Adaptations in the elbow flexors of elderly males after heavy-resistance training

W. J. ROMAN, J. FLECKENSTEIN, J. STRAY-GUNDERSEN, S. E. ALWAY, R. PESHOCK, AND W. J. GONYEA

Departments of Cell Biology and Neuroscience and Radiology, and Human Performance Laboratory, University of Texas Southwestern/St. Paul's Hospital, University of Texas Southwestern Medical Center, Dallas, Texas 75235-9039

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(2): 750-754, 1993. The structural and functional characteristics of the elbow flexors in five elderly males were studied before and after 12 wk of heavy-resistance training. Muscle volume and cross-sectional area of two of the elbow flexors (biceps brachii and brachialis) muscles were determined by magnetic resonance imaging. Mean muscle fiber area, percent fiber distribution, and collagen and noncontractile tissue densities were determined on histological sections from needle biopsies. Isokinetic strength of the elbow flexors was measured at velocities between 60 and 300°/s. Muscle volume and cross-sectional area of the biceps brachii and brachialis significantly increased by 13.9 and 22.6%, respectively, after the training program. A preferential hypertrophy of type II fibers (37.2%) was observed. Significant increases in peak torque were observed at all the tested velocities. The amount of work a subject could perform during a 25-repetition test at 240°/s increased by 41% after training. These results demonstrate that the skeletal muscles of elderly individuals can adapt to heavy-resistance exercise and do so by increases in both muscle size and strength.

A REDUCTION in muscle mass and strength is evident in older individuals. Maximum grip strength of elderly males with a mean age of 79 yr was only one-half that observed in younger individuals with a mean age of 25 yr (7). Significant reductions in cross-sectional area (CSA) of type II fibers have been demonstrated in elderly individuals (15). A decrease in the proportion of type II fibers was observed in some (15) but not all investigations (14). This loss of muscular size and strength limits the functional capabilities of elderly individuals.

The goal of a resistance training program for elderly individuals should be to improve their skeletal muscle mass and strength so that routine daily tasks (i.e., lifting packages) are easier to perform. However, multiple studies (4, 20) have produced variable results and conclusions. Moritani and deVries (20) reported that the increase in strength of the elbow flexors of elderly males after 8 wk of resistance training was due primarily to adaptations in the nervous system, with little increase in muscle mass. Aniansson and Gustafsson (4) reported an increase in muscle strength and the proportion of type IIa and IIb fibers but found no significant change in mean fiber areas after training. Although these studies demonstrated that elderly individuals are capable of undergoing increases in strength, the peripheral adaptation (i.e., muscle hypertrophy) typically observed in young individuals after resistance training was not found (16, 18). However, peripheral adaptations may be duration or intensity dependent, which may explain why changes in muscle size were not observed in these studies. A more recent study, which employed a training regimen similar to the programs used by younger individuals, found a significant increase in the CSA of type I and II fibers of the vastus lateralis and a significant increase in the size of the quadriceps of elderly males after 12 wk of resistance exercise (12). Several studies examined the effect of resistance training in muscle of the lower extremities in elderly individuals (4, 12). Because it is not known what effect, if any, normal locomotion may have on the structural characteristics of muscles, we have chosen to investigate the elbow flexor muscle group. We assume that any changes that are found in the elbow flexors after training are the result of the training stimulus rather than any change in activity pattern of the subjects.

With the advent of magnetic resonance imaging (MRI), it is now possible to image an entire muscle and determine its volume. These measurements can be determined without exposing the subject to ionizing radiation, which would be the case if similar measurements were made using computer tomography. Typically, the relationship between muscle size and strength has been examined by relating the CSA measured at the greatest girth of the muscle to the force generated by the muscle. However, this could overestimate the force output from regions other than that with the greatest CSA. In addition, the use of only a single CSA introduces the potentially important issue of accuracy in localization in test-retest studies. This method may be prone to error depending on precisely where the CSA is obtained. Because muscle volume is the summation of all the axial CSAs of the muscle from origin to insertion, it may be a more accurate and functional measure of muscle size.

The purpose of this study was to investigate the effects of a heavy-resistance training program on muscle mass,
fber size, and muscle strength of the elbow flexors in elderly males. The training program employed in this study was similar to a typical body-building routine that emphasized the use of moderate to heavy weights and was specifically designed to increase muscle mass (1, 3). A secondary purpose of this study was to determine whether muscle volume or muscle CSA would be a better predictor of isokinetic strength.

METHODS

Subjects. Five elderly men with a mean age of 67.6 ± 2.3 (SE) yr, whose mean body height and weight were 169.4 ± 7.4 cm and 84.1 ± 8.4 kg, respectively, participated in the study. The percent body fat (determined by underwater weighing) of the subjects was 22.9 ± 4.5% and did not change after training. These five subjects were selected out of 20 volunteers because they met the following criteria: they 1) lived within a 20-mile radius of the university, 2) were free of any cardiovascular or neuromuscular disease, and 3) had no prior weight-training experience. Also, a survey taken before the study showed that they did not use their upper extremities more frequently than less active people. Each subject was informed of the testing and training procedures and any possible risk of the study before giving his written consent. All of the subjects were encouraged to maintain their normal lifestyles but not to participate in any extra weight-training activities. This study was approved by the Institutional Review Board of Human Subjects at the University of Texas Southwestern Medical Center at Dallas/St. Paul’s Hospital.

Training regimen. The subjects participating in the study were required to train the elbow flexor muscles 2 times/wk for 12 wk with a heavy-resistance training program. The training protocol consisted of four different types of exercises, including elbow flexion on the Cybex 340, barbell curls, dumbbell curls, and hammer curls (dumbbell curls with the hand in a semipronated position). Four sets of eight repetitions were performed on a Cybex 340 at the following velocities: 60, 180, 240, and 300°/s. The subjects also performed three sets of eight repetitions on a Cybex 340 at the neutral position with his right arm abducted 180° and positioned in the center of the coil. Image acquisitions spanned 40 cm without the necessity of subject movement. This scanning sequence allowed the entire length of the biceps brachii and brachialis to be imaged from insertion to origin. The CSAs of individual consecutive 10-mm slices were determined, and the sum of these values was used to calculate muscle volume.

The accuracy of measuring muscle volume in this manner was determined by imaging a cadaver limb and calculating muscle volume. After the imaging, the biceps brachii was removed and muscle volume was determined by water displacement. The brachialis was not included in this measurement because of the difficulty in removing the entire muscle from the humerus. The muscle volume determined by MRI was 3.7% greater than that calculated by water displacement. The reliability of the method (coefficient of variation) for determining individual CSAs of muscle volume for upper extremity muscles by use of the same procedure was 1.8% (11).

All magnetic resonance images were examined to determine the largest muscle CSA. This value was used for the CSA of the biceps brachii and brachialis.

Histochemistry. Tissue samples were obtained from the long head of the right biceps brachii using the needle biopsy technique (5). The muscle sample was oriented cross sectionally, mounted on a cork block in embedding medium, frozen in isopentane cooled by liquid nitrogen, and stored at -80°C for subsequent histochemistry. Transverse sections (10 μm) were cut in a cryostat (Reichert-Jung) and stained for myofibrillar adenosinetriphosphatase (ATPase) after preincubation in an alkaline (pH 10.2) medium. Fibers were classified as either type I or type II (10). The percentage of type I and type II fibers was determined from a photomicrograph of muscle biopsy cross sections stained for myofibrillar ATPase. All the fibers in each biopsy (723.0 ± 156.5) were counted. Muscle fiber CSA was determined by planimetry from a photographic montage of muscle biopsy cross section stained for ATPase (preincubation at pH 10.2) on a minimum of 200 fibers of each fiber type (1).

Nonmuscle and connective tissue. The volume density of collagen and other noncontractile tissue was calculated from transverse sections (10 μm) stained with Gomori's trichrome (13) on a 121-point grid lattice according to standard stereological techniques (23) and in a manner similar to previous studies from this laboratory (1, 3).

Muscular strength. Dynamic voluntary strength of the right elbow flexors was measured with an isokinetic dynamometer (Cybex 340). The subject was tested with the hand in the neutral position. Three maximal voluntary contractions were performed to determine peak torque at angular velocities of 60, 180, 240, and 300°/s. The subject was instructed to begin each maximal contraction with the elbow fully extended and to continue through the full range of movement. There was a 1-min rest period between each tested velocity. Maximal isokinetic pretraining strength measurements were performed on two different occasions separated by ≥3 days. The higher value tested for each velocity was used as the pretraining value. Posttraining strength measurements were made at the end of the training period. The total work a subject could perform was determined by a 25-repetition test con-
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FIG. 1. Peak torque of elbow flexors (means ± SE of 5 elderly males) was determined on an isokinetic dynamometer at velocities of contraction between 60 and 300°/s before (pre) and after (post) 12 wk of heavy-resistance training. Posttraining peak torque values were significantly greater at all tested velocities compared with pretraining values.

ducted at an angular velocity of 240°/s. Isokinetic torque was corrected for the moment of inertia due to gravity in the upper arm. The impact artifact was not included in the measurement of maximal torque. A one-repetition maximum was not performed because of possible cardiovascular complications and/or joint problems that can occur as a result of a maximum lift with free weights.

Data analysis. Statistics include means ± SE. A Wilcoxon signed-rank test was performed to detect differences between pre- and posttraining data for muscle volume, muscle CSA, fiber CSA, and torque output of the elbow flexor muscle group. P < 0.05 was selected to indicate statistical significance.

RESULTS

Muscular strength. Peak torque significantly increased at all the tested velocities after training. There was a 47.9 ± 5.1% increase in peak torque occurring at 300°/s, a 44.6 ± 4.2% increase at 240°/s, a 36.0 ± 6.9% increase at 180°/s, and a 23.0 ± 5.1% increase at 60°/s (Fig. 1). The total amount of work a subject could perform, measured by the 25-repetition test at 240°/s, was 800.2 ± 26.3 ft lb. before training and 1,010.8 ± 72.4 ft lb. after training, a 28.6% increase.

Muscle volume and CSA. The combined muscle volume of the biceps brachii and brachialis significantly increased from 359.8 ± 28.1 to 409.4 ± 23.9 cm³ (13.9%) after the training program (Fig. 2). Although the greatest increase in CSA was observed at the point of maximal girth of the muscle [24.2 ± 1.8 to 29.4 ± 1.7 cm² (22.6%)], it was observed that the CSA may vary as much as 12% on contiguous images in this region. The slice-to-slice variation was greater distally near the elbow, where the greatest variation was 73%.

Fiber type distribution. The percentages of type I and type II fibers in the biceps brachii were 62.6 ± 3.7 and 37.4 ± 3.5%, respectively. There was no significant change in fiber distribution after training.

Mean fiber area. Mean fiber area averaged 5,401.7 ± 819.6 µm² for type I and 5,929.0 ± 499.4 µm² for type II fibers before the training period. After the resistance exercise program, type II fiber area significantly increased (37.2%). Although type I fiber area increased by 24.0%, this increase was not significant (Fig. 3).

Nonmuscle and connective tissue. The volume density of collagen and other noncontractile tissue was 12.0 ± 0.4% and did not change from the pretraining to the posttraining period.

DISCUSSION

Structural changes can significantly affect the physiological function of skeletal muscle in elderly individuals. If resistance training programs prove to offset, in part, some of the negative changes that occur in skeletal mus-
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Individuals after resistance training. It is likely that the overload presented to the muscle in previous studies was not sufficient to induce hypertrophic changes (4, 20). In contrast, our data suggest that significant increases in muscle mass and isokinetic strength can occur in elderly men after a heavy-resistance training program. Although a possible limitation of the present study may be the lack of a nontraining control group, we assume that the large changes in muscle structure and function were the result of our experimental intervention.

The training program used in our study was similar to a typical body-building routine, utilizing moderate to heavy weights to increase muscle mass. Extreme muscle hypertrophy is evident in elite body builders who have engaged in many years of vigorous weight training. Their training regimen primarily consists of working a muscle group 2 or 3 times/wk with ~8–12 sets of exercises (1). Similar training programs have also been successful in significantly increasing muscle size and strength of college-aged males after 3 mo of training (8, 15). Two factors that appear necessary for producing adaptive changes (i.e., hypertrophy) in skeletal muscles are the number of sets and repetitions performed and the intensity used in each training session.

Changes in muscle size after training have traditionally been determined by CSA measurements (6, 12). Our study examined changes in muscle size after training with muscle volume measurements determined from MRI. Our results showed a significant 13.9% increase in size of the elbow flexors when determined by volume measurements but a 22.6% increase in CSA (greatest girth) after training. These data demonstrate that, in the elbow flexors, muscle CSA gives a larger estimate of muscle mass changes than muscle volume measurements after training. In another study, Brown et al. (6) found a significant increase (17.4%) in the CSA of the biceps brachii and brachialis after 12 wk of resistance training in elderly males; this change likely overestimates changes in muscle size. In contrast to these studies, Moritani and deVries (20) found no change in the muscle CSA of the upper extremity in elderly men after 8 wk of training. However, they demonstrated a significant increase in muscle CSA in a group of college-aged male subjects. One possible explanation for the discrepancy between their results and those in our study may be that the training duration in their study was not long enough to elicit changes in elderly individuals. Also, the training intensity in the study by Moritani and deVries may have been too low (20).

The method used to determine muscle size (i.e., muscle volume vs. CSA) may affect the correlations between muscle size and strength. The relationship between muscle size and strength has typically been examined by relating the CSA measured at the midbelly of the upper arm to the force generated by the muscles. However, there may be a problem in using the CSA determined at the greatest girth of the muscle, because it may overestimate the CSA determined at points other than that of greatest girth. By measuring muscle volume we were able to measure the entire size of the biceps brachii and brachialis from origin to insertion. Although the small number of subjects prevented us from determining whether the relationship between muscle volume and strength is greater than that between muscle CSA and strength, we hypothesize that future experiments will show a stronger relationship between strength and muscle volume. This is predicated on the fact that the total torque produced by a muscle is an average of the torques produced by all the CSAs of the muscle. Because muscle volume takes into account the entire muscle, there should be a greater correlation between it and muscle strength.

Our results also suggest that muscle volume may be a more accurate method for determining changes in muscle size after training. We found a 12–18% difference between the CSA of consecutive magnetic resonance images at midarm and a maximum difference of 73% between any two consecutive slices. This may suggest that a portion of the increase in muscle size (determined from a single CSA) could be the result of where the CSA was acquired.

Previous investigations examining the cellular adaptations (e.g., muscle fiber CSA) in skeletal muscle of elderly individuals after resistance training have demonstrated conflicting results. Aniansson et al. (4) found no increase in fiber CSA but did observe an increase in the proportion of type Iib fibers. The training protocol employed in their study required the subjects to perform exercises using their own body weight as resistance. This type of training may not have provided the necessary stimulus for muscle hypertrophy to occur. In contrast, others have found significant increases in the CSA of both type I and type II fibers after training (6, 12). The 37% increase in type II fiber area and 24% increase in type I fiber area in our study demonstrate that the skeletal muscle of elderly individuals is capable of adapting to an intense weight training program by increases in muscle CSA and fiber size and that it may do so to an extent similar to that reported for younger individuals (8, 18).

The preferential increase in type II fiber CSA observed in this study is similar to what others (18) have found in college-aged males after training. Selective hypertrophy of type II fibers has also been observed in the biceps, triceps, and quadriceps of strength-power athletes and elite body builders (1, 3, 17, 22). However, not all studies have found preferential type II hypertrophy. Alway et al. (2) observed no significant difference between type I and type II fibers in the lateral and medial gastrocnemius of males after resistance training, whereas the soleus did have selective type II hypertrophy. These data suggest that preferential type II fiber hypertrophy may be muscle or training specific. Increases in type I CSA have also been observed in the quadriceps muscle of elderly individuals (12).

Significant increases in isokinetic strength were observed at all of the velocities tested. Although the percent change in strength from pre- to posttraining was greater than what has been observed by others (4, 11), this may be because isokinetic exercises were included in the training program so that the subjects became familiar...
with this equipment. Alternatively, the body-building regimen used in this study may have provided a more intense stimulus for neuromuscular adaptation than that used in previous studies. These data show that elderly individuals are capable of significant increases in muscle size and strength in their upper limbs provided that the intensity and duration of the resistance training program are sufficient.

In summary, a heavy-resistance training program of sufficient duration and intensity, designed to increase muscle mass by using moderate to heavy weights, can produce changes in the structural and functional characteristics of the skeletal muscle of elderly individuals. Also, this study used muscle volume measurements determined by MRI to examine changes in muscle size after resistance training. We showed that the use of only a single CSA may be subject to error in test-retest studies. The muscle volume measurements in this study were lower than the largest CSA for the trained muscles and may reflect a more functional measurement.

Present addresses: W. J. Roman and S. E. Alway, Dept. of Exercise Science, School of Physical Education and Recreation, The Ohio State University, Columbus, OH 43210; J. Stray-Gundersen, Tom Landry Sports Medicine Research Center, Dallas, TX 75246.

Address for reprint requests: W. J. Gonyea, Dept. of Cell Biology and Neuroscience, UTSMC at Dallas, 5323 Harry Hines Blvd., Dallas, TX 75235-9099.

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