ASSOCIATION OF AGE WITH MUSCLE SIZE AND STRENGTH BEFORE AND AFTER SHORT-TERM RESISTANCE TRAINING IN YOUNG ADULTS

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1Center for Lifestyle Medicine and Department of Health Professions, University of Central Florida, Orlando, Florida 32826; 2Florida Atlantic University, Boca Raton, Florida 33431; 3Hartford Hospital, Hartford, Connecticut 06102; 4Dublin City University, Dublin, Ireland; 5Vale University, New Haven, Connecticut 06510; 6University of Massachusetts, Amherst, Massachusetts 01003; 7West Virginia University, Morgantown, West Virginia 26506; 8University of Connecticut, Storrs, Connecticut 06269; 9Central Michigan University, Mt. Pleasant, Michigan 48859; and 10Children’s National Medical Center, Washington, DC 20010

Abstract

Lowndes, J. Carpenter, RL, Zoeller, RF, Seip, RL, Moyna, NM, Price, TB, Clarkson, PM, Gordon, PM, Pescatello, LS, Visich, PS, Devaney, JM, Gordish-Dressman, H, Hoffman, EP, Thompson, PD, and Angelopoulos, TJ. Association of age with muscle size and strength before and after short-term resistance training in young adults. J Strength Cond Res 23(6): 000–000, 2009—The purpose of this study was to assess the association of age with muscle mass and strength in a group of young adults before and after 12 weeks of progressive resistance training. Eight hundred twenty-six young males and females (age 24.34 ± 5.69 yr, range 18–39 yr) completed a strictly supervised 12-week unilateral resistance training program of the nondominant arm. Isometric (maximal voluntary contraction [MVC]) and dynamic strength (1 repetition maximum [1RM]) of the elbow flexors and cross-sectional area (CSA) of the biceps-brachii using magnetic resonance imaging (MRI) scans were measured before and after training. Pearson correlation coefficients were calculated for size and strength variables and age. In addition, the cohort was divided into groups according to decade of life and differences assessed by analysis of variance. Age correlated significantly and positively with all pretraining measures of muscle size and strength (CSA: r = 0.191, p < 0.001; MVC: r = 0.109, p = 0.002; 1RM: r = 0.109, p = 0.002). Age was not related to the training-induced changes in CSA or MVC but was negatively associated with the change in 1RM strength (r = -0.217, p < 0.001). The study indicates that age does have a significant positive relationship with muscle size and strength in untrained young adults. Although age was negatively associated with improvements in 1RM, the effect of age was small relative to the improvements induced through resistance training, thus suggesting age does not limit response to training in any practical way during early adulthood.

Keywords: magnetic resonance imaging, muscle cross-sectional area, isometric strength, isotonic strength, supervised resistance training

Introduction

The importance of skeletal muscle in maintaining metabolic and functional health is well established (7,26). Without intervention, decreases in muscle size and strength of 10–15% per decade are observed after the age of 50 years, with increasing rates of loss after the age of 65 (22). This is problematic because muscle strength may be the primary determinant in the risk of falling in the elderly (27). It has also been shown that low muscle strength reduces the force required to cause a fracture after a fall (5,6). As such, maintenance of adequate levels of muscle mass and strength into an advanced age are key components of healthy aging.

Skeletal muscle is a malleable tissue and responds well to resistance training (2). Numerous studies have shown that resistance training can attenuate the negative effects of aging on muscle size and strength. As such, current physical activity recommendations for older adults include the performance of resistance training at a moderate intensity (1). Although master athletes who have accrued years of training...
training remain stronger than their age-matched, nontrained peers (24), those who start resistance training late may experience attenuated gains (13,19,25).

Although the effect of age on muscle size has been studied in younger adults (14), the effect of age on the adaptability of skeletal muscle in individuals under the age of 40 is less well studied. Without this knowledge, the information required to develop a comprehensive long-term strategy to combat age-related changes in muscle morphology and performance is incomplete. The purpose of this study was to use data from the Functional Single Nucleotide Polymorphisms Associated with Human Muscle Size and Strength Study (FAMuSS), a large multicenter study with sensitive measures of muscle size and strength before and after 12 weeks of supervised resistance training in untrained young adults (18–40 yr), to investigate these questions. It was our hypothesis that an age-related association would not be evident in a group too young to have experienced the endocrine and other changes causing the reduced muscle size and strength seen in older adults.

METHODS

Experimental Approach to the Problem

The protocol for the FAMuSS study has been previously described in detail (28). Untrained young adults were tested on both arms for muscle cross-sectional area (CSA) of the upper arm and both isotonic and isometric strength of the biceps brachii. Subsequently, they were put through a 12-week unilateral (nondominant arm) periodized training program of the upper arm, with each session strictly supervised by research staff. Training-induced improvements were assessed by repeating the pretraining battery of tests shortly after completion of the training period.

Subjects

Participants were recruited from each institution’s student population and the local community. Potential participants were considered for enrollment in the study if they had not performed any resistance training for at least 12 months and did not perform a job that required repetitive use of their arms (e.g., server, delivery personnel, shelf stacker). Subjects older than 40 years were excluded to avoid the decrease in testosterone levels and other hormonal changes that affect skeletal muscle in older age groups (29,17). All participants provided written consent as approved by the institutional review board for human subjects experimentation of each institution involved in the project. Participants’ physical characteristics are presented in Table 1.

Procedures

Isometric Biceps Strength Testing. Isometric strength, as measured by a maximal voluntary contraction (MVC) of the elbow flexor muscles of each arm, was determined separately, before and after 12 weeks of strength training, using a specially constructed, modified preacher bench and strain gauge (model 32628CTL, Lafayette Instrument Company, Lafayette, IN, USA). Pretraining measures of MVC were assessed on 3 separate days spaced no more than 2 days apart. The first of these sessions was used for familiarization to the testing protocol, so the pretraining value was taken as the average of the results obtained on the second and third testing days. Post-training measures of MVC were assessed immediately before the last training session or 24 to 48 hours after the last training session.

One Repetition Maximum Biceps Strength Testing. The dynamic strength of the elbow flexor muscles of each arm was assessed separately by determining the maximum amount of weight with which a subject could perform 1 repetition maximum (1RM) of the 1-arm preacher curl exercise using a standardized protocol (4). The 1RM testing was performed only once after the final isometric tests both before and after the 12-week training program.

Measurement of Muscle Cross-Sectional Area. Magnetic resonance imaging (MRI) scan was performed before and after exercise training to assess changes in the biceps brachii CSA. The procedure for standardization of the MRI measurement (pretraining vs. post-training) has been explained in detail previously (28). Pre- and post-training MRI scans were performed either before the strength tests or 48 hours after the MVC and 1RM tests. This was done to avoid postexercise swelling that might spuriously increase muscle size and

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<th>Table 1. Pretraining characteristics.</th>
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<td>All subjects (n = 826)</td>
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<td>Mean</td>
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<td>Height (cm)</td>
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<td>Body mass index (kg/m²)</td>
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affect the validity of the measurements. Post-training images were taken 48 to 96 hours after the final training session.

Pre- and post-training MRI scans were obtained separately from both the dominant and nondominant arms. Images were analyzed using a custom-designed interactive processing and visualization program that operates in Matlab (The Math Works, Inc., Natick, MA, USA). On the basis of the MRI scan acquisition data (i.e., field of view and matrix resolution), the CSA (cm$^2$) of region of interest was then calculated.

**Exercise Training Program.** Subjects underwent gradually progressive, supervised strength training 2 times per week of their nondominant arm only, which was defined as the nonwriting arm. The exclusion of the dominant arm from the 12-week training program allowed the dominant arm to act as a control. The IRM measured during pretraining testing was used to estimate the amount of weight that could be lifted for 12, 8, and 6 repetitions using standard formulas (4). Each training session followed the same sequence of exercises: biceps preacher curl, overhead triceps extension, biceps concentration curl, triceps kickback, and standing biceps curl. All exercises were performed with dumbbells (Powerblocks, Intellibell, Inc., Owatonna, MN, USA), and some exercises used a preacher curl bench (Yukon International, Inc., Cleveland, OH, USA).

All training sessions were supervised and lasted approximately 45 to 60 minutes. The program periodization used the following weekly training protocol: weeks 1 to 4: 12 repetitions of the 12RM weight; weeks 5 to 8: 8 repetitions of the 8RM weight; weeks 9 to 12: 6 repetitions of the 6RM weight. Subjects performed 3 sets of each exercise throughout all 12 weeks with a mandatory 2-minute rest interval between sets. The weight lifted was increased when subjects could perform 2 extra repetitions on the third set of a given exercise beyond the goal repetitions for that week; the subject would then increase the weight lifted during the subsequent training session for that given exercise.

**Dietary Control Procedures.** Subjects were instructed to maintain their habitual dietary intake over the course of the study. Individuals who supplemented their diet with additional protein or any dietary supplement reported to build muscle or

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**Figure 1.** Comparison of A) biceps brachii cross-sectional area B) 1 repetition maximum C) maximum voluntary contraction across the second to fourth decade in nondominant arm of untrained individuals. *Greater than 18 to 19, $p < 0.05$.

**Table 2.** Correlation between age and change from pretraining values (post-training – pretraining) in nondominant (trained) arm after 12 weeks of resistance training.

<table>
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<th>Muscle cross-sectional area</th>
<th>1 repetition maximum</th>
<th>Maximum voluntary contraction</th>
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<tr>
<td></td>
<td>All</td>
<td>Male</td>
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<tr>
<td>$r$</td>
<td>0.036</td>
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<td>$p$</td>
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<tr>
<td>$n$</td>
<td>597</td>
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to cause weight gain within the 3 previous months were excluded.

**Standardization Between Sites.** Adaptations to resistance training are highly specific to the training protocol. Therefore, to control for any difference among sites, each site used an identical training protocol, and identical exercise equipment was purchased from the same manufacturers. The techniques for MRI, strength and anthropometric measurements, and exercise training were videotaped, and each site’s research personnel were required to review the videotaped procedures before the start of each cohort. All sites also met semi-annually to review standardized measurement and training techniques.

**Statistical Analyses**

Data were analyzed using SPSS (version 12.0, Chicago, IL, USA). A one-way analysis of variance was used to test for differences between age groups, classified by their decade of life. For the analysis of the response to training, delta scores were calculated (post–pre) and used as the dependant variable with baseline measures as a covariate. Significant Fratios were probed with a Tukey post hoc test. Pearson correlation coefficients were used to determine the relation between age and a) pretraining strength and size measurements, and b) the change in size and strength variables. The alpha level was set at 0.05 for all analyses. All data are presented as means ± SD.

**RESULTS**

**Pretraining Associations with Age**

In the entire cohort, age was significantly and positively correlated with all pretraining measures of muscle size and strength in the elbow flexors of the nondominant arm (CSA: $r = 0.191$, $p < 0.001$, $n = 605$; MVC: $r = 0.109$, $p = 0.002$, $n = 788$; 1RM: $r = 0.109$, $p = 0.002$, $n = 819$). Comparable results were seen in the dominant arm. There was also a significant difference in muscle CSA between both the third and fourth decade of life compared with the second. There were no age-related differences in muscle strength in the dominant arm, whether assessed by MVC or IRM (Figure 1).

**Effect of 12 Weeks of Resistance Training**

As previously described, the 12-week resistance training program resulted in positive adaptations in all measures of muscle size and strength in the trained arm (12). In short, increases of 18.9% ± 9.42 in CSA, 54.34% ± 33.46 in 1RM, and 20.66 ± 20.20 in MVC were seen in the trained arm. In the entire cohort, age was related to change in 1RM but not in muscle size or MVC (Table 2). A sex-specific pattern of adaptation to this protocol has previously been reported (12). We therefore also analyzed these data according to sex, but the relationship with age was not different to that of the entire cohort.

After controlling for baseline values, improvements in 1RM in the second decade were greater than the improvements in both the third and fourth decades. In turn, greater improvements were seen in the third decade than the forth (Figure 2). Although this analysis showed statistical significance, the effect was small, with the parameter estimates of a difference of just 3.07 kg across the entire cohort.

**DISCUSSION**

It is well established that age affects muscle size and strength in middle- and older-aged adults. However, we believe the
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training, and so age does not affect the response to training in a meaningful way through early adulthood.

**Practical Applications**

Skeletal muscle has a tremendous capacity for adaptation. The association between age and muscle size and performance demonstrated in the present study can be quickly overcome by the rapid adaptations made during a resistance training program. Furthermore, the very slight negative association age has with skeletal muscle’s adaptability is considerably less than the enduring capacity for adaptation, even in the fourth decade of life. The present data suggest that the muscle size and strength response to resistance training is not influenced by age in any practical manner through the fourth decade of life.

**Acknowledgments**

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**References**