Abstract This study aimed to examine how the muscularity of the abdomen at the umbilicus level differs between sedentary middle-aged and young men. Magnetic resonance imaging was applied to determine the cross-sectional areas of skeletal muscle, subcutaneous fat, and interperitoneal tissue in 43 middle-aged (40–58 yrs) and 38 young (21–29 yrs) men. The cross-sectional area of the skeletal muscle was analyzed as the sum of those of the rectus abdominis, abdominal oblique, lower back, and iliopsoas skeletal muscle groups. The middle-aged men showed greater waist circumference and whole abdominal cross-sectional area than the young men. In addition, the cross-sectional areas of subcutaneous fat and interperitoneal tissue were greater in the middle-aged men than in the young men. However, the total cross-sectional area of the skeletal muscle was similar between the two groups, although its percentage to the whole abdominal cross-sectional area was higher in the young men compared to the middle-aged men. Among the four skeletal muscle groups analyzed, the percentage of the cross-sectional areas in abdominal oblique muscles to that of total skeletal muscle was higher in the middle-aged men than in the young men. These results were similar even when cross-sectional area data were analyzed using a subsample (33 middle-aged and 23 young men) matched for body height and mass. Thus, the present study indicated that the total muscularity of the abdomen at the umbilicus level was similar between the middle-aged and young men, but the relative distributions of lower back and abdominal oblique muscles varied between the two generations. J Physiol Anthropol 26(5): 527–532, 2007 http://www.jstage.jst.go.jp/browse/jpa2 [DOI: 10.2114/jpa2.26.527]

Keywords: skeletal muscle, subcutaneous fat, interperitoneal tissue, waist circumference, aging

Introduction

For men, the circumference of the waist starts to increase dramatically during and after the 40 s (Wang et al., 2000) as a result of increments in visceral fat deposits (Enzi et al., 1986). However, available information on the profile of abdominal muscularity in middle-aged men is scarce. Skeletal muscle groups located in the trunk regions play an important role in transferring and/or stabilizing the body in various human movements (Krebs et al., 1992; MacKinnon and Winter, 1993; Sakurai and Miyashita, 1985). In addition to the quantification of the fat tissue, therefore, to determine the muscularity in the abdomen of middle-aged men may provide useful information for discussing not only the health conditions but also physical functions of individuals in this generation.

Previous studies using magnetic resonance imaging (MRI) or computerized tomography (CT) have provided substantial data on the age-related loss of the skeletal muscles in the whole body or certain limbs (e.g., Janssen et al., 2000). As a result of a cross-sectional observation, Janssen et al. (2000) observed a reduction in whole body skeletal muscle mass after the middle 40 s. In addition, cross-sectional observations on muscle thickness (Ishida et al., 1997; Miyatani et al., 2003; Kanehisa et al., 2004) have shown that the rectus abdominis is susceptible to aging as compared to those in other parts of the body. Considering these findings, it may be assumed that an increase in the abdominal fat in middle-aged men will be followed by a reduction of muscularity in this region. On the other hand, previous studies performing the muscle thickness measurements have examined only the rectus abdominis.
muscles among the skeletal muscles located in the lower trunk. The skeletal muscles located in the lower trunk are divided broadly into four groups in relation to their locations: the rectus abdominis, the abdominal oblique, the lower back, and the iliopsoas muscle groups. These skeletal muscle groups differ structurally and functionally from each other. Assuming that a reduction in abdominal muscularity occurs in middle-aged men, therefore, the magnitude of the aging effect might be assumed to be different among the individual skeletal muscle groups.

In the present study, the cross-sectional areas (CSAs) of the skeletal muscle, as well as the subcutaneous fat and interperitoneal tissue at the umbilicus level, were determined using MRI in sedentary middle-aged men and young men. The present study aimed to examine the differences in the muscularity of the abdomen between the two generations, with relation to muscle locations.

Method

Subjects

Forty-three middle-aged (46.0±5.3 yrs, mean±SD) and 38 sedentary young men (24.5±2.2 yrs) voluntarily participated in the present study. All subjects were healthy and had no functional disorder such as low-back pain. The subjects had not participated in any organized program of regular physical exercise (≥30 min per day, ≥2 days per week) for at least 1 year prior to being tested. The physical characteristics of the subjects are shown in Table 1. The average value in the body mass for the middle-aged group was greater than that for the young group, although the difference was not significant. The young group was significantly (p=0.0157) taller than the middle-aged group, so the body mass index (BMI) was significantly higher (p=0.0145) in the middle-aged men (26.3±2.2 kg/m²) than in the young men (24.7±3.4 kg/m²). For the comparison of CSA measurements between the two age groups, therefore, analyses of a sample matched for body height and mass were performed to diminish the influence of the difference in body size. First, subjects were selected in accordance with a range of the shortest height in the young group and the tallest one in the middle-aged group, i.e., from 162.7 cm to 181.1 cm. Secondly, the subjects whose body mass were within the range of the lightest in the middle-aged group and the heaviest in the young group, i.e., from 57.7 kg to 96.3 kg, were selected from the height-matched subjects. This sample consisted of 33 middle-aged (age, 40–54 yrs, 45.4±4.9 yrs) and 23 young (21–29 yrs, 24.5±2.4 yrs) men. There were no significant differences between the two age groups of the sub-sample in morphological variables, with the exception that waist circumference was significantly greater in the middle-aged man than in the young men (Table 1). All descriptive data were presented using the sub-sample data. This study was approved by the Office of the Department of Life Sciences, University of Tokyo, and was consistent with their requirements for human experimentation. The subjects were fully informed about the procedures and the purpose of this study. Written informed consent was obtained from all subjects.

MRI measurements

Using MRI scans with a body coil (Sierra 1.5 tesla, GE Yokokawa Medical Systems, USA), a transverse image at the height of the umbilicus (Ashwell et al., 1985) was obtained. The image condition was T-1 weighted, spin-echo, multi-slice breath for about 20 seconds at the top of the inhalation to reduce the respiratory-motion artifact. From the cross-sectional image, outlines of the tissue (skeletal muscle, subcutaneous fat, interperitoneal, bone, and others) were traced (Fig. 1) and digitized using a personal computer (Power Macintosh G4, Apple) to calculate their CSAs. Within the skeletal muscle compartment, the adipose fat tissue imaged in different tones was excluded when digitizing. From the cross-sectional area of the adipose tissue at the umbilicus level, were determined using MRI in sedentary middle-aged men and young men. The present study aimed to examine the differences in the muscularity of the abdomen between the two generations, with relation to muscle locations.

Table 1  Physical characteristics of subjects

<table>
<thead>
<tr>
<th>Variables</th>
<th>Middle-aged men, n=43</th>
<th>Young men, n=33</th>
<th>p values*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body height, cm</td>
<td>170.2±9.4</td>
<td>173.8±5.1</td>
<td>0.0157</td>
</tr>
<tr>
<td>Body mass, kg</td>
<td>76.4±9.4</td>
<td>74.6±10.6</td>
<td>0.4187</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>26.3±2.2</td>
<td>24.7±3.4</td>
<td>0.0145</td>
</tr>
<tr>
<td>Chest, cm</td>
<td>98.3±5.9</td>
<td>98.8±6.8</td>
<td>0.6795</td>
</tr>
<tr>
<td>Waist, cm</td>
<td>91.9±7.2</td>
<td>82.3±7.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Hip, cm</td>
<td>101.7±4.7</td>
<td>99.2±6.2</td>
<td>0.0493</td>
</tr>
</tbody>
</table>

Values are means±SDs.
* Student’s t-test

Using MRI scans with a body coil (Sierra 1.5 tesla, GE Yokokawa Medical Systems, USA), a transverse image at the height of the umbilicus (Ashwell et al., 1985) was obtained. The image condition was T-1 weighted, spin-echo, multi-slice sequences with a slice thickness of 10 mm, with a repetition time of 200 ms and an echo time of 20 ms. Each subject lay supine in the body coil with his arms and legs extended and relaxed. During the scan, the subjects were asked to hold their breath for about 20 seconds at the top of the inhalation to reduce the respiratory-motion artifact. From the cross-sectional image, outlines of the tissue (skeletal muscle, subcutaneous fat, interperitoneal, bone, and others) were traced (Fig. 1) and digitized using a personal computer (Power Macintosh G4, Apple) to calculate their CSAs. Within the skeletal muscle compartment, the adipose fat tissue imaged in different tones from the skeletal muscle tissue was excluded when digitizing. The CSA of the skeletal muscle was analyzed by separating it into four skeletal muscle groups: rectus abdominis (CSA_{RA}), abdominal oblique (CSA_{AO}), the sum of the internal oblique, external oblique, and transversus abdominis muscles), lower back (CSA_{LB}, the sum of the iliocostal, longissimus dorsi, semispinal, and quadratus lumborum muscles), and iliopsoas (CSA_{IP}, the sum of the psoas major and minor muscles) muscles. The total CSA of the skeletal muscle compartment,
that is, the sum of the CSAs of the four skeletal muscle groups, was referred to as CSA\(_{TSM}\). In addition to the absolute term, the CSA of every skeletal muscle group analyzed was expressed as a percentage of the CSA\(_{TSM}\) and referred to as %CSARA, %CSAAO, %CSALB, and %CSAIp.

**Statistics**

Descriptive data were presented as the means and SDs for each subject group. The Student’s t-test was used to test the significance of the difference between the means of the middle-aged and young men. A simple linear regression analysis was used to calculate the correlation coefficients between CSA\(_{TSM}\) and each of CSA\(_{RA}\), CSA\(_{AO}\), CSA\(_{LB}\), and CSA\(_{Ip}\). Statistical significance was set at \(p<0.05\).

**Results**

Table 2 indicates the descriptive data on CSA measurements. The middle-aged men showed significantly greater whole abdominal CSA than the young men. In addition, the CSAs of the subcutaneous fat and interperitoneal tissue were also significantly greater in the middle-aged men than in the young men. The CSA\(_{TSM}\) and CSAs of the four skeletal muscle groups were similar between the two age groups, with the exception that the young men showed significantly greater CSA\(_{LB}\) than the middle-aged men.

The CSA\(_{TSM}\) was significantly correlated to the whole abdominal CSA in both middle-aged (\(r=0.439, p=0.0029\)) and young (\(r=0.523, p=0.0015\)) men (Fig. 2). In this relationship, most of the data for the young men were distributed above the regression line for the middle-aged men, so the percentage of CSA\(_{TSM}\) to the whole abdominal CSA was significantly lower in the middle-aged men than in the young men (Table 3). On the other hand, the corresponding value of the interperitoneal

<table>
<thead>
<tr>
<th>Variables</th>
<th>Middle-aged men, (n=33)</th>
<th>Young men, (n=23)</th>
<th>(p) values*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdominal whole</td>
<td>600.7±79.7</td>
<td>389.9±96.2</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Total skeletal muscle</td>
<td>137.3±15.4</td>
<td>140.7±19.6</td>
<td>0.4684</td>
</tr>
<tr>
<td>RA</td>
<td>12.1±3.3</td>
<td>13.4±3.8</td>
<td>0.1654</td>
</tr>
<tr>
<td>AO</td>
<td>42.0±7.7</td>
<td>42.0±6.6</td>
<td>0.3353</td>
</tr>
<tr>
<td>LB</td>
<td>54.8±6.9</td>
<td>59.8±8.3</td>
<td>0.0177</td>
</tr>
<tr>
<td>Ip</td>
<td>28.3±4.4</td>
<td>27.3±6.4</td>
<td>0.4843</td>
</tr>
<tr>
<td>Subcutaneous fat</td>
<td>172.8±43.5</td>
<td>106.6±55.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Interperitoneal tissue</td>
<td>265.0±46.1</td>
<td>123.6±47.1</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Values are means±SDs.
* Student’s t-test.

RA, AO, LB, and Ip indicate the rectus abdominis, abdominal oblique, lower back, and iliopsoas muscle groups, respectively.

### Table 2 Descriptive data of CSA measurements: cm\(^2\)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Middle-aged men, (n=33)</th>
<th>Young men, (n=23)</th>
<th>(p) values*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total skeletal muscle</td>
<td>23.1±2.7</td>
<td>37.5±7.4</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Subcutaneous fat</td>
<td>28.6±5.0</td>
<td>26.1±9.0</td>
<td>0.1812</td>
</tr>
<tr>
<td>Interperitoneal tissue</td>
<td>44.0±4.6</td>
<td>31.4±6.6</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Values are means±SDs.
* Student’s t-test.
tissue was significantly higher in the middle-aged men compared to the young men, and that of the subcutaneous fat was similar between the two age groups.

Figure 3 indicates the relationship between CSA_{TSM} and the CSA of each of the four skeletal muscle groups. In all relationships, significant correlations were found, with correlation coefficients of 0.564 (p<0.0001) to 0.846 (p<0.0001) in the middle-aged men, and 0.599 (p=0.0002) to 0.863 (p<0.0001) in the young men. There were the tendencies for the data for the middle-aged men to be plotted above the regression line for the young men in the relationship for CSA_{AO} and vice versa in that for CSA_{LB}. The differences were reflected in the comparison between the two age groups on the percentages of the CSA of every skeletal muscle group to CSA_{TSM} (Table 4). Namely, %CSA_{AO} was significantly higher in the middle-aged men than in the young men, and

Table 4 Descriptive data on the percentages of the CSAs of rectus abdominis (RA), abdominal oblique (AO), lower back (LB), and iliopsoas (Ip) muscle groups to the total skeletal muscle CSA: %

<table>
<thead>
<tr>
<th>Muscle groups</th>
<th>Middle-aged men, n = 33</th>
<th>Young men, n = 23</th>
<th>p values*</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA</td>
<td>8.7±1.9</td>
<td>9.5±2.3</td>
<td>0.1554</td>
</tr>
<tr>
<td>AO</td>
<td>30.5±2.7</td>
<td>28.4±2.8</td>
<td>0.0067</td>
</tr>
<tr>
<td>LB</td>
<td>40.0±3.0</td>
<td>42.7±3.9</td>
<td>0.0055</td>
</tr>
<tr>
<td>Ip</td>
<td>20.7±3.2</td>
<td>19.4±3.2</td>
<td>0.1221</td>
</tr>
</tbody>
</table>

Values are means±SDs.
* Student's t-test.

%CSA_{LB} in the young men than in the middle-aged men. On the other hand, there were no significant differences in %CSA_{RA} and %CSA_{Ip} between the two age groups.
Discussion

The findings obtained here indicate that, at least at the umbilicus level, the middle-aged men can be characterized by greater CSAs of subcutaneous fat and interperitoneal tissue as compared to the young men, without a significant difference in the total skeletal muscle CSA. The present study did not quantify the intra-abdominal fat. In spite of the similarity of BMI, however, the CSA of the interperitoneal tissue was significantly greater in the middle-aged men than in the young men, in both the absolute value and the percentage to the whole abdominal CSA. Furthermore, the middle-aged men showed significantly greater waist circumference than the young men (Table 1). For men, the waist circumference has a strong potential for predicting the distribution of adipose tissue among several fat compartments in the abdominal region (Chan et al., 2003). In addition, a prior study using DEXA (Hunter et al., 2001) indicated that the trunk lean mass, which is largely representative of organ/visceral tissue mass (Piers et al., 1998), was relatively constant across ages. Hence, it is reasonable to assume that the observed difference in the CSA of the interperitoneal tissue between the two age groups can be attributed to the difference in the intra-abdominal fat CSA.

As described earlier, a reduction in whole body skeletal muscle mass occurs during and after the middle 40s (Jansen et al., 2000). In addition, previous studies measuring the muscle thickness of the rectus abdominis have provided evidence indicating that abdominal muscularity is susceptible to aging (Ishida et al., 1997; Miyatani et al., 2003; Kanehisa et al., 2004). At the start of this study, therefore, it was expected that a significant difference in abdominal muscularity would be found between the middle-aged and young men. However, the CSA_TSM was similar in the two age groups. If an older group had been involved as the subjects, we would have had a greater chance for detecting a significant effect of age on muscularity. In the present study, however, we intended to clarify how abdominal muscularity in men of middle age, in which the waist circumference starts to increase dramatically (Wang et al., 2000), differs from that in young men. In terms of total skeletal muscle CSA at the umbilicus level, the present result denies our hypothesis and indicates a similarity of abdominal muscularity between young and middle-aged men. However, CSA_LB was significantly greater in the young men than in the middle-aged men. In addition, the %CSA_AO and %CSA_LB significantly differed between the two age groups. This implies that, although the total CSA of the skeletal muscle compartment in the abdomen is similar between the two generations, the relative distributions of the abdominal oblique and lower back muscles vary between young and middle-aged men.

The reasons for the observed differences in %CSA_AO and %CSA_LB between the two age groups are unknown but may be related to the functional characteristics of these muscle groups. A prior study (Arokoski et al., 2001) examining the muscular activities of the paraspinal and abdominal muscles in 16 different therapeutic exercises provided evidence suggesting that the activation level of the lower back skeletal muscles during daily life might be higher as compared to other skeletal muscle groups located in the abdomen. Again, Danneels et al. (2000) reported that, for the paravertebral muscles in chronic low back pain patients, stabilization exercises had no effect, but dynamic training induced a significant hypertrophic change. These findings tempt us to assume that the observed differences between the two age groups in lower back skeletal muscles can be attributed to the possible changes in the patterns of the loading to the lower back muscles and/or its activation levels during physical activities in daily life, associated with aging. Furthermore, the transversus abdominis is the abdominal skeletal muscle whose activity is consistently related to changes in intra-abdominal pressure and breathing (De Troyer et al., 1990; Cresswell et al., 1992). With regard to the higher %CSA_AO in the middle-aged men, therefore, it might be speculated that the greater CSA of the interperitoneal tissue itself would be a factor inducing a percentage of CSA_AO by becoming a load during breathing. In any case, we have no data on the functional properties of the skeletal muscle groups examined here. Further investigation is needed to clarify the assumptions mentioned above.

Before summarizing the present results, we should comment on a limitation of the procedure used for the CSA measurements. In a preliminary study using 27 adult men, we observed a high correlation between skeletal muscle CSA at the umbilicus level and the whole trunk skeletal muscle volume ($r=0.805$, $p<0.05$). This implies that the CSA of the skeletal muscles located at the umbilicus level can be considered a useful marker of the whole trunk skeletal muscle volume. However, the height of the umbilicus varies between individuals. In addition, the CSA determined at the umbilicus for every skeletal muscle group is not always the maximal anatomical CSA. Hence, we cannot exclude that, if the maximal CSA or volume for every skeletal muscle group is determined as a variable indicating the skeletal muscle size, the result on the age-related difference in muscularity would differ from that obtained here.

In summary, the present results indicate that the total muscularity of the abdomen at the umbilicus level was similar between the middle-aged and young men. However, the relative distribution of the abdominal oblique muscles was significantly higher in the middle-aged men than in the young men, and that of the lower back muscles was the reverse. To investigate the influences of aging on abdominal muscularity, further study examining elderly populations of both genders is warranted.

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Abdominal Muscularity of Middle-aged Men