1. Introduction

With the aging of Japanese society, the number of patients with lumbar spinal degenerative disorders, which induce low back pain (LBP) and lower extremity symptoms, is expected to increase. It is generally assumed that lumbar spinal degenerative disorders are triggered by lumbar intervertebral disc degeneration (DD) that in turn is promoted by various factors such as aging [Battie et al. (2004); Hassett et al. (2003)], obesity [Hassett et al. (2003); Liuke et al. (2005)], heredity [Kawaguchi et al. (2002)], physical loading on lumbar spine [Videman et al. (1995)], atherosclerosis [Kauppila et al. (1994)], and smoking [Oda et al. (2004)]. Causes of LBP also vary, and include DD, lumbar spinal degenerative disorders, and, furthermore, psychological factors. Moreover, it has been suggested that LBP is associated with lumbar spinal posture and the strength and volume of the back muscle group and the psoas major muscle [Parkkola et al. (1993); Danneels et al. (2000)]; therefore, back muscle training and exercise intervention to improve lumbar spinal posture are currently advised for patients with LBP. However, because of the unclear relationships between DD and muscle volume or lumbosacral alignment, the effects of exercise intervention to prevent DD and lumbar spinal degenerative disorders have yet to be explained.

The purpose of this study is to clarify the relationships between DD and muscle volume of the extremities and trunk and between disc degeneration and lumbosacral spinal alignment in elderly people in Japan.

The subjects were 222 adults who were participating in a health promotion exercise program (82 males and 140 females; mean age, 70.0 years; range, 60-86 years). Disc degeneration, lumbar lordotic angle and sacral inclination angle were evaluated using T2-weighted lumbar sagittal MR images. The thicknesses of the back and abdominal muscles were determined by ultrasonography, and the humeral, forearm, femoral and crural muscle volumes were estimated from the associated muscle thicknesses examined through ultrasonography. The transversal area of the psoas major muscle was also measured with MR images.

Findings determined by a logistic regression analysis adjusted for age and gender, show a decrease of the anterior muscle volume of the femur was statistically significantly associated with disc degeneration (odds ratio = 0.80). The lumbar lordotic angle and sacral inclination angle were significantly small in the disc degeneration group. These results suggest that disc degeneration may be associated with the anterior muscle volume of the femur and lumbosacral spinal alignment in the elderly. We suspect that disc degeneration causes a decrease in the lumbar lordotic angle and also a compensatory decrease in the sacral inclination angle.

Keywords: disc degeneration, quadriceps femoris, sacral inclination, lumbar lordosis
alignment so as to examine the feasibility of exercise intervention to reduce DD and lumbar spinal degenerative disorders especially in the elderly.

2. Method

2.1. Subjects

Table 1 shows the characteristics of our subjects. The subjects were participants in an exercise program (low intensity muscle-strength training and endurance training) with the purpose of improving and promoting living function, and were publicly recruited by three municipalities in Japan in 2002 and 2003. The participants over 60 years old received written information about the study procedures and provided written informed-consent before participation in this program. Those who did not provide written informed-consent or wore magnetic materials such as pacemakers or could not be examined through magnetic resonance imaging (MRI) due to difficulties in maintaining constant supine positions during measurement were excluded. Two hundred and twenty two participants were selected for our study – 82 males and 140 females ranging in age from 60 to 86 years with a mean age of 70.0 years. The participants were chosen based upon the quality of their lumbar spinal MR images and ultrasonographic measurements of their muscle volumes. See Figure 1 for further details on the subjects. This study was approved by the Human Subjects Institutional Review Board of the Institute of Health and Sport Sciences, University of Tsukuba (Notification Number 29).

2.2. Lumbar intervertebral disc degeneration

We examined MR T2 density-weighted fast spin-echo sagittal images (TR 4000 ms/TE 125 ms) of the subjects’ lumbar spine using a 0.2-Tesla imager (AIRIS Mate, Hitachi Medical AG, Tokyo, Japan) with a surface coil. The slice thickness was 6.0 mm with no interslice gap, matrix 256 × 256 and field of view 300 × 300 mm. To evaluate DD, we only used the signal intensity in a Pfirrmann’s classification [Pfirrmann et al. (2001)], which normally involves using signal intensity and disc height. The degree of degeneration was classified from Grade I to Grade V as shown in Figure 2. We assessed the five discs from the disc between the 1st and 2nd lumbar vertebrae (L1/2) to the disc between the 5th lumbar vertebra and the 1st sacral vertebra (L5/S1). Grades IV and V were considered degenerated in the evaluation of individual discs. We calculated the means of each subject’s grades for the five discs (from L1/2 to L5/S1) and categorized the subjects who had a mean over 4.0 as the "total lumbar
Table 1  Characteristics of the subjects

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean ± SD (years)</td>
<td>70.0 ± 5.0</td>
</tr>
<tr>
<td>Gender</td>
<td>82 males</td>
</tr>
<tr>
<td></td>
<td>140 females</td>
</tr>
<tr>
<td>Height, mean ± SD (cm)</td>
<td>154.2 ± 8.3</td>
</tr>
<tr>
<td>Weight, mean ± SD (kg)</td>
<td>57.2 ± 8.5</td>
</tr>
<tr>
<td>Body mass index, mean ± SD (kg/m²)</td>
<td>24.0 ± 2.8</td>
</tr>
<tr>
<td>Education level</td>
<td></td>
</tr>
<tr>
<td>≤ junior high school (%)</td>
<td>43.7</td>
</tr>
<tr>
<td>senior high school (%)</td>
<td>33.3</td>
</tr>
<tr>
<td>university/college or higher level (%)</td>
<td>18.5</td>
</tr>
<tr>
<td>unknown (%)</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Figure 2  Classification of disc degeneration (modified Pfirrmann’s classification)
Grades IV and V were considered degenerated. The subjects for whom the mean of the L1/2 to L5/S1 grades was 4 or above were categorized into the “total lumbar intervertebral disc degeneration group”.

intervertebral disc degeneration group” (total DD group). Two orthopedic surgeons, who were unaware of the subject’s status, independently evaluated the degree of DD. If there was disagreement in an evaluation, a consensus decision was reached in conference. The reason that we used a grading based on only signal intensity is that the grades from signal intensity and disc height disagreed for our subjects over 60 years old.

We assessed interrater and intrarater agreement in the evaluation of DD by calculating the kappa coefficient (dichotomous variables). The kappa coefficient for interrater reliability was 0.81. Repeated measurements were done by the same evaluator in 2-month intervals for 40 images (200 discs), chosen at random, to estimate intrarater reliability. The intrarater agreement coefficient was 0.89. The agreement coefficients were excellent both in the interrater and intrarater agreement.

The MRI for evaluating DD was performed on 179 participants (Group A) before the exercise program, and after 12-18 months on 43 participants (Group B) who could not be examined before the program. In addition, Group A involved participants (Group A’) of whom a pair of MR images were taken – one before the program and the other 18 months later. To verify that there was not significant progression of DD due to the aging of the participants over 18 months and thereby, to confirm that the 43 images for group B were appropriate for analysis, we chose 40 pairs of images at random from Group A’ and compared images within each pair. The agreement coefficient from kappa statistics for the pair of images was 0.90, and this was higher than the interrater and intrarater agreement coefficients. So no progression due to aging over 18 months could be detected by our grading method.

2.3. Muscle thickness, normalized muscle volume, and muscle transectional area (muscle volumes = MVs)

Using a B-mode ultrasonic device (SSD-500, Aloka AG, Japan), we measured the muscle thickness of the abdominal rectus muscle at the right side of
the umbilicus and that at the inferior angle level of the right scapula, mainly the latissimus dorsi muscle, and the muscle thicknesses were used for analysis. Similarly, we measured the thicknesses of the anterior and posterior muscles of the humerus, the anterior of the forearm, the anterior and posterior of the femur and the anterior and posterior of the crus. We estimated the muscle volumes by applying the measured muscle thickness to multiple regression equations [Miyatani et al. (2000)], then divided the volumes by the body weight, obtaining a normalized measure of muscle volume. The transectional areas of the bilateral psoas major muscles were measured from MR axial images of the L4/5 intervertebral disc level and the mean of the left and right side areas for each subject was used for analysis. The muscle volumes were measured before the exercise program.

2.4. Sagittal alignment of the lumbosacral spine

From lumbar MR mid-sagittal images, the lumbar lordotic angle and the sacral inclination angle in supine position were evaluated. The lumbar lordotic angle was measured between the inferior endplate of the 12th thoracic vertebrae and the superior endplate of the 1st sacral vertebra, and the sacral inclination angle was measured as the slope of the superior endplate of the 1st sacral vertebra from the horizontal line of the film as in Figure 3. The imaging was performed with the hip joint with extended position. An orthopedic surgeon, who was unaware of the subject’s status, measured the lumbar lordotic angle and the sacral inclination angle.

2.5. Questionnaire

We conducted a self-administered questionnaire concerning experience of LBP during the subject’s lifetime and current medical treatment by either orthopedic surgeons or alternative medical facilities for LBP. The questionnaire was given to the participants to be completed when the MR imaging was performed.

2.6. Statistical Analysis

Relationships between total DD and MVs were analyzed using t-tests. Additionally, logistic regression analysis [Lilienfeld et al. (1984)] adjusted for age and gender was performed to investigate the relationships between total DD and MVs, and the odds ratios (ORs) and 95% confidence intervals were calculated for total DD because age- and gender-related differences in MVs were suggested. The calculated ORs were values per unit increase of muscle thickness (mm), normalized muscle volume (cm³/kg) and muscle transectional area (cm²). Relationships between total DD or DD of each disc level and the lumbar lordotic angle and the sacral inclination angle were also analyzed using t-tests, and a Pearson’s correlation coefficient for the lumbar lordotic angle and the sacral inclination angle was calculated. The relationships between total DD and the results of the questionnaire were analyzed using chi-square tests. The level of statistical significance was set at $P < 0.05$ and all statistical analyses were carried out using the computer software JMP version 5.1 (SAS Institute Inc., Cary, NC, USA).

Figure 3

$\alpha$: lumbar lordotic angle  
$\beta$: sacral inclination angle
Table 2 Grading of disc degeneration in the lumbar spine

<table>
<thead>
<tr>
<th>Lumbar disc level</th>
<th>Grade I (%)</th>
<th>Grade II (%)</th>
<th>Grade III (%)</th>
<th>Grade IV (%)</th>
<th>Grade V (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1/2</td>
<td>0</td>
<td>19.4</td>
<td>25.8</td>
<td>29.9</td>
<td>24.9</td>
</tr>
<tr>
<td>L2/3</td>
<td>0</td>
<td>12.2</td>
<td>24.4</td>
<td>43.4</td>
<td>20.0</td>
</tr>
<tr>
<td>L3/4</td>
<td>0</td>
<td>5.9</td>
<td>34.2</td>
<td>41.9</td>
<td>18.0</td>
</tr>
<tr>
<td>L4/5</td>
<td>0</td>
<td>5.0</td>
<td>28.4</td>
<td>45.9</td>
<td>20.7</td>
</tr>
<tr>
<td>L5/S1</td>
<td>0</td>
<td>11.7</td>
<td>27.9</td>
<td>37.9</td>
<td>22.5</td>
</tr>
</tbody>
</table>

Table 3 Muscle volumes and lumbosacral spinal alignments

<table>
<thead>
<tr>
<th>Variable</th>
<th>mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back muscle thickness (mm)</td>
<td>9.8 ± 4.9</td>
</tr>
<tr>
<td>Abdominal muscle thickness (mm)</td>
<td>8.5 ± 2.4</td>
</tr>
<tr>
<td>Psoas major muscle area (cm²)</td>
<td>14.9 ± 4.1</td>
</tr>
<tr>
<td>Anterior muscle volume of the humerus (cm³/kg)</td>
<td>3.9 ± 0.8</td>
</tr>
<tr>
<td>Posterior muscle volume of the humerus (cm³/kg)</td>
<td>4.1 ± 0.7</td>
</tr>
<tr>
<td>Anterior muscle volume of the forearm (cm³/kg)</td>
<td>5.8 ± 1.1</td>
</tr>
<tr>
<td>Anterior muscle volume of the femur (cm³/kg)</td>
<td>16.1 ± 3.0</td>
</tr>
<tr>
<td>Posterior muscle volume of the femur (cm³/kg)</td>
<td>20.5 ± 2.1</td>
</tr>
<tr>
<td>Anterior muscle volume of the crus (cm³/kg)</td>
<td>3.2 ± 0.6</td>
</tr>
<tr>
<td>Posterior muscle volume of the crus (cm³/kg)</td>
<td>10.9 ± 1.7</td>
</tr>
<tr>
<td>Lumbar lordotic angle (degree)</td>
<td>49.0 ± 12.1</td>
</tr>
<tr>
<td>Sacral inclination angle (degree)</td>
<td>37.8 ± 7.9</td>
</tr>
</tbody>
</table>

3. Results

Table 2 shows the results for each disc level separately for DD evaluated through MRI by our grading method. The proportion of the total DD group for whom the mean of the L1/2 to L5/S1 DD grades was 4 or above was 41.0%. Table 3 shows the measured results for MVs, the lumbar lordotic angle and the sacral inclination angle.

The relationships between total DD and MVs are shown in Table 4. Using univariate analysis, significant relationships were found between total DD and the normalized muscle volumes of the posterior of the humerus, the anterior of the forearm, the anterior of the femur and the anterior of the crus. In the logistic regression model adjusted for age and gender, only a decrease of normalized muscle volume of the anterior of the femur was significantly associated with total DD (OR = 0.80).

The means of the lumbar lordotic angle in the supine position were 46.8° in the total DD group and 50.7° in the non-total DD group, and the mean angle was significantly smaller in the total DD group than in the non-total DD group. In the relationship between DD at each disc level and the lumbar lordotic angle, the group with L5/S1 DD had significantly smaller lumbar lordotic angle. The sacral inclination angle showed a mean of 36.1° in the total DD group and 38.9° in the non-total DD group; the former being significantly smaller. Investigating relationships between DD at each disc level and the sacral inclination angle, the groups with L3/4 DD and L5/S1 DD had significantly smaller sacral inclination angles. The lumbar lordotic angle and sacral inclination angle had a significant correlation with each other (γ = 0.79).

The valid response rate to the questionnaires was 94.1%. The proportion of subjects who had experienced LBP during their lifetime was 73.7% while the proportion of subjects who were under current medical treatment by either orthopedic surgeons or alternative medical facilities for LBP
was 15.8%. The relationships between DD and the response to the questionnaire were not significant.

4. Discussion

In our subjects over 60 years of age, the decrease of the anterior normalized muscle volume of the femur was significantly associated with total DD, and the lumbar lordotic angle and sacral inclination angle in the supine position were significantly smaller in the total DD group. Previous studies have reported relationships between LBP and the back muscle group and between LBP and the psoas major muscle [Parkkola et al. (1993); Danneels et al. (2000)], and no relationships between DD and the atrophy of the multifidus muscle in patients with LBP [Kader et al. (1999)]. However, there are no reports other than those for patients with LBP, that clarify the relationship between DD and muscle volume. Furthermore, the above-mentioned reports are concerned about particular muscles such as the multifidus muscle or psoas major muscle; however, in reality, each muscle functions interactively. And, in our study for people over 60, it is especially important to clarify the relationships between the muscles and DD in addition to more fully understanding the systemic character of the muscle groups in the elderly. Therefore, we analyzed muscle volumes of the extremities and trunk for our analysis. The results revealed a relationship between DD and the anterior muscle volume of the femur. A relationship between gonarthrosis and the strength of the anterior muscle of the femur, which extend knee joint [Slemenda et al. (1998)], has been reported, but we could not find any study that showed a relationship between DD and the volume of the anterior muscle. This study was a cross-sectional survey so that the cause and effect between DD and the decrease of the anterior muscle volume of the femur could not be elucidated. However, it has been reported that obesity, a lifestyle-related disease, promotes DD [Hassett et al. (2003); Liuke et al. (2005)]. And in one of our previous findings, not only obesity but also a high level of low-density lipoprotein cholesterol (LDLc), which is also a lifestyle-related factor, was associated with DD [Hangai et al. (2005)]. Taking these previous reports into consideration, we surmised that bad habits such as lack of exercise and overeating promote obesity and a high level of LDLc and induce a decrease of the anterior muscle volume of the femur as well; consequently, the decrease of the anterior muscle volume of the femur is associated with DD.

With regards to the relationship between DD and lumbosacral sagittal alignment, we suppose that DD causes a decrease of the lumbar lordotic angle and that the sacral inclination angle decreases to compensate, and consequently, the pelvis becomes retroverted. Speculation of this mechanism is grounded in reports that the alignments of the
hip joint, pelvis and lumbosacral spine change in relation to each other in patients with lumbar spinal degenerative disorders [Sasaki et al. (2001)], and that tilting of the pelvis and flexion/extension angles of the hip joint is related to lumbar spinal posture [Offierski et al. (1983); Jackson et al. (1998)].

The back muscle group and the psoas major muscle, which are associated with LBP in previous reports [Parkkola et al. (1993); Danneels et al. (2000)], were not associated with DD in the present study. Our result may be due to the fact that the back muscle thickness that we measured mainly reflected the thickness of the latissimus dorsi muscle and did not include the erector spinae muscle, and also that DD does not necessarily induce LBP, as observed in the results of the questionnaire.

To realize practical exercise intervention for DD and lumbar spinal degenerative disorders, it is necessary to clarify whether the observed relationship between DD and the anterior muscle volume of the femur is direct or indirect through obesity and hyperlipidemia based on bad habits such as lack of exercise and overeating. To make the relationship clearer, investigations of the relationships between muscle volumes, including those not only of the trunk but the lower extremities as well, and lifestyle or lifestyle-related disease and long-term investigations between DD and these factors are recommended. Further, the relationship between DD and lumbosacral alignment, including the alignment of the lower extremities, should be examined to clarify physical characteristics in the elderly.

Muscle volume can be considerably accurately estimated by measuring the transversal area of a muscle using MRI. However, it is time-consuming to evaluate multiple muscle volume using MRI, and so the subjects would have had to remain in the same position for an uncomfortable length of time. On the other hand, measurement of muscle thickness using ultrasonography is a comparatively simple process. Miyatani et al. (2004) and Fukunaga et al. (2001) demonstrated the validity of estimating muscle volume from measured muscle thickness and noted predicted errors of the associated regression equations. Accordingly, we used ultrasonography to measure muscle thickness and calculated the muscle volume from those, except for psoas major muscle, where evaluation using ultrasonography was difficult because of its depth in the body.

In conclusion, the decrease of the anterior muscle volume of the femur was significantly associated with total DD, and the lumbar lordotic angle and sacral inclination angle of the total DD group were significantly smaller than those of the non-total DD group in our subjects, all of whom were over 60.

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References


Name: Mika Hangai

Affiliation: Department of Orthopaedic surgery, Institute of Clinical Medicine, Graduate School of Comprehensive Human Sciences, University of Tsukuba

Address: 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8575 Japan

Brief Biographical History:
1997- Resident's Program in Tsukuba University Hospital
2003- Completion of the Resident's Program
2003- Orthopedist, Ibaraki Seinan Medical Center Hospital
2004- Doctoral Program in Advanced Biomedical Applications, Graduate School of Comprehensive Human Sciences, University of Tsukuba

Main Works:

Membership in Learned Societies:
- Japan Society of Physical Education, Health and Sport Sciences
- The Japanese Orthopaedic Association
- The Japanese Spine Research Society
- The Japanese Society of Physical Fitness and Sports Medicine
- The Japanese Society of Lumbar Spine Disorders