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Alterations in muscle attenuation following detraining and retrainingin resistance trained older adults

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Abstract

Background—Aging skeletal muscle is characterized by not only a reduction in size (sarcopenia) and strength but also by an increase in fatty infiltration (myosteatosis). An effective countermeasure to sarcopenia is resistance exercise; however, its effect on fatty infiltration is less clear.

Objective—To examine in resistance trained older persons if muscle attenuation, a noninvasive measure of muscle density reflecting intramuscular lipid content, is altered with training status.

Methods—Thirteen healthy community-dwelling men and women aged 65–83 years (BMI, 27.0 ± 1.2 kg/m^2, mean ± SE) had computed tomography scans of the mid-thigh performed following 24 weeks training, 24 weeks detraining, and 12 weeks retraining. Training and retraining were undertaken twice weekly for several upper and lower body muscle groups. Skeletal muscle attenuation in Hounsfield Units (HU) as well as mid-thigh muscle volume was obtained for the quadriceps and hamstrings. Muscle strength was assessed by 1-repetition maximum and physical function by a battery of tests.

Results—The average change in muscle strength following training, detraining, and retraining was 48.8 ± 2.9%, −17.6 ± 1.3%, and 19.8 ± 2.0%, respectively. Strength changes were accompanied by significant alterations in muscle density ($p < 0.001$), with the quadriceps HU decreasing by 7.7 ± 1.0% following detraining and increasing by 5.4 ± 0.5% with retraining. For the hamstrings HU measure, detraining and retraining resulted in a 11.9 ± 1.4% loss and a 5.5 ± 1.8% gain, respectively. There was no significant change in muscle volume.

Conclusion—Cessation of resistance exercise in trained older persons increases the fatty infiltration of muscle while resumption of exercise decreases it. Monitoring changes in both muscle size and fat infiltration may provide for a more comprehensive assessment of exercise in combating age-related muscular changes.

Keywords

intramuscular fat; Hounsfield Units; computed tomography; muscle

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INTRODUCTION

Decreases in muscle mass (sarcopenia) and strength are well known characteristics of normal ageing and contribute to decreased muscle function and loss of independence. Resistance or weight training is an exercise mode that has been reliably shown to be a safe and effective method for strength development in older adults, including the very old, and an important contributor to improving muscle function and maintaining independence [1,2]. Increases in muscle size, the magnitude dependent on whether assessment is by the needle biopsy technique, computed tomography (CT) and nuclear magnetic resonance (NMR) imaging, or by dual x-ray absorptiometry (DXA) results from various training protocols [1–3]. However, ageing is also associated with not only changes in muscle size but also in muscle quality as evidenced by an increase in fat infiltration [4,5] which has been referred to as myosteatosis [6]. As determined by the CT attenuation coefficient of muscle, lipid infiltration is an important determinant of insulin resistance in healthy [7] and diseased patients [8], independent of visceral fat [7,8], and is associated with poorer muscle strength and physical performance in older persons [9,10]. However, little is known about how fat infiltration in muscle is altered with different physical training patterns, such as resistance exercise, especially in older adults, and none have examined this following a period of exercise cessation and then resumption of training.

Muscle attenuation in Hounsfield Units (HU) obtained by CT is a noninvasive measure of muscle density and correlates with intramuscular lipid content obtained by muscle biopsy [11]. As a result, lower HU reflect higher intramuscular lipid content, and has been used in a number of studies for this purpose [9,12–16]. As part of a 60-week resistance training, detraining, and retraining study, we took the opportunity to examine the effect of alterations in physical activity on muscle attenuation, to determine if muscle quality is substantially affected by this form of exercise. We hypothesized that in resistance trained older persons, cessation of resistance exercise would result in a decrease in muscle attenuation and that resumption of training would increase muscle attenuation reflecting improved muscle quality.

METHODS

Subjects

Subjects were 13 apparently healthy community-dwelling men (n = 7) and women (n = 6) aged 65–83 years participating in a 60-week resistance training, detraining, and retraining study. Details regarding recruitment for the study have been described previously [17]. Briefly, eligibility criteria included no acute or terminal illness, cardiovascular, respiratory, neurological or muscular disease, and no resistance training within the previous 12 months, and all subjects obtained their physician’s approval for participation. The study was approved by The University of Queensland Medical Ethics Committee and all participants provided informed consent. Sixty seven participants were recruited for the initial phase of the 60-week program and were randomized to either a strength training (ST, n = 22), power training (PT, n = 23), or a non-training control (n = 22) group for 24 weeks. Following the 24-week training period, exercisers underwent a 24-week period of detraining followed by 12 weeks of retraining [18]. Of the initial 45 exercisers, 38 entered the detraining and retraining phase of the program with 27 subjects completing these phases, while control subjects were provided the opportunity to participate in an 8-week exercise program. In total, 13 of the 38 subjects entering the detraining and retraining phase had serial CT scans performed at the end of training, detraining (effect of reduced physical training) and retraining (effect of increased physical training). The 13 participants were not distinguished from those in the initial cohort or from others taking part in the detraining/retraining portion of the study.

Intervention

Training was undertaken twice weekly in the initial 24-week training period and in the 12-week retraining period using Extek resistance equipment (Extek Pty Ltd, Brisbane, Australia). Exercises consisted of 3 sets of 8 repetitions for the chest press, seated row, and biceps curl for the upper body, and the leg press, leg curl and leg extension for the lower body. To prepare the participants for more intense exercise, the first 2 weeks of training and retraining formed a conditioning period, with resistance set at 65% of their 1 repetition maximum (1RM) in the first week and 70% of 1RM in the second week. Concentric and eccentric movements were performed at a rate of ~ 3 seconds. Following this initial period, ST continued with the same protocol but at 75% of their 1RM, while the PT group performed 1 set of 8 repetitions each at 45%, 60%, and 75% of their 1RM using high-velocity movements (concentric as explosively as possible with ~ 3 seconds for the eccentric portion). All sessions lasted approximately 1 hour, commencing with a 10-minute warm-up and concluding with a warm-down of stretching and abdominal/lower back exercises. To ensure that the program was progressive, the resistance was increased when the repetitions a subject could complete were greater than 8 in their final set [19]. All sessions were conducted in small groups and under direct supervision to ensure proper technique and minimize the risk for injury.

Subjects were instructed to maintain their customary activity and dietary patterns during the course of the program. During the 24-week detraining period, no resistance training was undertaken and subjects were requested to not engage in any resistance exercise.

Soft tissue analysis

Axial scans of the mid-thigh were obtained using a GE LightSpeed computer tomography scanner (General Electric, Milwaukee, WI) following the 24-week training period, detraining, and retraining (scans were not obtained prior to the commencement of training). With subjects in a supine position, the right mid-thigh was defined as the midpoint between the superior aspect of the greater trochanter and the inferior aspect of the lateral condyle. To locate the mid-point, an anterior-posterior scout of the entire femur was obtained. Nine contiguous slices 2.5 mm in thickness were then obtained, centered at the mid-thigh, in a cranial-caudal direction (scanning parameters were 120 kVp and 300 mAs). The 9 slices were then analyzed using specialized software written at the University of California, San Francisco (T. F. Lang), and implemented on the AVS5 processing platform (Waltham, MA, USA). Regions assessed were those specifically targeted by the exercise, the quadriceps and hamstring muscles. Within each muscle group, intermuscular fat (the fatty infiltration into fascial planes within muscle) was removed by thresholding, and the cross-sectional area (CSA) and HU of the lean component determined. The area of each individual slice was then multiplied by the slice thickness (2.5 mm) to obtain a volume, with the 9 volumes summed to derive the mid-thigh volume (2.25 cm thickness). Muscle attenuation in HU was averaged across all 9 slices per volume to approximate the density for that particular anatomical compartment/region. The HU number represents intramuscular lipid, which is a combination of intramyocellular and perimyocellular fat, as these areas are below the resolution of the scanner. In addition, intermuscular fat for the mid-thigh was obtained. The coefficient of variation (CV) for repeated measurements (duplicate scans with repositioning) was 3.7% for intermuscular fat volume, 1.1% for the quadriceps muscles volume, 1.0% for the hamstring muscles volume, and 0.7% and 0.6% for quadriceps and hamstrings HU, respectively.

Other measures

Height in centimeters and body weight in grams were obtained using a stadiometer and electronic scale, respectively. Body mass index (BMI) was calculated from weight (kg) divided by height squared in meters. Bone-free lean mass, fat mass, and percent body fat was determined by dual X-ray absorptiometry (DXA, Hologic Discovery W, Hologic Inc., MA).

Physical activity was assessed using the Physical Activity Scale for the Elderly (PASE) [20]. Dynamic muscle strength for the 6 exercises was measured using the 1RM method, as described previously [2]. Briefly, the 1RM is the maximal weight an individual can move through the full range of motion one time using correct technique. The 1RM value was also used to calculate an index of muscle quality (MQ, kg/cm^3) with the leg extension 1RM divided by the mid-thigh quadriceps muscle volume and the leg curl 1RM divided by the mid-thigh hamstring muscles volume. Lower extremity functional performance was assessed using a battery of tests which included a stair climb, repeated chair rise to standing (5 times), 6-m walk, 6-m backwards walk, and a 400-m walk [17]. The CV in our laboratory for body composition measures is < 1.0%, for repeated 1RM measures 2.5% to 8.8%, and 2.0 to 7.5% for the functional performance tasks.

Statistical analysis

Data were analyzed using the SPSS statistical software package (version 15.0, SPSS Inc, Chicago, IL). Normality of the data was tested using the Kolmogorov-Smirnov test. Intermuscular fat at the three time-points was not normally distributed and was log transformed. Across the time points for the outcome measures, there were no interactions by training group (ST or PT) and/or gender using repeated measures analysis of variance (ANOVA). Therefore, analyses were undertaken for subjects combined. Analysis included standard descriptive statistics, paired t-tests, Pearson and Spearman (for change in hamstring HU) correlation, and repeated measures ANOVA. Where appropriate, the Bonferroni post-hoc procedure for multiple comparisons was performed to locate the source of significant differences in means. Percent change was calculated on individual data as the difference between the present and previous measure, divided by the previous measure × 100. All tests were two-tailed and an alpha level of 0.05 was considered statistically significant. Results are presented as the mean ± SE.

RESULTS

The mean age of the participants was 70.8 ± 1.5 years with a BMI of 27.0 ± 1.2 kg/m^2 and 32.5 ± 2.3% body fat. The average number of medications taken was 1.8 ± 0.3, and self-reported physical activity using the PASE was 153.5 ± 21.6 units. During the course of the study, fat mass significantly increased following detraining, while lean mass increased with training, decreased following detraining, and increased again with retraining (Table 1). There was no change in self-reported physical activity. Significant change in muscle strength for all exercises ($p < 0.001$) occurred in response to the intervention (Table 1). The average upper body change following training, detraining, and retraining was 50.4 ± 3.9%, −17.6 ± 1.1%, and 19.9 ± 1.9%, and for the lower body 47.9 ± 3.1%, −17.5 ± 1.8%, and 19.9 ± 2.7%, respectively. Consequently, losses associated with reduced activity were recouped with retraining.

Following detraining and retraining, there were significant changes ($p < 0.001$) in muscle attenuation, with a decrease in HU following detraining and a subsequent increase following retraining (Table 2). For the quadriceps, the HU decreased by 7.7 ± 1.0% following 24 weeks detraining and increased by 5.4 ± 0.5% following 12 weeks retraining. The corresponding values for the hamstring muscles were 11.9 ± 1.4% and 5.5 ± 1.8%, respectively. Individual values at the three time points are shown in Figure 1. For both muscle groups, the muscle density for each individual declined with detraining and increased with retraining.

Across the three time points, there was no significant change in mid-thigh intermuscular fat or in muscle volume, although the decrease in intermuscular fat and increase in hamstrings muscle volume with retraining approached significance ($p = 0.142$ and 0.078, respectively), while the increase in quadriceps muscle volume was significant ($p = 0.036$). The muscle quality index (kg/cm^3) was significantly altered with the intervention for both the quadriceps ($p < 0.001$)

and hamstrings (p = 0.005), with values decreasing with detraining and increasing with retraining (quadriceps: 0.49 ± 0.03, 0.38 ± 0.01, 0.45 ± 0.02; hamstrings: 0.61 ± 0.03, 0.52 ± 0.03, 0.62 ± 0.03 for pre-detraining, detraining, and retraining, respectively). There was no significant association between change in HU following detraining and retraining and the corresponding change in lower body muscle strength or functional performance, except for the change in hamstrings HU and leg curl strength from detraining to retraining (rho = 0.753, p = 0.003).

DISCUSSION

The results of this study indicate that varying an individual's exercise pattern can substantially alter the radiological density of muscle. In previously resistance trained older persons, withdrawal of twice-weekly exercise resulted in a decrease in mid-thigh attenuation of the quadriceps and hamstrings muscles, whereas a period of retraining led to an increase in attenuation as determined by CT scanning. Alteration in attenuation or muscle density likely reflects changes in the fatty infiltration of muscle. Given that aging is associated with not only a loss of muscle mass but also an increase in fatty infiltration of muscle, embarking on a program of resistance exercise may be an appropriate strategy to not only combat sarcopenia but also myosteatosis, thereby improving the quality of the existing muscle.

The training, detraining, and retraining protocol had the desired effect resulting in substantial changes in muscle strength for all upper and lower body muscle groups examined, with strength improving with training, decreasing with detraining, although in general not to pre-training levels, and increasing to that of the trained levels with resumption of training. The changes in strength with training were accompanied by an increase in whole body lean mass of ~ 1.5 kg, and are similar to what we have previously found in training studies of a similar duration in older adults [2,21,22]. Similarly, the decline in muscle strength with cessation of resistance exercise and recouping of losses with an abbreviated period of retraining are similar to what we have previously found for this age group [23].

Following detraining, the HU of the quadriceps and hamstrings decreased by 7.7% and 11.9%, with losses partly recouped with retraining, increasing by 5.4% and 5.5%, respectively. However, the period of retraining was only half as long as the detraining period, so given sufficient time, it is possible that the losses occurring with exercise cessation would be fully regained with prolonged retraining. Surprisingly, we found no change in mid-thigh quadriceps or hamstrings muscle volume with detraining although there was a trend for an increase of ~ 3% with retraining for the hamstrings and the change in the quadriceps was significant. In a similar fashion, intermuscular fat for the mid-thigh volume did not increase with detraining, however, the decrease with retraining approached significance. Substantial variation among the group for this variable and the sample size limited our ability to detect a statistically significant effect.

We have previously shown that a yearlong program of high-impact exercise in early postmenopausal women results in a modest increase in muscle attenuation of the mid-thigh compared to non-exercising individuals [15]. In exercise studies, Sipilä and Suominen [13] reported an increase in HU of 9.1% for muscles of the lower leg but not for the quadriceps or hamstring muscles following 18 weeks of strength training. In a similar fashion, Jones & Rutherford [24] reported an increase in muscle strength and muscle CSA, and an increase in muscle density of 3.6–5.9% following 12 weeks of resistance training in young adults, while Driscoll et al. [25] reported that muscle attenuation of the anterior muscle compartment of the thigh increased by ~ 3.5% following 12 weeks of resistance and aerobic exercise. In contrast, Cheema et al. [26] recently examined the effect of 12 and 24 weeks progressive resistance training delivered to patients with end-stage renal disease during routine hemodialysis treatment and found no change in muscle CSA or intramuscular lipid content as determined by HU. However, the lower limb exercises were likely less intensive than that undertaken in the present or other strength training studies as they were performed using weighted ankle cuffs and Thera-Band tubing.

The alterations in HU or radiological density may reflect variations in either intramuscular lipid or the packing density of the myofilaments or a combination of the two. Given that resistance training is an anabolic exercise mode, it seems reasonable to conclude that changes in the packing of myosin may have occurred and be responsible for the training/detraining associated variations in HU. However, Claassen et al. [27] found no change in the ratio of actin to myosin or in the distance between myosin filaments, indicating no change in the packing density of the myofilaments, following 6 weeks of heavy resistance training in young men who experienced an increase in muscle strength and radiological density of 4.8%.

Resistance exercise acts to increase circulating growth hormone (GH), although the effect is severely attenuated in older adults [28], which has both an anabolic and lipolytic effect thereby potentially affecting muscle composition and density. Pratley and colleagues [29] have also demonstrated that strength training substantially increases plasma norepinephrine levels which would also promote lipolysis, potentially affecting the intramuscular fat depot. Further, it has been proposed that the reduction of intramuscular lipid may be due to its role as a substrate during the resistance training-induced muscle repair process whereby necrotic muscle fibers are degraded and new fibers are synthesized [30,31]. Intramuscular lipid may also vary based on fiber type distribution, with type I muscle fibers having a greater lipid content than type II fibers [32]. Type II fibers appear to be the most susceptible to aging [33], and a transformation of fiber types with resistance training and detraining could potentiallycontribute to the observed alterations we found in attenuation. However, evidence for this is scant [34] with most studies reporting no significant changes in the proportion of type I and II fibers with resistance exercise [3,35,36].

As accumulation of intramuscular lipid is associated with a reduction in insulin sensitivity, an increase in HU in response to resistive exercise indicates that insulin sensitivity may also be improved, and provide a protective effect for the development of type II diabetes. Acute [37] and chronic [38,39] aerobic exercise has been shown to improve insulin sensitivity, as has overall physical activity [40]. Progressive resistance exercise of 3 to 6 months duration also has been shown to improve glycemic control [41] and insulin sensitivity [42] in older persons with type 2 diabetes, with or without concomitant weight loss. Moreover, Driscoll et al. [25] have demonstrated that increased muscle attenuation is significantly associated with fasting insulin and 2-hr insulin, independent of subcutaneous fat and visceral abdominal fat.

A limitation of the current study is that the HU was used as a surrogate measure for intramuscular fat and we did not obtain a direct measure of intramyocellular lipid. In addition, changes in glucose handling associated with alterations in the HU were not undertaken. Consequently, future studies using direct measurements of intramyocellular lipid obtained with the muscle biopsy technique, especially in relation to potential fibre type differences with alterations in physical activity, with measures of glucose handling would be beneficial.

In summary, a prolonged period of training cessation in resistance trained older persons impacts on muscle quality with an decrease in muscle attenuation reflecting an increase in fatty infiltration or myosteatosis. Conversely, resuming resistance training leads to a reduction in myosteatosis, which may lead to an improvement in insulin sensitivity. As a result, monitoring changes in both muscle size and fat infiltration may provide for a more comprehensive assessment of the role of exercise in combating age-related muscular changes.

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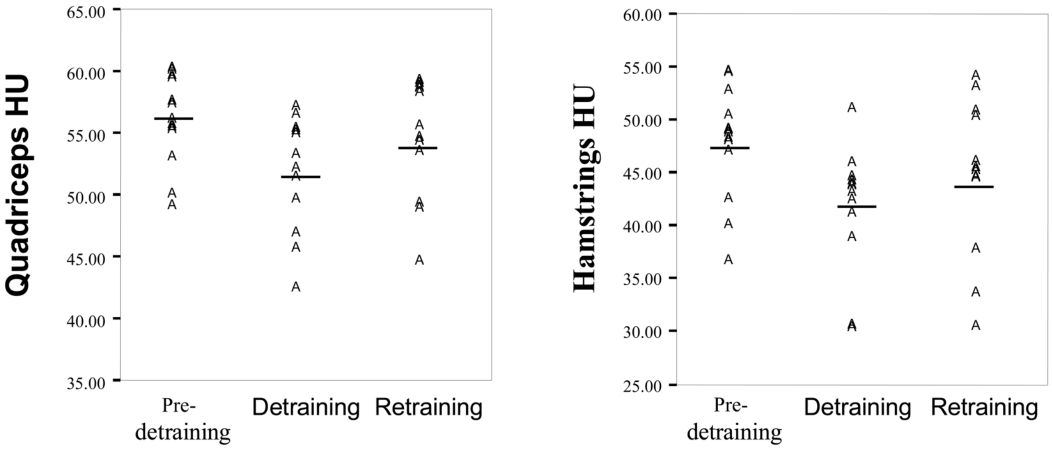

Figure 1.

Alterations in muscle attenuation (Hounsfield Units, HU) for the quadriceps and hamstring muscles following detraining and retraining in older men. Circles indicate values for individual participants (n = 13).

Table 1

Body composition and muscle strength changes following training, detraining, and retraining (n = 13). Values are the mean ± SE.

Variable	Baseline (1)	Training (2) (pre-detraining)	Detraining (3)	Retraining (4)	P-value	Comparison
Height (cm)	166.4 ± 2.1	166.3 ± 2.1	166.5 ± 2.1	166.5 ± 2.1	0.731	
Weight (kg)	74.6 ± 3.2	76.1 ± 3.3	75.7 ± 3.2	76.1 ± 3.1	0.003	2, 3, 4 > 1
Bone-free lean mass (kg)	47.5 ± 2.9	49.1 ± 2.9	48.0 ± 2.9	48.8 ± 2.8	< 0.001	2, 4 >1, 3
Fat mass (kg)	23.6 ± 1.8	23.3 ± 1.8	24.1 ± 1.8	23.5 ± 1.8	0.037	3 > 2
Physical activity (units)	153.5 ± 21.6	133.4 ± 10.1	144.5 ± 14.1	150.8 ± 15.2	0.533	
Muscle strength (kg)						
Chest press	32.9 ± 4.8	41.3 ± 5.4	34.2 ± 4.2	40.2 ± 5.2	< 0.001	2, 4 > 1, 3
Seated row	45.8 ± 3.7	75.7 ± 7.2	64.4 ± 5.6	75.4 ± 7.0	< 0.001	2, 4 > 3 > 1
Biceps curl	21.4 ± 2.6	32.6 ± 3.6	24.2 ± 2.8	32.0 ± 3.5	< 0.001	2, 4 > 3 > 1
Leg press	72.3 ± 7.0	96.2 ± 10.0	80.7 ± 7.6	96.3 ± 10.8	< 0.001	2, 4 > 3 > 1
Leg extension	35.5 ± 3.6	59.8 ± 5.5	46.9 ± 3.9	57.3 ± 5.2	< 0.001	2, 4 > 3 > 1
Leg curl	24.5 ± 2.5	38.5 ± 3.2	31.5 ± 2.7	38.5 ± 3.2	< 0.001	2, 3 > 3 > 1

Table 2

Mid-thigh muscle attenuation and composition at the end of training, detraining, and retraining (n = 13). Values are the mean ± SE.

Variable	**Pre-detraining (1)**	**Detraining (2)**	**Retraining (3)**	**P-value**	**Comparison**
Intermuscular fat (cm^3)	36.2 ± 6.1	36.1 ± 5.9	29.4 ± 5.2	0.173	
Quadriceps					
Muscle (cm^3)	122.4 ± 8.8	122.8 ± 8.8	126.4 ± 9.0	0.066	
HU*	55.7 ± 1.0	51.5 ± 1.3	54.2 ± 1.3	< 0.001	1 > 3 > 2
Hamstrings					
Muscle (cm^3)	62.9 ± 4.6	61.3 ± 4.9	63.1 ± 4.9	0.426	
HU	47.3 ± 1.5	41.9 ± 1.7	44.2 ± 2.0	< 0.001	1 > 3 > 2

*HU = Hounsfield Units