

Age-Related Change in Muscle Characteristics and Resistance Training for Older Adults

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ABSTRACT. In older adults, muscle weakness contributes greatly to functional restrictions on daily living activities, increased risk of falls, and adverse physiological changes. It has been suggested that not only muscle mass but also muscular infiltration of noncontractile elements may influence muscular performance such as strength and rapid force production. It is proved that resistance training may provoke substantial increases in muscle size even if it is performed at low intensities in older individuals. Also, recent studies have demonstrated the effectiveness of resistance training on muscle quality such as muscular infiltration of noncontractile elements for older people. This review shows the age-related changes in muscle mass and muscle quality, which were measured by muscle echo intensity on ultrasound images, and low-intensity resistance training effects on muscle volume and muscle quality.

Key words: muscle mass, muscle quality, age-related change, resistance training, older adults

(Phys Ther Res 23: 99-105, 2020)

To develop an evidence-based approach for improving muscle performance, it is important to understand the age-related changes in muscle characteristics such as muscle mass and muscle quality. Skeletal muscle mass decreases with aging, and it also decreases by 30%-50% between the ages of 40 and 80 years¹⁻⁴. It is well established that muscle mass loss contributes to muscle weakness in older people. Furthermore, muscle weakness easily causes gait disorders, functional restrictions on daily living activities, and an increase in the risk of falls in frail older people⁵⁻¹¹. Therefore, resistance training is essential for maintaining the ability to perform activities of daily living and preventing falls among older individuals.

Age-Related Change in Muscle Mass

In literature, there have been many studies on age-related muscle atrophy using an ultrasonographic measurement of muscle thickness. It has been reported that there

have been strong correlations between muscle thickness measured by B-mode ultrasound and site-matched skeletal muscle mass measured by magnetic resonance imaging¹²⁻¹⁵. Therefore, measurements of muscle thickness using ultrasound can be used to noninvasively estimate the degree of muscle atrophy¹⁶.

Our previous study using ultrasound showed relatively little atrophy of the soleus muscle among lower-limb muscles in older women who were able to walk without assistance^{17,18}. Furthermore, the relatively small atrophy of soleus muscle may be as a result of the different postural role and fiber-type characteristics of muscles. It has been reported that the mean percentage of type I fibers is 86.4% in soleus, 43.5% in gastrocnemius, 42.8% in rectus femoris, 37.8% in vastus lateralis, and 52.4% in gluteus maximus¹⁹. Generally, among type II fibers, greater rates of age-related loss occur, while among type I fibers, only moderate losses occur^{3,20,21}. Therefore, in older adults who were able to do ambulatory activity, the postural role of the soleus muscle may protect this muscle from marked reductions in thickness with aging, given its predominant type I composition. Besides, in our previous study, we demonstrated that age-related muscle atrophy was greatest for psoas major muscle among 10 muscles of the lower-limb muscles (Fig. 1). The psoas major muscle is considered to be closely related to the locomotory capacity such as running and stair climbing^{22,23}. This may be due to marked decreases in muscle

Received: July 27, 2020

Accepted: September 13, 2020

Advance Publication by J-STAGE: December 4, 2020

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doi: 10.1298/ptr.R0009

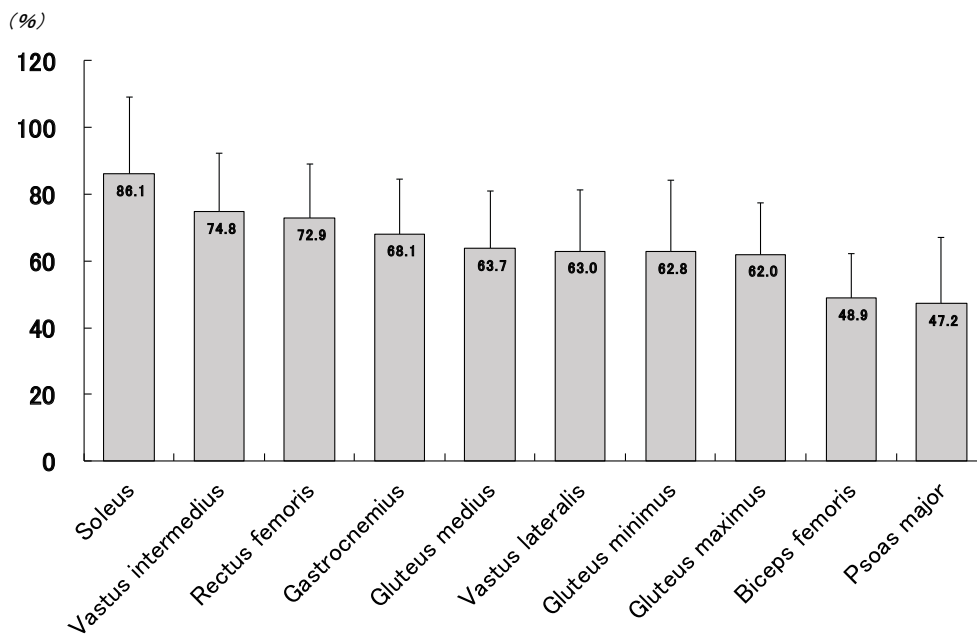


Figure 1. Magnitude of age-related decline (%) in the thickness of lower-limb muscles compared to the young reference group

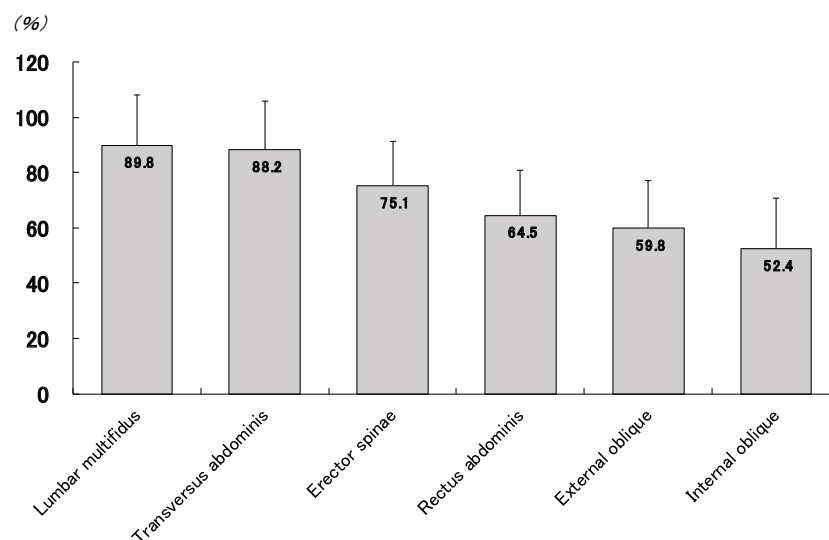


Figure 2. Magnitude of age-related decline (%) in the thickness of trunk muscles compared to the young reference group

mass of psoas major muscles because of decreased opportunities to run and stair climb in older adults.

The trunk muscles have a significant role in stabilizing the body, maintaining posture, and controlling spinal and pelvic movement, so atrophy of trunk muscle may cause an increase in fall risk and disability in daily living activities in older adults²⁴⁻²⁶. In literature, there have been many studies on age-related atrophy of the trunk muscles²⁷⁻³¹. In our previous study³¹, we showed that age-related muscle atrophy was smallest for the deep trunk muscles, including the transversus abdominis and lumbar multifidus muscles, in older women who were able to perform activities of daily living involving walking independently compared with

young women (Fig. 2). Deep trunk muscles, including the transversus abdominis and lumbar multifidus muscles, predominantly contain type I muscle fibers³². The transversus abdominis and lumbar multifidus muscles have an essential role in lumbar spine stabilization³³⁻³⁵. An electromyographic study showed that muscle activation levels of the trunk muscles, which are necessary to maintain stability for neutral spine posture are only 1%-3% of maximum voluntary contraction³⁶. Therefore, the muscle mass of the transversus abdominis and lumbar multifidus muscles might be maintained by a small amount of muscle contraction during daily physical activities, regardless of the aging process. On the other hand, in older women, the magnitude of the de-

Table 1. Changes in muscle thicknesses between baseline and 12 months later

Muscles	Baseline (mm)	12 months later (mm)	Percent change (%)
Rectus abdominis	6.2±1.9	6.1±1.9	0.4±16.4
External oblique	4.9±1.2	4.9±1.5	1.6±22.5
Internal oblique	7.1±2.0	6.8±2.5	-1.1±33.1
Transversus abdominis	3.2±1.0	3.1±1.1	0.8±23.3
Erector spinae	26.6±6.4	21.9±5.7*	-12.0±35.6
Lumbar multifidus	26.8±5.8	26.3±6.3	1.1±25.6
Psoas major	13.7±5.2	11.6±3.1	-5.4±35.7
Gluteus maximus	15.3±4.0	14.8±4.8	-1.7±23.4
Gluteus medius	15.5±4.4	15.2±5.0	-0.1±27.2
Gluteus minimus	12.3±3.9	12.3±4.0	1.6±30.2
Rectus femoris	16.5±4.2	11.5±4.2**	-28.3±25.0
Vastus lateralis	13.2±3.9	10.6±3.4**	-17.3±25.2
Vastus intermedius	10.8±3.1	8.4±2.8**	-19.8±22.9
Biceps femoris	18.3±4.6	17.3±5.5	-2.6±30.8
Gastrocnemius	11.3±3.3	10.9±2.4	1.8±26.4
Soleus	29.3±6.8	28.3±5.5	-0.6±20.8
Tibialis anterior	21.8±3.1	18.7±2.5**	-12.8±14.0

*p < 0.05 compared with baseline. **p < 0.01 compared with baseline.

cline in muscle mass was greater for internal and external oblique muscles than that in young women, suggesting marked age-related changes in these muscles among the trunk muscles. There may be an association between the decrease in the opportunity to perform physical activity with the movement of trunk rotation in older people and the greatest degree of atrophy for these muscles.

Additionally, due to the lack of specialized exercise training, decreases in muscle mass may occur in as little as 12 months and may lead to difficulty ambulating. Our longitudinal study³⁷⁾ showed that age-related atrophy progression may occur in the erector spinae, quadriceps femoris, and tibialis anterior muscle in as little as 12 months among trunk and lower-limb muscles (Table 1). Furthermore, our findings suggested that, among frail older women, reduced walking ability exacerbates age-related muscle atrophy in the trunk and lower-limb muscles, especially in the vastus lateralis muscle³⁷⁾.

Age-Related Change in Muscle Quality

Several cross-sectional studies have demonstrated that the amount of intramuscular fibrous and adipose tissue (noncontractile tissue) in the muscle increases with aging³⁸⁻⁴⁰⁾. Muscle echo intensity on ultrasound images using grayscale analysis has been used as an index of the amount of noncontractile tissue in the muscle. Enhanced echo intensity indicates changes in muscle quality due to increased intramuscular fibrous and adipose tissue, that is, noncontractile tissue in the muscle^{41,42)}. In our previous study⁴³⁾, we showed that muscle echo intensity of the quadriceps femo-

ris muscles was significantly higher in older women than in young women, which may suggest increases in noncontractile tissue in the muscle due to aging.

In some reports, it was revealed that not only muscle mass but also muscle quality has influenced muscle strength, which were measured by muscle echo intensity on ultrasound images using grayscale analysis as an index of the amount of noncontractile tissue⁴⁴⁻⁴⁷⁾. Fukumoto et al.⁴⁴⁾ showed that muscle echo intensity measured using computer-aided grayscale analysis of an ultrasound image independently contributes to muscle strength in middle-aged and older people, which suggests an association between increased fat and fibrous tissues within the muscle and poor muscle strength. Furthermore, several studies indicated that muscle quality, which was determined by muscle echo intensity on ultrasound images, influences muscle power, and rate of torque development, that is, the ability to produce rapid muscle contraction and the capacity to perform functional activities such as standing up from a chair and gait speed in older populations^{43,47-49)}.

Age-related changes in muscle quality may occur at an earlier age than the loss of muscle mass^{50,51)}. Ota et al.⁵¹⁾ demonstrated that age-related decreases in muscle thickness of the rectus abdominis and external oblique muscles occur after 50 years of age; on the other hand, age-related changes in muscle quality, which were measured by muscle echo intensity occur after 30 years of age (Table 2). Thus, the proportion of noncontractile tissue such as intramuscular fat may be more susceptible to aging than muscle atrophy. Therefore, from middle age onward, interventions that are aimed at decreasing intramuscular fat and fibrous tissue

Table 2. Comparison of muscle thickness (mm) and echo intensity (0-255) among the age groups

	age group of 20's (n = 23)	age group of 30's (n = 18)	age group of 40's (n = 22)	age group of 50's (n = 26)	age group of 60's (n = 23)
Muscle thickness					
Rectus abdominis	9.59 ± 1.75	8.94 ± 1.86	8.20 ± 1.85	7.72 ± 2.13**	7.27 ± 1.39**†
External oblique	6.15 ± 1.45	5.77 ± 1.49	5.31 ± 1.40	4.39 ± 1.16***‡	4.35 ± 1.11***‡
Transversus abdominis	3.72 ± 0.49	3.92 ± 1.18	3.78 ± 1.13	3.28 ± 0.65	3.58 ± 0.82
Lumbar multifidus	26.25 ± 3.76	27.18 ± 4.45	26.65 ± 4.53	27.87 ± 4.66	26.85 ± 4.27
Echo intensity					
Rectus abdominis	38.93 ± 28.58	60.52 ± 18.68*	73.13 ± 18.35**	82.24 ± 14.34***‡	87.61 ± 20.98***‡
External oblique	56.77 ± 17.17	73.50 ± 10.82**	81.74 ± 13.39**	85.18 ± 10.56***†	88.23 ± 13.49***‡
Transversus abdominis	19.42 ± 13.36	32.90 ± 12.84*	34.07 ± 15.69***‡	48.68 ± 13.12***§	46.00 ± 17.61***‡
Lumbar multifidus	30.22 ± 13.21	34.23 ± 14.02	41.06 ± 14.91*	49.52 ± 10.08***‡	51.36 ± 12.90***‡

Significant difference compared with 20's group (*p < 0.05, **p < 0.01)

Significant difference compared with 30's group (†p < 0.05, ‡p < 0.01)

Significant difference compared with 40's group (‡p < 0.05, §p < 0.01)

may be needed.

Resistance Training for Older Adults

At the end of the 1980s, Frontera et al.⁵²⁾ reported that a heavy-resistance training program caused an increase in the knee extensor strength of older men, accompanied by muscle hypertrophy. Since then, an annually increasing number of studies have continued to document the benefits of resistance training for older people. It is traditionally believed that, to stimulate muscle hypertrophy, an individual must train with at least 60%-80% of their one-repetition maximum (1RM). However, high-load training is often unsuitable for older patients who have uncontrolled hypertension or cardiovascular diseases and degenerative joint diseases. Therefore, developing an effective method of low-load training is necessary. Regarding the effects of low-intensity resistance training, a similar degree of muscle hypertrophy has been reported to be achieved with low-intensity training by increasing the number of repetitions⁵³⁻⁵⁵⁾. This result suggests that, by increasing the number of repetitions, low-intensity training can generate similar effects on muscle mass and characteristics similar to those of high-intensity training. High muscle fiber recruitment and type II fiber activation have been generally accepted to be necessary to induce muscle hypertrophy. Muscle hypertrophy seems to be largely dependent on elevated muscle protein synthesis, which is independent of training load, as long as the training volume is sufficient to recruit type II fibers⁵⁶⁾. Therefore, resistance training with high-repetition frequency has been assumed to increase fiber recruitment to sustain muscle tension and stimulate muscle protein synthesis, which promote muscle hypertrophy, regardless of low-intensity condition⁵⁷⁾.

Several studies indicated that quantitative and qualitative muscle properties, including muscle mass and accumu-

lation of noncontractile elements in the muscles, are independent contributors to muscle strength and rapid force production among older people. Therefore, the effective interventions' development to prevent not only the aging-related muscle atrophy but also the intramuscular accumulation of noncontractile tissue may be worthwhile in a clinical setting. The recent studies have shown that resistance training can elicit significant decreases in echo intensity, which is considered an indication of intramuscular infiltration by noncontractile elements⁵⁸⁻⁶¹⁾. From our previous study, it is shown that, even at the low intensity, 8-week resistance training has an effect on muscle hypertrophy and results in muscle quality improvement regardless of exercise velocity in older adults (Table 3).

Some reports suggest that, in order to improve muscle quality than to improve muscle mass, a longer period of intervention is possibly required, which was measured by muscle echo intensity^{61,62)}. Our time-course study⁶²⁾ revealed that significant change in muscle thickness of rectus femoris muscle was evident after week 4 during resistance training on knee extensor muscles (Fig. 3), whereas that for echo intensity of rectus femoris muscle was observed after week 8, which suggest that muscle mass changed at an earlier stage of the intervention than did muscle quality (Fig. 4). Radaelli et al.⁶¹⁾ who investigated changes in muscle thickness and echo intensity at weeks 6, 13, and 20 during resistance training in healthy older women also showed that although muscle thickness changes were observed after week 6, echo intensity changes were observed after week 13.

Conclusion

In literature, there are numerous studies that have demonstrated that resistance strength training has an effective role in improving or maintaining muscle function of

Table 3. Effects of low-intensity resistance training on muscle function in HV and LV groups

Variables	HV group (n = 17)			LV group (n = 15)		
	Before	After	%	Before	After	%
Muscle strength (Nm)	51.3 ± 16.6	64.2 ± 20.3 **	29.0%	51.9 ± 11.0	67.8 ± 18.8 **	32.3%
Muscle thickness (cm)	1.52 ± 0.54	2.10 ± 0.59 **	43.8%	1.83 ± 0.52	2.47 ± 0.54 **	40.7%
Echo intensity (0 - 255)	67.3 ± 14.8	53.8 ± 7.56 **	16.9%	67.8 ± 8.95	53.5 ± 9.47 **	20.5%

Abbreviations: HV, High-velocity; LV, Low-velocity.

* p < 0.05, ** p < 0.01; significant difference compared with before training

Percentage indicates ratio between before and after training

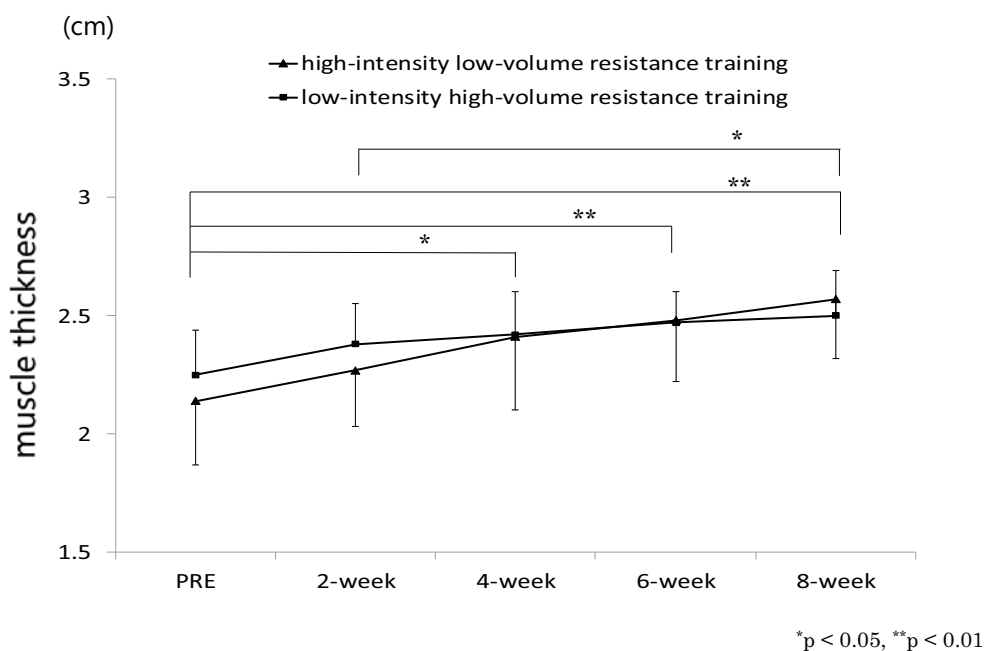


Figure 3. Change in rectus femoris muscle thickness over time

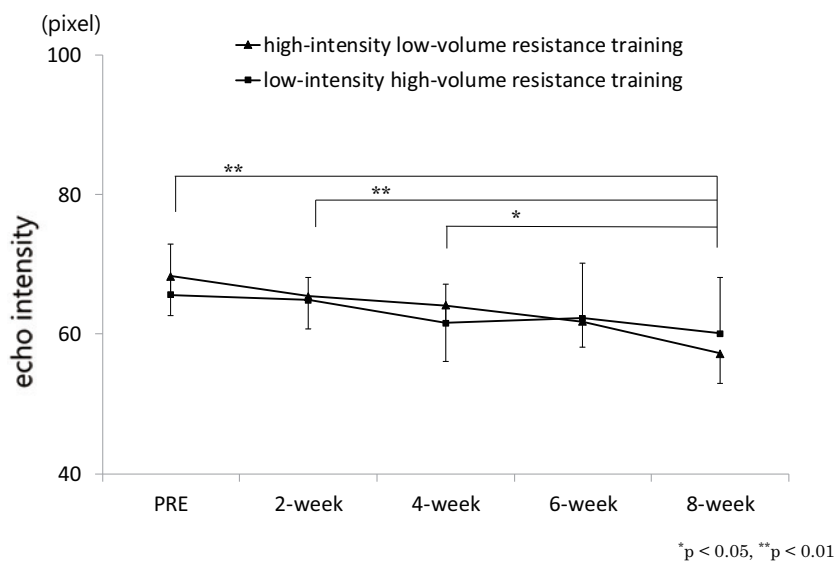


Figure 4. Change in rectus femoris echo intensity over time

older people. Thereby, resistance training contributes to improved capacity to perform functional activities as well as enhanced quality of life among older adults. It has been pointed out that the accumulation of noncontractile elements in the muscles may be a key mechanism related to decreased capacity of generated force. Therefore, strategies that are aimed at enhancing the functional performance of older people should also focus on muscle quality improvement. Recent studies have reported the effectiveness of resistance training on muscle quality such as muscular infiltration of noncontractile elements for older people. Moreover, for examining the long-term effects of resistance training on muscle characteristics and further clarifying the most effective intervention for improving muscle function, future studies will be needed.

Conflict of Interest: There are no conflicts of interest to disclose.

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