Effects of Gender on Age-related Changes in Muscle Thickness in the Elderly

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This study investigated the effect of gender on age-related changes in muscle thickness (Mt) in the elderly, with relation to the differences due to the location of muscle groups. Mt values at the forearm, upper arm anterior and posterior, abdomen, subscapular, thigh anterior and posterior, and lower leg anterior and posterior were determined using ultrasonography in 188 men and 204 women aged 65 to 79 yrs. The men had thicker muscles than the women, with a greater relative difference in the upper limb and trunk compared to the lower limb muscles. For the men, Mt values at the upper limb, thigh and abdomen were negatively correlated to age ($r = -0.330$ to $-0.214$, $p < 0.05$). For the women, only the Mt at the thigh anterior showed a significant negative correlation with age ($r = -0.346$, $p < 0.05$). At the thigh anterior, there was no significant difference between both genders in the slope of the regression line for the relationship between age and percentages of Mt to the mean value for the subjects aged 65 to 69 yrs of men and women, respectively, suggesting that the rate of the age-related loss of Mt at this site was independent of gender. These results were the same even when Mt was expressed as the value relative to (body mass)$^{1/3}$, calculated to normalize the influence of the difference in body mass. The findings obtained here indicated that, in an age span from 65 to 79 yrs, 1) gender difference in muscle thickness was more apparent in the upper limb and trunk than in the lower limb muscles, and 2) men showed significant age-related losses in muscle thickness at more body sites as compared to women, especially at the upper limb and abdomen.

Keywords: muscle thickness, ultrasonography, aging, site-related difference

1. Introduction

The effects of age and gender on muscle size have been extensively studied using computerized tomography (CT) (Frontera, et al., 2000), magnetic resonance imaging (MRI) (Janssen, et al., 2000; Kent-Braun, et al., 2000), Dual-Energy X-ray Absorptiometry (DEXA) (Gallagher, et al., 1997) or the urinary creatinine excretion method (Frontera, et al., 1991). Janssen et al. (2000) reported that, regardless of gender, aging was associated with a decrease in the muscle mass of the total body, which was explained by a decrease in that of lower body. However, the previous studies cited here determined the cross-sectional area of only limited muscle groups located in limbs or else the muscle mass of either limb or total body. To our knowledge, only three studies (Ishida, et al., 1997; Miyatani, et al., 2003; Reimers, et al., 1998) have given attention to the site-related difference, i.e., anterior versus posterior sites within the same body segment, in muscle loss with aging. From the limited information, the age-related loss of muscle thickness differs between body segments and between sites within the same...
segment. In the two of the three studies, however, the subjects examined were only men (Miyatani, et al., 2003) or women (Ishida, et al., 1997). In the other study (Reimers, et al., 1998), both genders were used as subjects, but muscles examined were limited to those located in limbs.

Furthermore, the previous studies cited above have examined the effects of age and gender on muscle size using cross-sectional data obtained from samples with a wide variation of age, including both younger and older populations. After the fifth or sixth decade of life, there are noticeable decreases in not only absolute skeletal muscle mass (Janssen, et al., 2000) but also strength (Brooks and Faulkner 1994). Women generally weigh less and are shorter than males, with smaller muscles and less muscle strength, and thus have less functional reserve (Kwon, et al., 2001). Individual muscle groups located at each of the anterior and posterior sites of the body have different functional significances to each other. From the finding of Hughes et al. (2001), who determined longitudinally muscle strength in both genders with average ages of 60 yrs at the start of the study, females had a greater loss in knee extensor strength compared to elbow extensor strength, whereas men demonstrated similar rates of strength loss in both muscle groups. On the elderly who are in after the fifth or sixth decade of life, therefore, to clear the effect of gender on the age-related change in muscle size, with relation to the location of muscles, may provide useful information for discussing the possible gender differences in the functional aspects of this population.

In the present study, we determined muscle thickness (Mt) values at nine body sites using a brightness-mode (B-mode) ultrasonographic apparatus in men and women aged 65 to 79 yrs. The main purpose of the present study was to investigate the effect of gender on age-related changes in Mt in the elderly, with relation to the differences due to the location of muscle groups.

2. Methods

2.1. Subjects

A total of 392 healthy Japanese men (n=188) women (n=204) aged 65 to 79 yrs voluntarily participated in this study. The means and standard deviations (SDs) of age and anthropometric variables for the men and women are shown in Table 1. Regardless of gender, the height and body mass of every subject were within the normal range of the corresponding age group in the Japanese. None of the subjects was or had been an athlete. Moreover, none were using sticks 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 their requirements for human experimentation. The subjects were fully informed about the procedures to be used as well as the purpose of the study. Written informed consent was obtained from all the subjects.

2.2. Muscle thickness (Mt) 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 a previous study (Miyatani, et al., 2003). During the measurements, the subjects remained in a standing position with legs and arms straight and muscles relaxed. The anthropometric locations of the measurement sites were first precisely determined and marked by an experienced technician before the ultrasonic measurement. The anatomical landmarks for the measurement sites are noted below.

Forearm: on the anterior surface 30% distal to the styloid process from the head of the radius.
Upper arm: on the anterior and posterior surfaces 60% distal to the lateral epicondyle of the humerus from the acromial process of the scapula.
Thigh: on the anterior and posterior surfaces midway between the lateral condyle of the femur and the greater trochanter.
Lower leg: on the anterior and posterior surfaces 30% distal to the lateral malleolus of the fibula from the lateral condyle of the tibia.
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.

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 at 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. Mt was determined in accordance with the procedure described in a previous study (Miyatani, et al., 2003). 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 representative of Mt. The Mt 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 to the nearest 0.1 mm. The accuracy and test-retest repeatability of the Mt measurements were certified in prior studies (Abe, et al., 1994; Miyatani, et al., 2000) imaging a human cadaver and 21 adult males, respectively.

2.3. Statistical analyses

Descriptive data were presented as the mean and SD for each subject group. As shown in Table 1, there was a significant effect of gender on body height and mass. The possible age- and/or gender-related differences in skeletal muscle mass are influenced by the difference in body size such as body height and mass (Gallagher, et al., 1997). The organ diameter in a variety of mammals is theoretically a function of (body mass)$^{1/3}$ (Günther 1975). In addition to the absolute value, therefore, we calculated Mt relative to (body mass)$^{1/3}$, Mt:BM$^{-1/3}$. Prior to the data treatment, we certified the correlation between (body mass)$^{1/3}$ and Mt and obtained significant correlation coefficients of 0.213 to 0.516, ($p<0.05$) for the men and 0.211 to 0.598 ($p<0.05$) for the women. The observed correlation coefficient at every measurement site was higher than that between Mt and body height ($r=0.028$ to 0.218 for the men and $r=-0.024$ to 0.234 for the women). The significance of difference between the mean values of the men and women was tested by Student’s t-test. The relative difference between the mean values of the groups was expressed as a percentage of the mean value for the men. A simple regression analysis was used to calculate the correlation coefficient between age and each of Mt and Mt:BM$^{-1/3}$. For the site where

### Table 1  Physical characteristics of subjects

<table>
<thead>
<tr>
<th>Variables</th>
<th>Men, n=188</th>
<th>Women, n=204</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>70.7 ± 3.8</td>
<td>71.3 ± 3.7</td>
</tr>
<tr>
<td>Height, cm</td>
<td>161.5 ± 5.5</td>
<td>148.8 ± 5.5#</td>
</tr>
<tr>
<td>Body mass, kg</td>
<td>61.5 ± 7.4</td>
<td>52.5 ± 7.5#</td>
</tr>
<tr>
<td>BMI, kg·m$^{-2}$</td>
<td>23.5 ± 2.5</td>
<td>23.7 ± 3.1</td>
</tr>
<tr>
<td>Limb length, cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forearm</td>
<td>30.5 ± 1.3</td>
<td>28.5 ± 1.5#</td>
</tr>
<tr>
<td>Upper arm</td>
<td>22.1 ± 1.0</td>
<td>20.2 ± 1.1#</td>
</tr>
<tr>
<td>Thigh</td>
<td>36.7 ± 1.8</td>
<td>34.0 ± 1.9#</td>
</tr>
<tr>
<td>Lower leg</td>
<td>35.7 ± 1.8</td>
<td>33.2 ± 1.7#</td>
</tr>
<tr>
<td>Circumference, cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forearm</td>
<td>25.2 ± 1.5</td>
<td>22.5 ± 1.7#</td>
</tr>
<tr>
<td>Upper arm</td>
<td>27.4 ± 2.2</td>
<td>26.6 ± 2.6#</td>
</tr>
<tr>
<td>Thigh</td>
<td>46.1 ± 3.1</td>
<td>44.5 ± 3.6#</td>
</tr>
<tr>
<td>Lower leg</td>
<td>34.1 ± 2.1</td>
<td>32.8 ± 2.5#</td>
</tr>
<tr>
<td>Chest</td>
<td>92.4 ± 5.0</td>
<td>87.1 ± 5.7#</td>
</tr>
<tr>
<td>Waist</td>
<td>84.9 ± 7.9</td>
<td>78.4 ± 8.1#</td>
</tr>
<tr>
<td>Hip</td>
<td>91.3 ± 4.3</td>
<td>90.6 ± 5.4</td>
</tr>
</tbody>
</table>

Values are means±SDs.  
# denotes that the mean value for the women is significantly ($p<0.05$) lower than that for the men.
Table 2  Descriptive data on muscle thickness (Mt) measurements: mm

<table>
<thead>
<tr>
<th>Sites</th>
<th>Men, n=188</th>
<th>Women, n=204</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forearm</td>
<td>23.8 ± 3.7</td>
<td>19.9 ± 3.4#</td>
</tr>
<tr>
<td>Upper arm anterior</td>
<td>34.3 ± 4.4</td>
<td>28.9 ± 4.1#</td>
</tr>
<tr>
<td>Upper arm posterior</td>
<td>32.4 ± 4.5</td>
<td>26.4 ± 4.5#</td>
</tr>
<tr>
<td>Thigh anterior</td>
<td>42.6 ± 5.7</td>
<td>36.8 ± 5.0#</td>
</tr>
<tr>
<td>Thigh posterior</td>
<td>62.4 ± 6.5</td>
<td>58.0 ± 6.7#</td>
</tr>
<tr>
<td>Lower leg anterior</td>
<td>28.0 ± 2.8</td>
<td>25.4 ± 2.6#</td>
</tr>
<tr>
<td>Lower leg posterior</td>
<td>64.8 ± 4.9</td>
<td>59.6 ± 4.9#</td>
</tr>
<tr>
<td>Abdomen</td>
<td>10.1 ± 2.0</td>
<td>7.1 ± 1.6#</td>
</tr>
<tr>
<td>Subscapular</td>
<td>20.9 ± 4.8</td>
<td>16.7 ± 4.2#</td>
</tr>
</tbody>
</table>

Values are means±SDs.
# denotes that the mean value for the women is significantly (p<0.05) lower than that for the men.

Table 3  Descriptive data on muscle thickness measurements: mm·g⁻¹×10⁻³

<table>
<thead>
<tr>
<th>Sites</th>
<th>Men, n=188</th>
<th>Women, n=204</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forearm</td>
<td>6.042 ± 0.876</td>
<td>5.311 ± 0.874#</td>
</tr>
<tr>
<td>Upper arm anterior</td>
<td>8.696 ± 0.992</td>
<td>7.720 ± 0.973#</td>
</tr>
<tr>
<td>Upper arm posterior</td>
<td>8.219 ± 1.076</td>
<td>7.060 ± 1.124#</td>
</tr>
<tr>
<td>Thigh anterior</td>
<td>10.814 ± 1.315</td>
<td>9.844 ± 1.212#</td>
</tr>
<tr>
<td>Thigh posterior</td>
<td>15.823 ± 1.478</td>
<td>15.505 ± 1.511#</td>
</tr>
<tr>
<td>Lower leg anterior</td>
<td>7.103 ± 0.682</td>
<td>6.800 ± 0.630#</td>
</tr>
<tr>
<td>Lower leg posterior</td>
<td>16.449 ± 1.072</td>
<td>15.960 ± 1.046#</td>
</tr>
<tr>
<td>Abdomen</td>
<td>2.557 ± 0.485</td>
<td>1.910 ± 0.426#</td>
</tr>
<tr>
<td>Subscapular</td>
<td>5.297 ± 1.136</td>
<td>4.466 ± 1.076#</td>
</tr>
</tbody>
</table>

Values are means±SDs.
# denotes that the mean value for the women is significantly (p<0.05) lower than that for the men.

Mt and/or Mt·BM⁻¹/³ were significantly correlated to age in both genders, regression analysis was used to test gender-related difference in the slope of the regression line for the relationship between the two variables, in which Mt and Mt·BM⁻¹/³ were expressed as percentages of mean values for the subjects aged 65 to 69 yrs of men and women, respectively. The probability level for statistical significance was set at p<0.05. Statistical significance for the correlation coefficient was tested as that the number of the subject was ∞ (r=0.195 at p=0.05) (Vincent 1995).

3. Results

Table 2 shows the mean and SD of Mt at every site in each subject group. Mt values at all sites were significantly greater in the men than in the women. These differences were still significant even in terms of Mt·BM⁻¹/³ (Table 3). The relative differences between the men and women ranged from 7.1% to 29.7% in Mt and from 2.0% to 25.3% in Mt·BM⁻¹/³ (Figure 1). In the two variables, the relative differences between the men and women tended to be greater in the trunk and upper limb than the lower
limb.

For the men, there were significant ($p<0.05$) negative correlations between age and each of Mt values at the forearm ($r=-0.303$), upper arm anterior ($r=-0.303$) and posterior ($r=-0.214$), thigh anterior ($r=-0.330$), and abdomen ($r=-0.332$). In these sites except for the upper arm posterior, the relationships between age and Mt·BM$^{-1/3}$ were also significant ($r=-0.313$ to -0.283, $p<0.05$). For the women, however, the corresponding correlation was significant at the thigh anterior only: $r=-0.346$ ($p<0.05$) for Mt and $r=-0.332$ ($p<0.05$) for Mt·BM$^{-1/3}$. At the thigh anterior, there were no significant differences between the men and women in the slopes of the regression lines for the relationships between age and each of Mt and Mt·BM$^{-1/3}$, expressed as percentages of mean values for the younger men and women (aged 65 to 69 yrs), respectively (Figure 2).

4. Discussion

The Mt at every site was significantly greater in the men than in the women, with a greater relative difference in the upper limb and trunk compared to the lower limb muscles. On the other hand, the present results indicated that the sites where muscle thickness predominantly decreased with aging varied between men and women and between the locations of muscle groups. Namely, the men showed significant age-related losses in muscle thickness at more body sites as compared to women, especially at the upper limb and abdomen. Meanwhile, both genders showed a significant age-related loss in Mt at the thigh anterior, without significant difference between the men and women in the slope of the regression line for the relationship between age and percentages of Mt to mean values for the younger subjects. This implies that the rate of the age-related loss in Mt at this site is similar in both the men and women. Again, the observed age-related changes
and gender-related differences in MT were almost the same even in terms of Mt-BM^{1/3}. The possible age and/or gender differences in muscle mass are influenced by the difference in body size (Gallagher, et al., 1997). As described earlier, the organ diameter is theoretically a function of (body mass)^{1/3} (Günther 1975). Hence, the similarity between the present results on Mt and Mt-BM^{1/3} suggests that the age-related changes and gender-related differences observed in Mt are independent of the difference in body mass.

From the findings of previous studies using MRI (Janssen, et al., 2000), DEXA (Gallagher, et al., 1997) or the urinary creatinine excretion method (Hughes, et al., 2000), the age-related loss in total muscle mass or its value relative to body mass is greater in men than in women. In the present study, because no measurement of total muscle mass was performed, we cannot refer to how the age-related losses in Mt values for the men are associated to that in total muscle mass. However, Gallagher et al. (1997) reported that a larger magnitude decrease in arm muscle mass with aging was found in Caucasian men than women. In addition, a longitudinal study on individuals initially 46 to 78 yrs old indicated that women had a greater loss in knee extensor strength compared to elbow extensor strength, whereas men demonstrated similar rates of strength loss in both muscle groups. These findings support the present results that both genders showed a significant age-related loss in Mt at the thigh anterior, but only the men had a significantly decrease in Mt values at the upper extremity with older age.

It has been documented that the loss of skeletal muscle mass with aging is greater in the muscles located in the lower than upper body regardless of gender (Janssen, et al., 2000; Gallagher, et al., 1997). In the lower extremity, however, the site where the significant age-related loss was found in Mt was limited to the thigh anterior in both genders. From the findings of Kubo et al. (2003), who investigated the architectural characteristics of vastus lateralis and medial gastrocnemius in young (20 to 39 yrs) and elderly (60 to 85 yrs) men and women, the Mt relative to limb length for the vastus lateralis was significantly greater in the young than in the elderly, but that for the medial gastrocnemius was similar in the two generations. The present result on the age-related changes in Mt values at the thigh anterior and lower leg posterior agrees with the report of Kubo et al. (2003) and indicates that, even in the muscles located in the lower limb, the age-related changes in the Mt are specific to the kind of muscle.

In addition to the age-related change in the Mt of limb muscles, the present study provided evidence that for the men the muscle located in the abdomen also decreased with aging. Miyatani et al. (2003) observed a higher relative loss in Mt at the abdomen as compared to those at limb sites through a comparison between young and elderly men. In addition, the findings of Ishida et al. (1997) indicated that the relative difference between young and middle-aged women in Mt at the abdomen was greater as compared to that at other sites. Again, a prior study reported that the percentage of Mt at

**Figure 2** Relationships between age and each of Mt (the upper panel) and Mt-BM^{1/3} (the lower panel) at the thigh anterior. The Mt and Mt-BM^{1/3} were expressed as percentages of mean values for the subjects aged 65 to 69 yrs of men and women, respectively.
the abdomen in elderly group to that in younger group was similar for men (68%) and women (65%) (Kanehisa, et al., 2004). Considering these findings, it seems that not only the men but also the women might show a significant age-related loss in Mt at the abdomen. In the previous studies cited here, however, it should be noted that for the elderly population the relationship between age and Mt at the abdomen has not been analyzed. They have reported only the relative difference in Mt between younger and older generations. On the other hand, previous studies using DEXA (Hunter, et al., 2001; Klitgaard, et al., 1990) have provided evidence that trunk lean mass is relatively resistant to age-related changes in body composition. It is unclear whether the discrepancy between the findings of the studies mentioned above can be explained by the differences in the age of subjects tested, the variables analyzed (muscle thickness vs. lean tissue area or mass) and/or the methods used for the quantification (ultrasonography vs. DEXA). In any case, the present study indicates that, in the age span of 65 to 79 yrs, men show a progressive decrease with aging in abdominal muscle similar to that observed in muscle groups located in the thigh anterior and upper limb.

The present study cannot provide information on the mechanisms leading to the site- and gender-related differences in the age-related changes in Mt. With regard to the difference between the upper and lower bodies in skeletal muscle loss with aging, differences between muscles in the magnitude of their activities during daily life have been considered (Janssen, et al., 2000; Bemben, et al., 1991). A reduction in physical activity with aging would primarily be associated with a decreased use of lower body muscles, not upper body muscles, because the use of the hand would remain important at all ages (Janssen, et al., 2000; Bemben, et al., 1991). However, this cannot be a reason responsible for the present results on the men, because most of the muscles, which showed significant age-related losses in Mt, were those located in the upper rather than lower body. On the other hand, Hughes et al. (2001) hypothesized that a gender difference in muscle distribution could be a reason for the greater loss of upper arm strength with aging in men than in women. Namely, women have a smaller percentage of muscle mass in their upper body as compared to men (Janssen, et al., 2000). At the developmental age, there is a difference between boys and girls in the growth pattern of each of the upper arm and calf muscles; the relative gender difference in muscle width at full maturity is much greater in the upper arm than in the calf (Tanner, et al., 1981). In the subjects examined in this study, too, the relative differences between the men and women in Mt and Mt·BM$^{-1/3}$ were greater for the upper limb and trunk sites than for the lower limb sites. These points tempt us to speculate that, as compared to men, women have less potential to gain and lose muscle in their upper body as suggested by Hughes et al. (2001).

Before summarizing the present results, we should comment on the limitation of 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 elderly individuals show a higher percentage of non-muscle tissue content in the cross-sectional area or volume of the muscle compartment as compared to younger populations (Kent-Braun, et al., 2000; Borkan, et al., 1983; Overend, et al., 1992; Rice, et al., 1989). Therefore, if the amount of non-muscle tissue significantly increases even over the age span of the subjects examined in this study and the magnitude of the increase varies between men and women, it is likely that the effects of age and gender on muscle thickness will differ from those observed here. For the elderly aged from 65 to 79 yrs, however, less information on the age-related changes and/or gender-related difference in the amount of non-muscle tissue in the tested muscles is available from previous studies. Further investigation is warranted to clear this point.

In summary, the present results indicated that, at least in the age span from 65 to 79 yrs, men showed significant age-related losses in muscle thickness at more body sites as compared to women, especially at the upper limb and abdomen where a greater gender-related difference was observed in muscle thickness.

Acknowledgements
This study was partly supported by financial aid from the Ministry of Education, Culture, Sports, Science and Technology (no. 12480007) and Basic Research for Life and Society, STA

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