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

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 years. 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 people. 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 imaging. Therefore, measurements of muscle thickness using ultrasound can be used to noninvasively estimate the degree of muscle atrophy.

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. 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 maximus. Generally, among type II fibers, greater rates of age-related loss occur, while among type I fibers, only moderate losses occur. 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. This may be due to marked decreases in muscle...
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 adults. In literature, there have been many studies on age-related atrophy of the trunk muscles. In our previous study, 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 fibers. The transversus abdominis and lumbar multifidus muscles have an essential role in lumbar spine stabilization. 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 contraction. 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-
tractile tissue in the muscle

intramuscular fibrous and adipose tissue, that is, noncontractile tissue in the muscle. Enhanced echo intensity indicates changes in muscle quality due to increased noncontractile tissue in the muscle. Computer-aided grayscale analysis has been used as an index of the amount of noncontractile tissue.

grayscale analysis has been used as an index of the amount of intramuscular fibrous and adipose tissue, that is, noncontractile tissue in the muscle. Enhanced echo intensity may occur in the erector spinae, quadriceps femoris, and tibialis anterior muscle in as little as 12 months among elderly 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. 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 tissue. Fukumoto et al. 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.

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 aging. 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. In our previous study, we showed that muscle echo intensity of the quadriceps femoris 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 tissue. Fukumoto et al. 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.

Age-related changes in muscle quality may occur at an earlier age than the loss of muscle mass. Ota et al. 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>
<thead>
<tr>
<th>Muscles</th>
<th>Baseline (mm)</th>
<th>12 months later (mm)</th>
<th>Percent change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectus abdominis</td>
<td>6.2±1.9</td>
<td>6.1±1.9</td>
<td>0.4±16.4</td>
</tr>
<tr>
<td>External oblique</td>
<td>4.9±1.2</td>
<td>4.9±1.5</td>
<td>1.6±22.5</td>
</tr>
<tr>
<td>Internal oblique</td>
<td>7.1±2.0</td>
<td>6.8±2.5</td>
<td>-1.1±33.1</td>
</tr>
<tr>
<td>Transversus abdominis</td>
<td>3.2±1.0</td>
<td>3.1±1.1</td>
<td>0.8±23.3</td>
</tr>
<tr>
<td>Erector spinæ</td>
<td>26.6±6.4</td>
<td>21.9±5.7*</td>
<td>-12.0±35.6</td>
</tr>
<tr>
<td>Lumbar multifidus</td>
<td>26.8±5.8</td>
<td>26.3±6.3</td>
<td>1.1±25.6</td>
</tr>
<tr>
<td>Psoas major</td>
<td>13.7±5.2</td>
<td>11.6±5.1</td>
<td>-5.4±35.7</td>
</tr>
<tr>
<td>Gluteus maximus</td>
<td>15.3±4.0</td>
<td>14.8±4.8</td>
<td>-1.7±23.4</td>
</tr>
<tr>
<td>Gluteus medius</td>
<td>15.5±4.4</td>
<td>15.2±5.0</td>
<td>-0.1±27.2</td>
</tr>
<tr>
<td>Gluteus minimus</td>
<td>12.3±3.9</td>
<td>12.3±4.0</td>
<td>1.6±30.2</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>16.5±4.2</td>
<td>11.5±4.2**</td>
<td>-28.3±25.0</td>
</tr>
<tr>
<td>Vastus lateralis</td>
<td>13.2±3.9</td>
<td>10.6±3.4**</td>
<td>-17.3±25.2</td>
</tr>
<tr>
<td>Vastus intermedius</td>
<td>10.8±3.1</td>
<td>8.4±2.8**</td>
<td>-19.8±22.9</td>
</tr>
<tr>
<td>Biceps femoris</td>
<td>18.3±4.6</td>
<td>17.3±5.5</td>
<td>-2.0±30.8</td>
</tr>
<tr>
<td>Gastrocnemius</td>
<td>11.3±3.3</td>
<td>10.9±2.4</td>
<td>1.8±26.4</td>
</tr>
<tr>
<td>Soleus</td>
<td>29.3±6.8</td>
<td>28.3±5.5</td>
<td>-0.6±20.8</td>
</tr>
<tr>
<td>Tibialis anterior</td>
<td>21.8±3.1</td>
<td>18.7±2.5**</td>
<td>-12.8±14.0</td>
</tr>
</tbody>
</table>

*p < 0.05 compared with baseline. **p < 0.01 compared with baseline.
Resistance Training for Older Adults

At the end of the 1980s, Frontera et al.\(^\text{52}\) 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 repetitions\(^\text{53,54}\). 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 fibers\(^\text{55}\). 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 condition\(^\text{56}\).

Several studies indicated that quantitative and qualitative muscle properties, including muscle mass and accumulation 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 elements\(^\text{56,61}\). 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\(^\text{62}\). Our time-course study\(^\text{62}\) 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.\(^\text{61}\) 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

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

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

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 \((p < 0.05, \ p < 0.01)\)
Table 3. Effects of low-intensity resistance training on muscle function in HV and LV groups

<table>
<thead>
<tr>
<th>Variables</th>
<th>HV group (n = 17)</th>
<th></th>
<th>LV group (n = 15)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>%</td>
<td>Before</td>
</tr>
<tr>
<td>Muscle strength (Nm)</td>
<td>51.3 ± 16.6</td>
<td>64.2 ± 20.3 **</td>
<td>29.0%</td>
<td>51.9 ± 11.0</td>
</tr>
<tr>
<td>Muscle thickness (cm)</td>
<td>1.52 ± 0.54</td>
<td>2.10 ± 0.59 **</td>
<td>43.8%</td>
<td>1.83 ± 0.52</td>
</tr>
<tr>
<td>Echo intensity (0 - 255)</td>
<td>67.3 ± 14.8</td>
<td>53.8 ± 7.56 **</td>
<td>16.9%</td>
<td>67.8 ± 8.95</td>
</tr>
</tbody>
</table>

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.

References
30) Ota M, Ikezoe T, et al.: Age-related changes in the thickness of...