Site-related Differences in Muscle Loss with Aging
“A Cross-sectional Survey On The Muscle Thickness in Japanese Men Aged 20 to 79 Years”

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The studied muscle loss with aging, focusing on differences due to muscle group location. Muscle thickness at nine sites—forearm, upper arm anterior and posterior, abdomen, subscapular, thigh anterior and posterior, and lower leg anterior and posterior—were determined using a brightness-mode ultrasonography in 348 Japanese men aged 20 to 79 years. Only the upper arm anterior did not show a significant effect of age. For other sites, the starting age group that significantly decreased from 20-29 yr and 30-39 yr was 40-49 yr for the forearm and abdomen, 50-59 yr for the thigh anterior, 60-69 yr for the upper arm posterior, lower leg anterior and posterior, and subscapular, and 70-79 yr for the thigh posterior. The relative reduction between the 20-29 yr and 70-79 yr groups in the muscle thickness at the abdomen and thigh anterior were greater than those in the other sites. In addition, the upper arm and thigh showed a preferential loss with aging at the posterior and anterior sites. Thus, the present results indicated that the loss of muscle thickness with aging differed between body segments and between sites within the same segment. The reasons for the site-related differences in muscle loss with aging may be attributed to age-related changes in the patterns of loading to individual muscles and/or their activations, which are encountered during daily life.

Keywords: aging, ultrasonography, reciprocal muscles, site-related difference

1. Introduction

The influences of aging on muscle size have been studied extensively through observations on muscle cross-sectional area [Bemben et al. (1983); Frontera et al. (2000); Kent-Braun et al. (2001); Klein et al. (2001); Kitgaard et al. (1990); Overend et al. (1992); Rice et al. (1989,1990)] and muscle mass [Janssen et al. (2000)]. What seems to be lacking, however, is information on muscle groups located in the trunk. It is unknown whether age-related change in muscle size differs between muscle groups located in the posterior and anterior sites within the same segment. Functional significance clearly differs between individual muscle groups located at each of the anterior and posterior sites of the body. Hence, data on the age-related changes in the size of reciprocal muscle groups in the body may provide significant information on muscle function and physical working potential in the elderly.

Ultrasonography using the real time brightness mode (B-mode) has the same advantages as computed tomography (CT) or magnetic resonance imaging (MRI) in visualizing fat and muscle tissues regardless of location [Ishida et al. (1995)]. Hence ultrasonographic techniques have been successfully used to measure muscle cross-sectional area [Sipila and Suominen (1991)] and thickness [Ishida et al. (1997)] in elderly populations. In addition, muscle thickness determined from a single ultrasonographic image can be highly correlated to the whole cross-sectional area [Abe et al. (1997)] and volume [Miyatani et al. (2002)] measured by MRI, although the muscle group examined was limited to knee extensors. This suggests that the thickness of a muscle, determined using ultrasonography, reflects its whole cross-sectional area and volume, even if it is determined at a single site, and
can be a representative variable to investigate the loss of muscle size with aging.

We determined muscle thickness at nine sites using a B-mode ultrasonographic apparatus in males aged 20 to 79 years. The aim of the present study was to investigate the age-related changes in muscle thickness, with specific emphasis on the differences due to the location of muscle groups.

2. Methods

Subject. 348 healthy Japanese men volunteers aged 20 to 79 years, divided into six age groups (20-29 yr, G20; 30-39 yr, G30; 40-49 yr, G40; 50-59 yr, G50; 60-69 yr, G60; 70-79 yr, G70). The means and standard deviations (SDs) in age and anthropometric variables for each age group are shown in Table 1. The height and weight of each subject were within the normal range of the corresponding age group in Japanese men. None of the subjects was or had been an athlete. Moreover, none used canes or other walking aids and all were functionally independent in daily life. This study was approved by the Office of the Department of Sports Sciences, University of Tokyo and was consistent with requirements for human experimentation. Subjects were fully informed about procedures to be used and the purpose of the study. Written informed consent was obtained from all subjects.

Muscle thickness measurements. A real time B-mode ultrasound apparatus (SSD-500, Aloka Co., Tokyo) with a 5MHz scanning head was used to obtain cross-sectional images at nine sites on the body. The position of the subjects during the ultrasonographic measurements and the site selected for the measurements were the same as those described in previous studies [Abe et al. (1994); Ishida et al. (1995)]. During the measurements, the subjects remained in a standing position with legs and arms straight and the muscle relaxed. The anthropometric locations of the measurement sites were first precisely determined and marked by experienced technicians before the ultrasonic measurement. The anatomical landmarks for the measurement sites are noted below.

Forearm anterior: on the anterior surface 30% proximal between the styloid process and the head of the radius.

Upper arm anterior and posterior: on the anterior and posterior surfaces 60% distal between the lateral epicondyle of the humerus and the acromial process of the scapula.

Abdomen: at a distance 2-3 cm to the right of the umbilicus.

Subscapula: at a distance 5 cm directly below the inferior angle of the scapula.

Thigh anterior and posterior: on the anterior and posterior surfaces midway between the lateral condyle of the femur and the greater trochanter.

Lower leg anterior and posterior: on the anterior and posterior surfaces 30% proximal between the lateral malleolus of the fibula and the lateral condyle of the tibia.

The scanning head together with water-soluble transmission gel, which provided acoustic contact without depression of the skin, was placed perpendicular to the tissue interface under the marked sites. Distortion of tissue due to excess compression was
eliminated ensuring that no movement of tissues occurred in the real-time ultrasonic image. The thickness of muscle tissue was determined in accordance with the procedure described in previous studies [Abe et al. (1994); Ishida et al. (1995, 1997)]. Namely, the interfaces between subcutaneous adipose tissue and muscle and between muscle and bone were identified from the ultrasonic image, and the distance from the adipose tissue-muscle interface to muscle-bone interface was measured as a representative of muscle thickness. The muscle thickness at the abdomen was measured from the fat-muscle tissue interface to the muscle abdominal cavity boundary. The measurements were taken with a vernier caliper and measured to the nearest 0.1 mm. The accuracy and test-retest repeatability of the muscle thickness measurements were certified in prior studies [Abe et al. (1994); Miyatani et al. (2000)] imaging human cadaver and 21 young adult men.

Because the older subjects were shorter and weighed less than the younger counterparts as shown in Table 1, it was considered that the age-related differences observed in muscle thickness could be attributed to the difference in body size. The organ diameter in a variety of mammals is theoretically a function of (weight)\(^{0.3}\) (Gunther 1975). In addition to the absolute value, therefore, muscle thickness was expressed as a relative value to (body weight)\(^{0.3}\), Mt*BW\(^{-0.3}\) to compare age groups on muscle thickness regardless of the difference in body size. Before calculating the ratio, we confirmed that the muscle thickness at every site was significantly (P<0.001) correlated to BW with correlation coefficients of 0.390 to 0.690, as a result of a regression analysis for the data including all subjects.

Statistical analyses. Descriptive data were presented

### Table 2. Descriptive data on muscle thickness: mm.

<table>
<thead>
<tr>
<th>Sites</th>
<th>G20, n=61</th>
<th>G30, n=70</th>
<th>G40, n=48</th>
<th>G50, n=39</th>
<th>G60, n=68</th>
<th>G70, n=82</th>
</tr>
</thead>
<tbody>
<tr>
<td>forearm</td>
<td>25.8 (2.85)</td>
<td>26.0 (3.42)</td>
<td>24.5 (3.23) #</td>
<td>23.0 (2.88) #</td>
<td>24.9 (2.75)</td>
<td>23.4 (3.66) #</td>
</tr>
<tr>
<td>upper arm anterior</td>
<td>33.5 (2.90)</td>
<td>34.2 (2.95)</td>
<td>33.6 (2.69)</td>
<td>33.6 (2.69)</td>
<td>34.7 (3.21)</td>
<td>33.9 (3.05)</td>
</tr>
<tr>
<td>upper arm posterior</td>
<td>36.8 (4.41)</td>
<td>36.6 (6.08)</td>
<td>36.3 (5.03)</td>
<td>35.6 (3.74)</td>
<td>34.4 (4.01) #</td>
<td>32.6 (4.11) #</td>
</tr>
<tr>
<td>thigh anterior</td>
<td>54.8 (6.38)</td>
<td>53.2 (6.79)</td>
<td>51.2 (6.61)</td>
<td>48.0 (5.76) #</td>
<td>44.1 (4.70) #</td>
<td>40.6 (4.93) #</td>
</tr>
<tr>
<td>thigh posterior</td>
<td>65.2 (6.48)</td>
<td>66.2 (6.73)</td>
<td>63.5 (6.33)</td>
<td>64.3 (6.36)</td>
<td>65.0 (4.75)</td>
<td>61.4 (5.53) #</td>
</tr>
<tr>
<td>lower leg anterior</td>
<td>32.1 (2.70)</td>
<td>31.7 (3.21)</td>
<td>32.2 (3.95)</td>
<td>31.3 (2.93)</td>
<td>28.0 (2.69) #</td>
<td>27.8 (2.62) #</td>
</tr>
<tr>
<td>lower leg posterior</td>
<td>72.3 (6.33)</td>
<td>71.1 (5.82)</td>
<td>71.0 (6.15)</td>
<td>69.2 (5.50)</td>
<td>66.2 (5.04) #</td>
<td>63.0 (4.67) #</td>
</tr>
<tr>
<td>abdomen</td>
<td>14.0 (2.31)</td>
<td>13.4 (2.64)</td>
<td>12.1 (2.73) #</td>
<td>11.9 (2.49) #</td>
<td>10.8 (1.82) #</td>
<td>9.7 (1.60) #</td>
</tr>
<tr>
<td>subscapular</td>
<td>25.5 (5.49)</td>
<td>23.9 (5.01)</td>
<td>23.1 (4.99)</td>
<td>22.5 (4.77)</td>
<td>20.2 (3.86) #</td>
<td>18.7 (4.25) #</td>
</tr>
</tbody>
</table>

Values are means (SDs). #, significantly lower than G20 and G30 at P<0.05

### Table 3. Descriptive data on muscle thickness relative to (body weight)\(^{0.3}\): mm\(\times 10^{-3}\).

<table>
<thead>
<tr>
<th>Sites</th>
<th>G20, n=61</th>
<th>G30, n=70</th>
<th>G40, n=48</th>
<th>G50, n=39</th>
<th>G60, n=68</th>
<th>G70, n=82</th>
</tr>
</thead>
<tbody>
<tr>
<td>forearm</td>
<td>8.31 (0.64)</td>
<td>8.30 (0.74)</td>
<td>6.08 (0.74)</td>
<td>5.70 (0.67) #</td>
<td>6.32 (0.68)</td>
<td>6.03 (0.60) #</td>
</tr>
<tr>
<td>upper arm anterior</td>
<td>8.20 (0.62)</td>
<td>8.30 (0.66)</td>
<td>8.58 (0.64) b</td>
<td>8.33 (0.59)</td>
<td>8.82 (0.83) b</td>
<td>8.75 (0.83) b</td>
</tr>
<tr>
<td>upper arm posterior</td>
<td>9.01 (0.98)</td>
<td>8.87 (1.28)</td>
<td>8.96 (1.21)</td>
<td>8.96 (1.21)</td>
<td>8.72 (0.98)</td>
<td>8.42 (1.06) #</td>
</tr>
<tr>
<td>thigh anterior</td>
<td>13.36 (1.44)</td>
<td>12.89 (1.36)</td>
<td>12.62 (1.44)</td>
<td>11.93 (1.43) #</td>
<td>11.19 (1.13) #</td>
<td>10.46 (1.10) #</td>
</tr>
<tr>
<td>thigh posterior</td>
<td>15.96 (1.35)</td>
<td>16.06 (1.34)</td>
<td>15.68 (1.34)</td>
<td>15.96 (1.29)</td>
<td>16.49 (1.07) b</td>
<td>15.83 (1.00)</td>
</tr>
<tr>
<td>lower leg anterior</td>
<td>7.85 (0.60)</td>
<td>7.70 (0.68)</td>
<td>7.95 (0.88)</td>
<td>7.77 (0.58)</td>
<td>7.11 (0.62) #</td>
<td>7.16 (0.64) #</td>
</tr>
<tr>
<td>lower leg posterior</td>
<td>17.68 (1.28)</td>
<td>17.28 (1.06)</td>
<td>17.53 (1.18)</td>
<td>17.18 (1.11)</td>
<td>16.79 (1.18) #</td>
<td>16.25 (0.92) #</td>
</tr>
<tr>
<td>abdomen</td>
<td>3.42 (0.56)</td>
<td>3.25 (0.61)</td>
<td>2.99 (0.63) #</td>
<td>2.95 (0.57) #</td>
<td>2.74 (0.46) #</td>
<td>2.49 (0.39) #</td>
</tr>
<tr>
<td>subscapular</td>
<td>6.23 (1.30)</td>
<td>5.78 (1.12)</td>
<td>5.69 (1.13)</td>
<td>5.58 (1.07)</td>
<td>5.12 (0.92) #</td>
<td>4.82 (1.05) #</td>
</tr>
</tbody>
</table>

Values are means (SDs). #, significantly lower than G20 and G30 at P<0.05
b, significantly higher than G20 and G30 at P<0.05
Age-related Change in Muscle Distribution

![Graph showing percentage of G70 to G20 in Mt (%)](image)

Fig. 1. Comparison between sites of the percentage of the mean value of muscle thickness in G70 to that of G20.

as the mean and SD for each age group. A one-way analysis of variance (ANOVA) was used to assess the effect of age on the measured variables. When a significant effect of age was found, Dunnet’s multiple comparison technique was used to determine the specific age group that was significantly different from G20 and G30. In this connection, at first, we confirmed that there were no significant differences between G20 and G30 in any measurement values. The probability level for statistical significance was set at \( P<0.05 \).

3. Results

Table 2 shows the mean and SD of the muscle thickness at every site in each age group. Among the sites examined, only the upper arm anterior did not show a significant effect of age. For the other sites, the starting age group that was significantly different from G20 and G30 was G40 for the forearm and abdomen, G50 for the thigh anterior, G60 for the upper arm posterior, lower leg anterior and posterior, and subscapular, and G70 for the thigh posterior.

The percentage of the mean value of muscle thickness in G70 to that in G20 was lower at the abdomen (69.3%), subscapular (73.3%) and thigh anterior (74.4%) than at the upper arm anterior (101.2%), thigh posterior (94.2%), and forearm (90.7%) (Fig.1). The corresponding values at the upper arm posterior, and lower leg anterior and posterior ranked in the middle position (86.6-88.6%) between the sites mentioned above.

The mean and SD of Mt•BW\(^{1/3}\) at every site in each age group are shown in Table 3. Dunnet’s multiple comparison of Mt•BW\(^{1/3}\) indicated that G40 for the abdomen, G50 for the forearm and thigh anterior, and G60 for the lower leg anterior and posterior and subscapular were the starting age groups that were significantly lower from G20 and G30 (Table 3). However, Mt•BW\(^{1/3}\) at the upper arm anterior for G40, G60 and G70 and thigh posterior for G60 showed significantly higher values than those for G20 and G30.

4. Discussion

The major findings of this study were that 1) the relative reductions between the 20-29 yr and 70-79 yr groups in the muscle thickness at the abdomen and thigh anterior were greater than those in the other sites, and 2) the upper arm and thigh showed a preferential loss with aging at the posterior and anterior sites. These results indicate that the loss of muscle thickness with aging differs between body segments and between sites within the same segment. Since the muscle thickness at every site was significantly correlated to BW\(^{1/3}\), the age-related differences observed in muscle thickness can be partially attributed to the difference in body size. However, the present result on the muscle thickness relative to BW\(^{1/3}\) indicated that skeletal muscle at all sites except for the upper arm anterior and thigh posterior were relatively reduced with aging regardless of the difference in body size.

Prior studies using imaging techniques such as MRI or CT have indicated that the loss of skeletal muscle mass with aging was greater in the lower than upper body (Janssen et al. (2000); Klitgaard et al. (1990)). In this study, too, the relative differences in muscle thickness between the younger and elderly groups tended to be greater in the upper than lower extremity. However, it should be noted that the muscle thickness and Mt•BW\(^{1/3}\) at the forearm showed significant age-related losses at earlier ages as observed in those at the thigh anterior. In addition, the upper arm and thigh showed a preferential loss at the posterior and anterior sites, respectively. Notably, the upper arm posterior showed a similar age-related change to that observed in the lower leg, i.e., significant losses from the sixth decade of age. Conversely, the muscle thickness at the thigh posterior showed a maintenance phase into the sixth decade and the difference between G20 and G70 became insignificant in terms of Mt•BW\(^{1/3}\). These results indicate that, regardless of the upper and lower extremities, the age-related losses in limb muscles differ between sites.
The result that the forearm showed age-related loss at earlier ages as observed at the thigh anterior is consistent with previous findings on the effect of aging on grip strength [Kallman et al. (1990); Viitasalo et al. (1985)]. From the report of Kallman et al. (1990), grip strength declined at an accelerating rate after the fourth decade of life. Viitasalo et al. (1985) also observed a similar age-related change in grip as that in knee extensor strength. With regard to the age-related changes in the size of the reciprocal muscle groups located in the thigh for men, available information is limited to data obtained by applying the CT method to a small sample size of subjects [Frontera et al. (2000); Overend et al. (1992)]. As a result of a cross-sectional observation, Overend et al. (1992) found that the cross-sectional area of the knee extensors was significantly greater in young compared to elderly men, but that the knee flexors showed an insignificant difference between the two populations. On the other hand, Frontera et al. (2000) reported that, based on a longitudinal observation for 12 years, both the knee extensor and flexor muscles for elderly men showed similar declines in their cross-sectional areas. However, it should be noted that the initial mean age of the subjects examined by Frontera et al. (2000) was 65.4 yr. If one calculates the relative difference between the average values of G60 and G70 in the muscle thickness, a similar value is also found between the thigh anterior (8%) and posterior (6%). Hence, the discrepancy between the results of this study and Frontera et al. (2000) may be referred to the difference in the range of the age of subjects tested.

In addition to the site-related differences in the age-related changes in limb muscles, this study provided evidence that the muscles located in the trunk region, especially at the abdomen, are as susceptible to the influence of aging as those at the thigh anterior. As in vivo observations, available data on the age-related change in muscle thickness in the trunk region is limited to the findings of Ishida et al. (1997) on women. They compared young and middle-aged women of muscle thickness at nine sites of the body, determined using the same procedure taken in this study, and reported that muscle thickness at the abdomen showed a greater loss as compared to that at the thigh anterior.

Borkan et al. (1983) have compared the lean tissue area of the trunk, determined by the CT method, between middle-aged and older men. In their results, the relative difference between the two age groups in the whole lean tissue area of abdomen at the umbilicus (9%) was similar to that observed in the leg and arm (12%). It is unclear whether the discrepancy between the findings of the studies mentioned above can be explained by the differences in the gender and age of subjects tested and/or the variables analyzed (muscle thickness vs. lean tissue area). From the findings of an autopsy study [Inokuchi et al. (1975)], however, the percentage of the mean cross-sectional area of the rectus abdominis in men in their 70’s compared to those in their 20’s, 67%, was lower than that in women, 83%. As compared to the relative value for the men, the corresponding difference between G20 and G70 in the muscle thickness at the abdomen, 69%, was almost the same.

As one reason for the site-related difference in skeletal muscle loss with aging, differences between muscles in the magnitude of their activities during daily life have been considered [Buben et al. (1991); Janssen et al. (2000); Viitasalo et al. (1985)]. A reduction in physical activity with aging would primarily be associated with a decreased use of lower body muscles, but not upper body muscles, because the use of the hand would remain important at all ages [Buben et al. (1991); Janssen et al. (2000)]. This may be responsible for the age-related losses of muscles located in the trunk and lower extremities, which function in postural and locomotion-like activities. Klitgaard et al. (1990) observed that the type II fiber area and whole cross-sectional area of the quadriceps femoris and elbow flexors muscles in elderly strength-trained men were identical to those in young controls. However, the corresponding values in elderly swim- and running-trained men were similar to those in elderly control subjects [Klitgaard et al. (1990)]. As a countermeasure to deconditioning during immobilization such as bed rest, the effect of resistance training is limited to the exercising muscles [Akima et al. (2000)]. From the findings of Danneels et al. (2001), who investigated the effect of different training programs on the cross-sectional area of the paravertebral muscles in chronic low back pain patients, stabilization exercises had no effect, but dynamic training induced significant hypertrophic change. Taking these findings into account, it seems that the site-related differences observed in the loss of muscle thickness with aging can be attributed to changes in the specific patterns of loading to individual muscles and/or their activation levels rather than total amounts during physical activities in daily life. In another investigation, we observed that the muscle thickness of the lower leg posterior for the elderly aged in their 80’s was significantly correlated to the physical activity level determined by pedometers, but that of the thigh anterior was not (Abe and Fukunaga, unpublished data). This partially supports the assumption mentioned above. In any case, further study is needed to elucidate the reasons for the site-related difference in the loss of muscle size with aging.

Before generalizing the present results, we should comment about the limitation of the muscle thickness
measurements taken in this study. Namely, the muscle thickness obtained in this study included non-muscle tissue located within a muscle compartment, and was not the thickness of ‘pure’ muscle tissue. It is well documented that aging increases the percentage of nonmuscle tissue content in the cross-sectional area or volume of the muscle compartment (Borkan et al. (1983); Kent-Braun et al. (2000); Overend et al. (1992); Rice et al. (1989,1990)]. Unfortunately, we have no data on how the amount of non-muscle tissue in the tested muscles influences the observed age-related changes in the muscle thickness. If the amount of non-muscle tissue is taken into account, it is likely that the relative difference in the muscle thickness between the younger and elderly groups will become greater as compared to that observed here.

In summary, the present results indicate that, at least in healthy men aged 20 to 79 years, the muscles located in the trunk and lower limb, especially in the abdomen and thigh anterior, were more susceptible to the influences of aging as compared to those in the upper limbs. Further, the comparisons between the muscle thickness of the anterior and posterior sites provided evidence that the upper arm and thigh showed a different age-related loss of muscles between the two sites even within the same segment. The reasons for the site-related differences in muscle loss with age remain to be answered but may be attributed to the age-related changes in the pattern and/or intensity of physical activities during daily life.

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