Effects of Short-Term Resistance Training on Muscle Strength and Morphology in the Elderly


Ten moderately active participants (8 women, 2 men; mean age 66.3 ± 1.2 years), engaged in 8 weeks of isometric knee-extensor resistance training. Afterward, peak torque output (180°/s) and mean power increased 30.8% and 27.2%, respectively, in the experimental limb (EL). A moderate, nonsignificant cross-over training effect was observed in the contralateral untrained limb (CL) for the same measures. Whereas mean fiber cross-sectional area (CSA) was unaltered in the CL by training, Fiber Types I and IIb in the EL displayed increased CSA. However, mean CSAs for all fiber types in the trained EL were no larger (p > .05) than those observed in the CL before or after training. There were no significant changes in muscle-fiber-type composition, the proportion of Type I myosin heavy chain, or Type IIa CSA. These data suggest that short-term resistance training can significantly increase isokinetic peak torque in the elderly, with minimal changes in the histochemical and biochemical parameters examined.

Key Words: fiber type, fiber cross-sectional area, one-legged training

Significant increases in the strength of skeletal muscle in the elderly after resistance training have been reported (Charette et al., 1991; Frontera, Meredith, O’Reilly, Knuttgen, & Evans, 1988; Pyka, Lindenberger, Charette, & Marcus, 1994). Many authorities have suggested that resistance training might arrest or reverse age-related losses in strength and, consequently, maintain or increase independence (for reviews, see Porter, Vandervoort, & Lexell, 1995; Thayer, Rice, Pettigrew, Noble, & Taylor, 1993). In studies of moderate to long duration (12 weeks to >1 year) employing elderly participants, significant strength gains have been reported and attributed in part to hypertrophy of muscle fibers (Brown, McCartney, & Sale, 1990; Charette et al.; Frontera et al.; Pyka et al.). However, the contribution of fiber hypertrophy to short-term strength gains is less clear.

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Moritani and deVries (1980) reported significant increases in strength after short-term (8 weeks) training in both young and old participants, with an absence of muscle hypertrophy in the latter group. They concluded that the effect of muscle training on the elderly might rest entirely on neural factors. In one study of 90-year-olds, computed tomography scans revealed a 9% increase in thigh cross-sectional area (CSA) after 8 weeks of strength training (Fiatarone et al., 1990). If nonagenarians are capable of hypertrophy after short-term training, why then did the comparatively younger participants (70 years old) of Moritani and deVries fail to exhibit such a response? Researchers reporting hypertrophy have used direct measures of muscle CSA and/or biopsy sampling, whereas Moritani and deVries employed data derived from skinfolds and girths of the elbow flexors. The latter methods have been criticized as lacking the sensitivity required to detect changes in CSA (Welle, Tottermann, & Thornton, 1996), which could have resulted in the reported absence of hypertrophy.

Recently, Taaffe and Marcus (1997) demonstrated the effects of short-term (8 weeks) retraining on muscle strength and fiber characteristics of elderly participants after 24 weeks of training and 12 weeks of detraining. Although detraining resulted in a 30% loss of initial strength gains, resumption of training resulted in a return of strength to trained values. Types I and II fiber CSA reverted to pretraining values after detraining and were unchanged after retraining. Thus, the reacquisition of lost strength with retraining reflected neural adaptation (Taaffe & Marcus). Because biopsy samples were not taken during the initial 8 weeks of training, however, the contribution of nonhypertrophic changes during the initial strength gains could not be estimated.

Resistance training might alter the contractile protein composition in addition to its effects on CSA. It has been reported that lifelong resistance training results in a significantly lower proportion of Type I myosin in skeletal muscle of the elderly (Klitgaard et al., 1990a). To our knowledge, however, no comparable data are available on the influence of short-term resistance training. Therefore, the aim of the present study was to examine muscles of elderly participants after an 8-week resistance-training regimen, using information provided by biopsy sampling to assess the extent of change in selected muscle-fiber characteristics.

Methods

Participants

Ten moderately active (i.e., partaking in recreational physical activity), healthy elderly participants (8 women, 2 men; mean age 66.3 ± 3.8 years, range 60–72 years) with no history of participation in a vigorous exercise program volunteered to participate in this study. The protocol was approved by the Ethics Committee for Research on Human Subjects at Lakehead University. Inclusion criteria mandated an age of 60 years or greater, medical approval by the family physician to engage in a resistance-training program, a willingness to undergo muscle biopsies, and an ability to attend regular exercise sessions. Potential participants with hip or knee replacements, previous hip fracture, or significant arthritis (requiring a cane for ambulation) were excluded.
RESISTANCE TRAINING AND STRENGTH TESTING

Before commencement of the study, participants were familiarized with the testing/training equipment during three orientation sessions. For each participant, the leg that achieved the higher value during isokinetic testing acted as the control (CL). The contralateral leg (EL) was subjected to the strength-training program.

The strength of the quadriceps muscles was tested unilaterally on the Cybex II dynamometer (Lumex Corporation, New York, NY) before and after training. Torque calibration was verified before each testing session using known loads. During the test, the participant did not grip the machine and was seated erectly, with only the thigh stabilized with straps. The length of the dynamometer arm was recorded during the pretesting for each participant and reset to the same length for the posttesting session. Efforts were initiated from a knee-flexed position of 90°, and isokinetic strength was tested at a constant angular velocity of 180°/s. In order to reduce the effects of limb acceleration or deceleration, peak torque was measured between 15 and 75°. Participants performed two sets of four maximal repetitions, with a 2-min recovery period between sets (Grimby et al., 1992). In order to verify test–retest reliability, strength tests were repeated (48 hr apart) during both pretraining and posttraining testing sessions. For reliability analysis, intraclass correlation coefficient estimates for test–retest stability (reliability) ranged from \( \rho = .84 \) to \( \rho = .95 \) (\( p < .05 \)).

Peak torque (N-m) was defined as the maximum value of torque over four repetitions. Mean power (N-m-radians/s) values were determined by multiplying the total torque produced throughout a range of motion (work) by the limb velocity, and then dividing by the time required for the movement. Although both flexion and extension strength data were examined, participants considered flexor testing to be technically difficult, so we chose not to include these data. We speculated that these gains might, in part, reflect a learning rather than a training effect.

RESISTANCE-TRAINING PROGRAM

The resistance-training program took place over a period of 9 weeks, wherein a total of 25 workout sessions was completed. Training sessions took place three times per week, with each session lasting approximately 1 hr. Training sessions included a warm-up period (15 min), an exercise period (35 min), and a cool-down period (10 min). Warm-up and cool-down periods included stretching and walking and/or low-intensity riding on a stationary bicycle. All participants began the training program simultaneously. Participants performed unilateral knee extensions and knee curls on pin-selected resistance machines with weight increments of 4.5 kg. These machines were chosen for training because of their availability and simplicity of use. Because of the large weight increments, however, they were considered unsuitable for assessing strength because substantial relative gains could be made without a change in setting. Consequently, isokinetic dynamometry was chosen as the method of testing. One female participant withdrew from one training session because of a mild muscle strain. Notwithstanding, protocol compliance was excellent—the remainder of participants completed all scheduled sessions.

The training program was intended to provide an overload stimulus for the quadriceps muscles. During the first 3 weeks of the program, participants completed
three sets of each exercise. In the following weeks, participants adapted to the training regimen, and the required number of sets increased to four (Weeks 4–6) and five (Weeks 7 and 8). Each set was completed using 10 repetitions of the exercise, except for the final set of each session, which was completed until failure of concentric contraction. Training sets were separated by 2-min rest periods. After successful completion of 15 or more repetitions on the final set of an exercise session, the resistance was increased one increment (e.g., 4.5 kg) at the start of the next session. Resistance was adjusted primarily by increasing repetitions rather than resistance setting because of the relatively small load (9–18 kg, or <5 plates) and comparably large weight increments. During the exercises, participants were asked to execute the concentric phase of each repetition in less than 1 s, and the eccentric phase over 2 s. Actual time was not measured, however, and therefore might have been slower in some participants in some instances.

FIBER-TYPE DISTRIBUTION AND CROSS-SECTIONAL AREA

Biopsy samples (30–60 mg) were taken from both thighs of each participant before the training program (Week 0) and at its completion (Week 9). The biopsies were obtained from the vastus lateralis, as described by Bergstrom (1962). Samples were frozen in 2-methyl butane and stored in a temperature-controlled cabinet at −80°C. Histochemical procedures were performed to determine the fiber-type distribution and fiber CSA in the muscle. The muscle sample was sectioned in a cryostat at −20°C (Lauda Kryostat 1620 Digital, Leitz, Germany). Serial cross-sections (10 mm thick) were cut and stained for myofibrillar ATPase after acid and alkaline pre-incubations (pH 4.3 and 4.6 for 1.0 min and pH 10.3 for 10.0 min) in order to differentiate between Fiber Types I, IIa, and IIb (Brooke & Kaiser, 1970). The percentages of fiber types were estimated by counting approximately 25–30 fibers in each of eight regions evenly distributed throughout the muscle cross-sections (Ianuzzo & Chen, 1979). Planimetric measures of fiber CSA were calculated from images obtained by video camera (Sony UP-3000) of slides examined on a Zeiss Scientific Light Microscope (Zeiss 63173, Germany). Images were projected onto a color monitor and analyzed using Quantimet 520 image-analysis software (Leica Instruments, Cambridge, England) on a Compac 386DX (Compaq, U.S.A.) computer. Muscle fibers selected for measurement were free of artifact, had distinct cell borders, and, when possible, were centrally located in the sample (Bloomstrand, Celsing, Friden, & Ekblom, 1984). An average of 200 or more fibers of each muscle sample (Bloomstrand et al.) were classified by fiber type and quantified in terms of CSA (mm²) by a single investigator. Slide labels were concealed to keep the investigator from knowing initial/final and experimental/control biopsy status.

TYPE I MYOSIN HEAVY CHAIN

Muscle samples weighing 20–40 mg were added to 40 volumes of 15-mM Tris buffer, 600-mM NaCl containing 1/200th volume each of 0.2-M phenylmethylsulfonyl fluoride in ethanol, 0.2-mg/ml Pepstatin A in ethanol, and 0.1-mg/ml leupeptin in double-distilled H₂O. Samples were homogenized on ice with a Polytron homogenizer for 30 s and centrifuged at 5,000 g for 10 min at 4°C, and the supernatant was stored at −70°C until analysis. Proteins were quantified (Lowry,
Rosebrough, Farr, & Randall, 1951) using known amounts of purified bovine serum albumin (BSA) to generate a standard curve. One-dimensional sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE; Laemmli, 1970) was performed on muscle homogenates using a BioRad Mini-Protean II gel apparatus. A 12% acrylamide (97.33% acrylamide, 2.67% bis acrylamide) separating gel was used. Proteins were electrophoretically transferred to 0.2-μm-pore-size nitrocellulose (Towbin, Staehelin, & Gordon, 1979) in a BioRad Mini-Protean trans blot apparatus. Bands were quantified with an LKB Ultrascan laser densitometer equipped with an LKB 2220 recording integrator and expressed relative to bands from standard samples run on every blot. A monoclonal antibody (10D10) to Type I myosin heavy chain (MHC) was generously donated by Dr. Peter Merrifield (Department of Anatomy, University of Western Ontario).

**Statistical Analysis**

Statistical methods included routine descriptive statistics, paired *t* tests (height, weight), and two-way repeated-measures ANOVA. On determination of significant main effects or interaction, pairwise comparisons employing a Tukey’s post hoc test were conducted. In addition, effect sizes (*ES*) were calculated (mean difference between groups + SD of the control group; Thomas, Salazar, & Landers, 1991). This latter analysis, although less common than ANOVA, also assesses the magnitude of an experimental treatment effect and is especially relevant when observed large mean treatment differences fail to attain statistical significance as a result of individual participant variability, that is, because of a Type II error. *ES* of 0.8, 0.5, and 0.2 are typically considered to represent large, moderate, and small treatment effects, respectively. Differences were considered significant at *p* < .05.

**Results**

Participants had a mean height of 161 ± 7.0 cm and mean body mass of 72.6 ± 8.2 kg, which did not change with training.

**ISOKINETIC STRENGTH**

Pre- and posttraining values for all knee-extension strength measures are presented in Table 1. Before the training program there were no differences in strength between the CL and EL. After training, increases (*p* < .05) of 30.8% and 27.2% in peak torque (PT) and mean power (MP), respectively, were observed in the EL. In contrast, a moderate increase that was not statistically significant was observed in the CL for the same measures (*p* = .24, *ES* = 0.50, and *p* = .11, *ES* = 0.59, for PT and MP, respectively). Measures of PT (*p* = .05, *ES* = 0.54) and MP (*p* = .06, *ES* = 0.65) in the EL tended to be higher than those in the CL after training.

**FIBER-TYPE DISTRIBUTION AND CROSS-SECTIONAL AREA**

The mean (± SD) values for both distribution and CSA in the three fiber types examined are shown in Table 2. Before the training program, a small (ES = 0.36)
### Table 1  Mean (± SD) Values for Isokinetic Peak Torque and Mean Power at 180°/s, Pre- and Posttraining, for Control (CL) and Experimental (EL) Limbs

<table>
<thead>
<tr>
<th>Limb</th>
<th>Pretraining</th>
<th>Posttraining</th>
<th>p</th>
<th>ES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak Torque (Nm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CL</td>
<td>54.0 ± 11.4</td>
<td>59.8 ± 16.4</td>
<td>.24</td>
<td>0.50</td>
</tr>
<tr>
<td>EL</td>
<td>52.4 ± 9.5</td>
<td>68.6 ± 12.0a</td>
<td>.01</td>
<td>1.28</td>
</tr>
<tr>
<td></td>
<td>Mean Power (Nm · rad⁻¹ · s⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CL</td>
<td>173.8 ± 35.1</td>
<td>194.6 ± 38.3</td>
<td>.11</td>
<td>0.59</td>
</tr>
<tr>
<td>EL</td>
<td>172.6 ± 21.3</td>
<td>219.5 ± 27.2a</td>
<td>.01</td>
<td>1.30</td>
</tr>
</tbody>
</table>

*Note.* The same 10 participants were used in all conditions. *ES =* effect size.

*aSignificantly different (p < .05) from pretraining values.

### Table 2  Means (± SD) and Percent Change for Fiber Cross-Sectional Area and Percent Distribution of Fiber Types I, IIa, and IIb, in Experimental (EL) and Control (CL) Limbs, Pre- and Posttraining

<table>
<thead>
<tr>
<th>Type/Limb</th>
<th>Pretraining</th>
<th>Posttraining</th>
<th>% change</th>
<th>p</th>
<th>ES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cross-Sectional Area (µm²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I CL</td>
<td>3661.6 ± 611.3</td>
<td>3580.7 ± 616.8</td>
<td>-2.3</td>
<td>.44</td>
<td>0.13</td>
</tr>
<tr>
<td>I EL</td>
<td>3455.1 ± 646.7b</td>
<td>3625.5 ± 617.0c</td>
<td>5.4</td>
<td>.04</td>
<td>0.29</td>
</tr>
<tr>
<td>IIa CL</td>
<td>3263.5 ± 821.2</td>
<td>3337.2 ± 566.4</td>
<td>2.3</td>
<td>.99</td>
<td>0.09</td>
</tr>
<tr>
<td>IIa EL</td>
<td>3192.0 ± 768.4</td>
<td>3426.5 ± 743.8</td>
<td>7.3</td>
<td>.80</td>
<td>0.31</td>
</tr>
<tr>
<td>IIb CL</td>
<td>1998.0 ± 187.5a</td>
<td>2005.7 ± 160.6</td>
<td>0.3</td>
<td>.99</td>
<td>0.04</td>
</tr>
<tr>
<td>IIb EL</td>
<td>1906.0 ± 107.4a</td>
<td>2108.3 ± 163.4c</td>
<td>10.6</td>
<td>.04</td>
<td>1.88</td>
</tr>
<tr>
<td></td>
<td>Distribution (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I CL</td>
<td>54.0 ± 7.6</td>
<td>52.4 ± 7.0</td>
<td>-3.0</td>
<td>.56</td>
<td>0.21</td>
</tr>
<tr>
<td>I EL</td>
<td>53.4 ± 6.0</td>
<td>53.2 ± 5.4</td>
<td>-0.2</td>
<td>.99</td>
<td>0.03</td>
</tr>
<tr>
<td>IIa CL</td>
<td>31.1 ± 5.4</td>
<td>32.0 ± 4.4</td>
<td>2.9</td>
<td>.78</td>
<td>0.16</td>
</tr>
<tr>
<td>IIa EL</td>
<td>32.0 ± 3.1</td>
<td>33.1 ± 4.4</td>
<td>3.4</td>
<td>.62</td>
<td>0.35</td>
</tr>
<tr>
<td>IIb CL</td>
<td>14.9 ± 3.1</td>
<td>15.6 ± 2.8</td>
<td>4.7</td>
<td>.93</td>
<td>0.23</td>
</tr>
<tr>
<td>IIb EL</td>
<td>14.6 ± 5.1</td>
<td>13.7 ± 4.1</td>
<td>-6.2</td>
<td>.88</td>
<td>0.18</td>
</tr>
</tbody>
</table>

*Note.* No difference in fiber-type distribution was detected. The same 10 participants were used in all conditions. *ES =* effect size.

*aSignificantly different (p < .05) from those of Fiber Types I and IIa (p < .05). *bSignificant difference (p = .03, *ES = 0.36) between limbs, before training, within Type I fibers. *cTraining effect (p < .05).
Figure 1. Type I myosin heavy-chain (MHC) content in control and experimental limbs pre- and posttraining, expressed as a percentage of a known standard (data represent means ± SD). No significant differences were observed. The same 10 participants were used in all conditions.

but significant ($p = .03$) difference could be observed between the Type I fibers of the control and experimental limbs. A small ($ES = 0.29$) but significant ($p = .04$) training effect that occurred only in the EL eliminated the deficit in the EL. Consequently, after training no difference ($p = .63, ES = 0.10$) in Type I CSA could be observed between limbs. Type IIa fibers were similar between limbs and unaffected by training (CL: $p = .99, ES = 0.09$; EL: $p = .80, ES = 0.31$). Type IIb fiber CSA observed in both limbs was smaller ($p < .05$) than that of other fiber types before training. Although there were no differences between limbs before (CL = 1,998.0 ± 187.5, EL = 1,906.0 ± 107.4) and after (CL = 2,005.7 ± 160.6, EL = 2,108.3 ± 163.4) training, a large training effect ($ES = 1.88, p = .04$) occurred in the EL. Distribution of fiber types was unaltered by training.

**TYPE I MYOSIN HEAVY CHAIN**

One-dimensional SDS-PAGE of muscle homogenates followed by immunoblotting revealed no significant increases in the relative expression of MHC Type I content in either experimental or control limbs after training (See Figure 1).

**Discussion**

**STRENGTH GAINS**

Charette and colleagues (1991) studied older women (mean age = 69.9 years) after 12 weeks of resistance training and reported a 92.6% ± 12.6% increase in knee-extension 1RM values. In other studies, however, the same increases in strength
have required a year of training to achieve (Pyka et al., 1994). Thus, there are discrepancies in reported strength gains between studies employing 1RM measures. The 1RM strength gains reported by Frontera and coworkers (1988) were approximately 10 times greater than the strength gains in the same participants measured with the isokinetic testing modes similar to those employed in the present study. In one study using younger participants, 10 weeks of unilateral training of the quadriceps produced comparable increases in peak torque output of 39–60% at various velocities (Houston, Froese, Valeriote, Green, & Ranney, 1983). The 30.8% increase ($p = .01, ES = 1.28$) in peak torque in the EL observed in our participants compares favorably with other studies of resistance-trained seniors (Brown et al., 1990; Frontera et al.) and with the 23% increase in isometric force reported by Moritani and deVries (1980). Such strength gains might be a consequence of the intense nature of the training. Relative gain in strength could, in part, however, be determined by low initial values (Frontera et al.) such as those observed in the present study. Porter, Myint, Kramer, and Vandervoort (1995) reported low values ($61 \pm 16.0 \text{ Nm}$) for 73-year-old women on a similar test, executed at 90%.

The strength gains observed in the present study support the notion that progressive overload will result in a training adaptation and, subsequently, improved strength in the elderly in an 8-week period. In fact, the use of isokinetic strength testing data in the present study might underestimate the gains made with isotonic training. It is well established that tests mimicking the speed and characteristics of the movements used during training demonstrate the greatest enhancement of force generation (Coyle et al., 1981). Hence, these data demonstrate the potential for considerable increases in strength and might reflect the training-induced decrease in neurological inhibition and increased motor-unit synchronicity described by Sale (1988).

Some (Hellebrandt, Parrish, & Houtz, 1947; Houston et al., 1983), but not all (Narici, Roi, Landoni, Minetti, & Cerretelli, 1989), researchers have noted a tendency for increases in strength in the CL after training of the EL in studies using unilateral training. This “cross-over training effect” (reviewed in Sale, 1988) has been suggested to result from the diffusion of motor impulses from the EL to the CL and tonic postural cocontractions by the CL during exercise (Hellebrandt et al.). In the present study, the CL also displayed a moderate cross-over training effect (=10% increase in MP and PT) that was not statistically significant ($p = .24, ES = 0.50$, and $p = .11, ES = 0.59$, for PT and MP, respectively). Notably, strength values for the trained EL were significantly ($p < .05$) higher than the pretraining CL values were. However, as a consequence of a cross-over training effect, measures of PT ($p = .05$, $ES = 0.54$) and MP ($p = .06, ES = 0.65$) in the trained EL only tended to be higher than the posttraining CL.

FIBER CROSS-SECTIONAL AREA AND DISTRIBUTION

The mean ($\pm SD$) fiber CSA before training in the present investigation (Type I = $3.662 \pm 611 \text{ \mu m}^2$, Type IIA = $3.264 \pm 821 \text{ \mu m}^2$, Type IIB = $1.998 \pm 188 \text{ \mu m}^2$) was similar to previously reported data for all three fiber types in comparable populations (Charette et al., 1991; Lexell, Henriksson-Larsen, Winbald, & Sjostrom, 1983). Whereas CSA has been reported to be similar across all fiber types in younger participants (Staron et al., 1994), a preferential atrophy of Type II fibers has been
suggested to occur in elderly participants (Porter, Vandervoort, & Lexell, 1995). In particular, Type IIb–fiber CSAs of approximately, 3,000 μm² have been observed in younger women (Staron et al.). Data derived from the subtyping of fibers (IIa and IIb) employed in the present study support previous comments (Cress et al., 1991) that suggest that IIb fibers make the greater contribution to overall Type II–fiber atrophy in muscles of the elderly.

Hypertrophy of both Type I and Type II fibers has been demonstrated after high-intensity training in the elderly. Frontera and coworkers (1988) reported 34% and 28% increases in CSA of Types I and II fibers, respectively, for elderly men. Elderly women, however, after the same duration of training demonstrated only a 7% increase in Type I–fiber CSA, which was accompanied by a 20% increase (p < .02) in Type II–fiber CSA (Charette et al., 1991). Studies that used a long-duration training program (0.5–1.0 year) reported relatively larger gains in strength and fiber CSA of both fiber types (Pyka et al., 1994; Taaffe & Marcus, 1997).

After training, Types I and IIb fibers increased (p < .05) in CSA approximately 5% and 10%, respectively. Although these data suggest some hypertrophy in the EL, the changes are not reflective of the substantial gains in strength. Indeed, mean CSA for all fiber types in the trained EL (I, 3642.5 ± 617.0 μm²; IIa, 3426.5 ± 743.8 μm²; IIb, 2108.3 ± 163.4 μm²) were no larger (p > .05) than those observed in the CL either before or after training. Moreover, the tendency toward a cross-over training effect in CL in measures of strength was virtually nonexistent in indicators of CL hypertrophy. These results are in general agreement with those of other studies employing short-term training alone (Moritani & deVries, 1980) or retraining after a period of detraining (Taaffe & Marcus, 1997). They support the concept that neural factors might be primarily responsible for increases in strength in the elderly after short-term resistance training and suggest that hypertrophy is not essential for establishing a strength gain in an older population (Moritani & deVries; Welle et al., 1996). Nonetheless, the present results appear to provide a portrait of an active remodeling of trained muscle, with the beginning of the hypertrophying process occurring as early as 8 weeks after initiation of the training program. Differences in relative training intensity might account in part for differences in the extent of hypertrophy in long-term training (discussed earlier) and the occurrence or extent of hypertrophy after short-term training.

Although the biopsy method has been considered suitable for assessing fiber hypertrophy in elderly participants (Pyka et al., 1994; Taaffe & Marcus, 1997), there are a number of limitations to this technique. Variability is introduced as a result of studying only a small fraction of the whole muscle. Because the coefficient of variation for determining fiber-type distribution and area can range from approximately 10% to 20% (Bloomstrand et al., 1984), extrapolation to the muscle as a whole might slightly over- or underestimate fiber adaptations. The inherent variability in this technique might explain the small difference (ES = 0.36, p = .03) between Type I fibers of the EL and CL before training. Second, the changes in a single muscle might not be representative of the training effect. Narici et al. (1989), using NMR, reported significantly less hypertrophy in the vastus lateralis (VL) muscle than in other quadriceps muscles after concentric isokinetic knee extensions. Because our participants trained the quadriceps muscle group that was assessed in the VL using the biopsy technique, our fiber CSA might underestimate the more general training effect.
TYPE I MHC CONTENT AND FIBER-TYPE DISTRIBUTION

Changes in MHC isoform expression (Klitgaard et al., 1990a) and fiber-type distribution (Lexell et al., 1983) as a result of aging have been investigated, but to our knowledge no studies have examined the former after short-term resistance training in the elderly. In young participants, resistance training (8–19 weeks) causes MHC-isoform shifts that are mirrored by alterations in fiber-type distribution (Adams, Hather, Baldwin, & Dudley, 1993; Staron et al., 1994). Indeed, a gradual shift from histochemically assessed Type IIb fibers toward Type Ila fibers corresponds with MHC-isoform expression and begins early (≤4 weeks) in heavy resistance training in young participants (Staron et al.). Whereas these molecular changes occur along with significant increases in strength but before fiber hypertrophy, a similar pattern was not observed in our participants. In the current study and others (Brown et al., 1990; Charette et al., 1991; Cress et al., 1991; Frontera et al., 1988; Pyka et al., 1994), elderly participants maintained their fiber-type distribution in conjunction with significant strength gains as a consequence of resistance training (8–30 weeks). Although these data suggest that the muscles of the elderly might be different from those of the young in response to training, differences might be a consequence of the significant atrophy of Type IIb unique to elderly participants before training (Cress et al., 1991; Table 2, current study). Finally, although Type I fiber grouping has been reported in older participants (Lexell et al., 1983), it was not observed in the present investigation on inspection of muscle-biopsy cross-sections.

Lifelong strength-trained seniors have been reported to exhibit significantly lower expression of Type I MHC than do aged-matched controls (Klitgaard et al., 1990a). In the present study, however, short-term resistance training did not alter the expression of slow (Type I) myosin. Recently, researchers using a qualitative reverse transcriptase polymerase chain reaction approach reported an increase in Type I MHC mRNA after a slightly longer period (12 weeks) of resistance training in the elderly (Willoughby & Pelsue, 1998). Although mRNA was not examined in the present study, protein data are in agreement with the observation of unaltered histochemical parameters. One possible explanation for these discrepancies is that elderly participants appear to be more inclined to exhibit fibers coexpressing different myosin isoforms (Klitgaard et al., 1990b). These “promiscuous” fibers might account for subtle changes in MHC distribution not observed by histochemical analysis (Klitgaard et al., 1990b). Because single-fiber analysis was not performed in the present study, we cannot rule out such a redistribution.

Increasing or maintaining independence should be a major goal of resistance training for the elderly. Although long-term training in elderly participants might indeed result in hypertrophy, the significant gain in strength that can be achieved without altering muscle-fiber characteristics is noteworthy. Shorter term training programs might be more economically and practically suitable, and thus future research should examine the minimum amount of training needed to maintain strength gains derived in this manner. Elucidating the contribution of neural adaptations is a critical step in making inferences about the specificity of training and the transferability of strength from the training mode to other tasks (Porter, Vandervoort, & Lexell, 1995). The training program used in the present study was designed to accommodate a one-legged training protocol, but it is recommended for
research purposes only. For training seniors in a community setting, the reader is encouraged to refer to standardized recommendations (e.g., American College of Sports Medicine, 1998).

In summary, the training undertaken by elderly participants in this study resulted in an increase in muscle strength, with only minor corresponding changes in the histochemical and morphometric parameters examined. These data support previous research that indicates that short-term resistance training is capable of producing significant increases in strength in the elderly without significant muscle hypertrophy. Indirectly, these data suggest that neural factors might be primarily responsible for significant strength gains observed after short-term resistance training in the elderly.

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References


