 16 weeks of resistance training in young men and women, but only a 3% increase in thigh muscle CSA. Elbow flexor hypertrophy after 3 months of resistance training in older subjects was 17% in a previous study that used CT to measure hypertrophy (1), and 23% in another study that used MRI to measure hypertrophy (6). These findings are comparable to the results observed in the young group in the present study, but no direct comparisons between young and old subjects were made in these previous studies. The elbow flexor training used by Roman et al. (6) was much more extensive than the training regimen used in the present study, which can explain why they observed greater elbow flexor hypertrophy in old subjects. Studies that used CT or MRI to measure knee extensor or total thigh muscle hypertrophy after 8 to 42 weeks of resistance training in older subjects have yielded results ranging from no significant effect to a 9% increase in muscle CSA (3,4,7–11,26), although a 13% increase was observed in a study in which a nutritional supplement was provided during training (10). Thus, the 6% knee extensor muscle hypertrophy in the older subjects in the present study was consistent with previous research.

Any conclusions about muscle CSA determined by MRI must be tempered by the realization that MRI does not directly measure myofibrillar mass. It is possible that there are age-related or training-related effects on muscle protein concentration, water content, connective tissue content, or fat deposition (not including the large, visible fat deposits). Thus, age or training effects on CSA could be related in part to factors other than myofibrillar mass. However, there is little evidence for any major change in the gross composition of muscle from healthy older people. Forsberg et al. (27) found that the amount of alkali-soluble protein and potassium, relative to fat-free dry weight, was only 3% less in muscle biopsy samples from 61- to 85-year-old subjects than in samples from 18- to 40-year-old subjects. They reported an increase in the amount of fat and extracellular water in the older muscle, but the magnitude of the change was enough to cause only a 4 to 5% reduction in the intracellular fat-free mass per gram of tissue. These results are compatible with our own unpublished observation that the amount of myofibrillar protein that can be recovered from muscle biopsies is not reduced in older muscle. Moreover, we have observed

no effect of age on the relation between MRI-derived muscle CSA and either urinary creatinine excretion or whole-body potassium content, both of which are related to intracellular muscle mass (28).

As expected, there was an increase in the specific tension of the muscles during the resistance training. This effect, which can be attributed to neural factors or learning (24), was similar in the elbow flexors and knee extensors of the young and old subjects, and was increased somewhat in the knee flexors of the older subjects. Thus, substantial strength gains can be achieved in older subjects even in the absence of muscle hypertrophy, as has been reported in other studies (11,26). A reduced hypertrophic response to weight lifting in older people therefore should not be used to argue against strength training in old age.

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