Three-dimensional distribution of acetabular cartilage thickness in patients with hip dysplasia: a fully automated computational analysis of MR imaging
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Summary
Objective: The aim of this study was to evaluate three-dimensional (3D) distribution of acetabular articular cartilage thickness in patients with hip dysplasia using in vivo magnetic resonance (MR) imaging, and to compare cartilage thickness distribution between normal and dysplastic hips.
Design: Forty-five dysplastic hips without joint space narrowing on radiographs and 13 normal hips underwent MR imaging with fat-suppressed 3D fast spoiled gradient echo (SPGR) sequence. Acetabular cartilage thickness was measured with a fully automated segmentation technique, and cartilage thickness distribution was compared between the dysplastic and normal hips on the celestial spherical coordinate system.
Results: Average cartilage thickness was significantly greater for the dysplastic hips than the normal hips (1.77 mm vs 1.34 mm). There was a general trend of gradient increase of cartilage thickness at the superolateral area in normal and dysplastic hips. The gradient increase of cartilage thickness was significantly greater in the dysplastic hips than the normal hips.
Conclusions: Dysplastic hips have general thick cartilage distribution as well as more prominent gradient increase of thickness at the superolateral portion. The knowledge of fundamental morphological feature of dysplastic hips at a preradiologic stage may aid early detection of cartilage thinning in association with osteoarthritic progression, accurate computational biomechanical analysis in the hip joint, and planning periacetabular osteotomy with satisfactory cartilaginous congruency.

Introduction
Hip dysplasia is one of the major causes of osteoarthritis in the hip joint, and relationships between specific parameters of bone morphology of hip dysplasia and likelihood of subsequent osteoarthritic advancement have been extensively studied using plain radiographs or computed tomography. These studies of bone morphology have indicated an insufficient biomechanical environment of increasing contact stress for articular cartilage of the acetabulum or femoral head due to reduced contact area between the opposing surfaces. Computational biomechanical assessments using precise bone models along with simplified articular cartilage models also support this mechanism. There have been few studies concerning specific morphology of the articular cartilage in the dysplastic hip joint.

Articular cartilage has distinctly different material property with adjacent pelvic or femoral bone. Detailed relationship between articular cartilage structure and pelvic or femoral bone structure may have significant implications for biomechanical assessment of the hip joint as compared with biomechanical analysis based on bone morphology alone. The lack of studies concerning cartilage morphology is mainly due to difficulty with in vivo imaging of the articular cartilage in the hip joint. Because cartilage tissue cannot be directly delineated on plain radiographs, the sum of acetabular and femoral cartilage thickness has been estimated as bone-to-bone distance on plain radiographs. Some investigators have studied three-dimensional (3D) distribution of the articular cartilage in the normal hip joint using cadaveric specimens and destructive techniques such as cartilage anatomical slices, a needle probe, or ultrasound, however, there have been no such studies involving dysplastic hips, due to the limited availability of dysplastic cadaveric specimens. Spatial distribution of the acetabular and femoral cartilage in dysplastic hips remains unclear, even though such information is necessary to understand morphological structure, biomechanical environments, and initial mechanism of osteoarthritic change.
Magnetic resonance (MR) imaging allows direct visualization of the articular cartilage in the 3D spaces, due to its excellent soft tissue contrast and ability to acquire 3D information. The 3D distribution of the articular cartilage in other joints, such as knee\textsuperscript{10–13}, shoulder\textsuperscript{14}, elbow\textsuperscript{15}, ankle and hind foot\textsuperscript{16}, has been studied quantitatively using MR imaging in conjunction with computational processing techniques. In recent investigations, the articular cartilage of the hip joint has been visualized using MR imaging\textsuperscript{17,18}. The purpose of the present study was to evaluate 3D distribution of acetabular articular cartilage thickness in patients with hip dysplasia using \textit{in vivo} MR imaging, and compare patterns of thickness distribution between normal and dysplastic hips. To eliminate inter- or intraobserver errors and increase the accuracy of measurements, a fully automated computer analysis system for cartilage segmentation and subvoxel measurements of imaging resolution was utilized.

Methods

PATIENTS AND STUDY DESIGN

The subjects were 40 patients who had bilateral or unilateral dysplastic hips and five normal volunteers without history of hip pain. Criteria for enrollment in the study as a dysplastic hip were as follows: radiological evidence of dysplasia with center edge (CE) angle less than 25°\textsuperscript{19} on anteroposterior radiographs; Class I degree of subluxation (the percentage of the displaced head height due to proximal migration less than 50% of the head height), according to the classification of Crowe \textit{et al.}\textsuperscript{20}; no radiological evidence of joint space narrowing, in order to eliminate secondary change by osteoarthritic involvement and clarify intrinsic morphology of the articular cartilage; and no previous operation on the acetabulum. The 8 hips that were examined due to dysplasia of the contralateral hip, but showed no radiological evidence of dysplasia and no osteoarthritis change on plain radiographs, were included as normal hips. The 5 left hips of the five volunteers showed CE angle equal to or more than 25° on the mid-coronal MR image, and were considered as normal hips. As a result, 45 hips were enrolled as dysplastic hips, and 13 hips were included in normal hips. Out of the dysplastic hips, 28 hips were examined due to hip pain and the other 17 hips were detected on examinations of the symptomatic contralateral hip. All patients and volunteers were females, and the average age was 32 years (range, 14–64 years) in the patients with dysplastic hips and 28 years (range, 16–44 years) in the volunteers and patients with normal hips (Table I). There was a significant difference in CE angle between the normal hips and dysplastic hips ($P < 0.0001$; Mann–Whitney \textit{U} test), but there was no significant difference in age, weight, height, or body mass index of the patients. Informed consent was obtained in written format from all patients and volunteers after explanation of the nature of the MR examinations. For patients younger than 20 years old, informed consent was also obtained from their parents.

MR imaging was performed with fat-suppressed 3D fast spoiled gradient echo (SPGR) sequence using a unilateral surface coil (TORSO, General Electric, Milwaukee, WI) on a 1.5-T MR system (Horizon, General Electric). Imaging parameters were as follows: TR/TE, 24.4/5.7 ms; flip angle, 20°; section thickness, 1.5 mm; in-plane resolution, 0.625 mm; imaging matrix, 256 × 256; signal acquisition, 2; imaging direction, sagittal. Imaging time was 10 min and 17 s. To allow clear separation of acetabular and femoral cartilage on MR images, the original continuous leg traction technique was used during MR imaging\textsuperscript{12}. Briefly, this system comprises a leg apparatus that pulls the leg caudally with approximately 15 kg of force, and a pelvic apparatus that pulls the pelvis cranially with approximately 10 kg of force; thus, traction force is exerted on the hip joint. Immediately after setting this traction device on patients, MR imaging was performed. Using this imaging technique, acetabular and femoral cartilages at high signal were clearly detected by interposition of low signal space between the two cartilages (Fig. 1A). This space was enhanced in high signal by intravenous injection of gadolinium-DTPA in a previous study\textsuperscript{21}, and considered to represent joint fluid. Without use of the traction device during MR imaging, complete delineation of the cartilage border was difficult, due to the inherent adhesive nature of the two types of cartilage at the weight-bearing area\textsuperscript{17}.

**Image Processing**

The MR imaging data were transferred in DICOM format to a UNIX workstation. Image processing of fully automated measurement of the acetabular cartilage thickness was performed using custom-written software\textsuperscript{22}. In arthroscopic studies\textsuperscript{23,24}, acetabular cartilage is subject to high incidence of abnormalities compared with femoral cartilage in a preradiologic stage of dysplastic hips. Therefore, we assumed that detailed assessment of acetabular cartilage is more valuable, and focused on quantification of acetabular cartilage in this study.

Briefly, the image processing involves the following three steps:

(1) The center of a sphere that approximates the femoral head was automatically determined using the Hough transform, based on the assumption that the gradient vector of the MR volume at the boundaries of the femoral head is aligned from the femoral head center to the voxel positions, and the magnitude of the gradient vector is large.

(2) Cartilage regions and the cartilage–bone interface were enhanced using the first and second directional derivatives along radial directions originating from the sphere center determined in the previous step. This image filtering was based on the generally acknowledged theory that an edge corresponds to an abrupt change in the image function, and that the first derivative should have an extreme and the second derivate should be equal to zero at the position of the edge.
After interpolation of discrete MR data, a subvoxel (1/10 of the original voxel) zero-crossing search of the second directional derivatives was performed along the radial directions. The thickness of the acetabular cartilage was measured from the distance between the inner and outer cartilage edge positions, using adaptive thresholding and connectivity analysis, which allowed automatic determination of the optimal threshold value to minimize overlooking true cartilage edges and avoid any unwanted regions for the cartilage. In a previous study, this processing technique provided accurate measurements of a cartilage phantom made of a sheet-like acrylic plate, from MR images obtained using similar MR imaging parameters.

After processing, segmentation of the cartilage was checked visually by two observers, and compared with the original MR images, on the DICOM image viewer (Virtual Place ver 1.156; Medical Imaging Laboratory, Inc., Tokyo, Japan) [Fig. 1(A,B)].

DATA ANALYSIS

To facilitate quantitative comparison of 3D distribution of acetabular cartilage thickness among patients, the celestial spherical coordinate system was defined for the acetabulum (Fig. 2). The center of the femoral head corresponded to the center of the spherical coordinate system. The equator plane of the celestial sphere was rotated from the axial plane passing the spherical center, by 45° medially around the anteroposterior axis passing the spherical center. For simplification of the coordinate system, images of right hips were converted to their mirror images (i.e., left hip) by mirroring with respect to the mid-sagittal plane of the body. In this spherical coordinate system, the location of the acetabular articular cartilage was represented by two independent angles: longitude and latitude. The acetabular fossa was assumed to be located at around 90° latitude. The posterior, lateral and anterior edge of the acetabulum corresponded to 90, 180 and 270° longitude, respectively.

The cartilage thickness was measured along the radial directions from the center of the sphere at 1° increments of longitude and latitude, and was averaged for each discrete region defined on the longitude grid by a 30° interval and on the latitude grid by a 10° interval. We only evaluated the area commonly covered by the cartilage at the weight-bearing area, ranging from 90 to 270° longitude and from 10 to 70° latitude.

VALIDATION AND REPRODUCIBILITY

To evaluate the accuracy of quantification in cartilage thickness, four cadaveric specimens of human hip joints were harvested from four individuals. The joint capsule was left intact, and saline solution was introduced into the joint. After making four bony defects artificially in the pelvis and the femur for landmarks, MR imaging was conducted in coronal direction with reference to the landmarks. After imaging, the hip joints were sectioned into halves, assuming an exact correlation to the imaging plane from the position of the landmarks, and the anatomical section was digitized. Macroscopically, there was no abnormality in articular cartilage of all specimens. The anatomic thickness of articular cartilage, measured manually at 10° increments with a digital template describing the radial lines originated from the centroid on computers, was compared with cartilage thickness on the corresponding MR images, calculated by the automated computer analysis method. The average cartilage thickness of the examined 31 locations was 1.91 mm (range, 1.10–4.0 mm) at the anatomical sections and 1.98 mm (range, 0.95–3.51 mm) at MR images. Mean error of measurements was 0.28 ± 0.23 mm. Correlation coefficient between MR and anatomic thickness was 0.89 (P < 0.001, Pearson’s correlation).

To assess reproducibility of the measurements, two consecutive MR data sets were acquired in four normal volunteers (aged 28–36 years, all females) and two patients with dysplastic hip (38 and 40 years, CE angle of 9 and 12°). Between the sets of MR imaging, the volunteers
and patients were encouraged to reposition the pelvis and lower legs. The reproducibility of measurements of the acetabular cartilage thickness in each discrete region defined on the longitude and latitude grids was calculated as coefficient of variation (CoV: standard deviation/mean × 100 [%]), and the mean reproducibility was calculated as the root means square average for each volunteer or patient\(^{25}\). The mean reproducibility of all the six subjects averaged 3.9% (range, 1.8–5.7%).

**STATISTICS**

We compared overall cartilage thickness of the whole area as well as 3D distribution of cartilage thickness between the normal and dysplastic hips. Overall cartilage thickness was calculated by averaging mean thickness at all discrete regions of all patients in normal and dysplastic hips, and was compared using nonparametric Mann–Whitney U test. Distribution of cartilage thickness was assessed in each row of the discrete regions with the same longitude grid (90–120, 120–150, 150–180, 180–210, 210–240, and 240–270\(^{\circ}\)) and difference of the distribution pattern was examined using repeated-measure analysis of variance with regard to longitude angles, between the normal and dysplastic hips. Pairwise comparisons between different longitude angles and between the normal dysplastic hips were performed with a Bonferroni adjustment for multiple comparisons. A \(P\) value of <0.05 was considered to indicate statistical significance.

**Results**

Overall acetabular cartilage thickness in normal and dysplastic hips averaged 1.34±0.15 mm and 1.77±0.31 mm, respectively, and the dysplastic hips had significantly greater cartilage thickness than the normal hips (\(P<0.0001\)). Cartilage thickness at each discrete region of the normal and dysplastic hips, defined by the longitude and latitude grid, is summarized in Table II. There was a general trend that the cartilage thickness increased as the latitude decreased and the longitude located around 150–210\(^{\circ}\), both in normal and dysplastic hips (Fig. 3). In the dysplastic hips, cartilage thickness in the row of region with longitude

![Diagram](image)

**Table II**

<table>
<thead>
<tr>
<th>Longitude ((^{\circ}))</th>
<th>Latitude ((^{\circ}))</th>
<th>60–70</th>
<th>50–60</th>
<th>40–50</th>
<th>30–40</th>
<th>20–30</th>
<th>10–20</th>
</tr>
</thead>
<tbody>
<tr>
<td>90–120 Normal</td>
<td>1.25±0.17</td>
<td>1.20±0.08</td>
<td>1.12±0.80</td>
<td>1.23±0.12</td>
<td>1.32±0.28</td>
<td>1.28±0.09</td>
<td></td>
</tr>
<tr>
<td>120–150 Normal</td>
<td>1.31±0.15</td>
<td>1.35±0.22</td>
<td>1.40±0.27</td>
<td>1.58±0.45</td>
<td>1.80±1.03</td>
<td>1.78±0.58</td>
<td></td>
</tr>
<tr>
<td>120–150 Dysplasia</td>
<td>1.24±0.19</td>
<td>1.23±0.19</td>
<td>1.23±0.16</td>
<td>1.29±0.25</td>
<td>1.44±0.44</td>
<td>1.69±0.53</td>
<td></td>
</tr>
<tr>
<td>150–180 Normal</td>
<td>1.39±0.27</td>
<td>1.54±0.40</td>
<td>1.74±0.56</td>
<td>1.97±0.63</td>
<td>2.34±0.94</td>
<td>2.25±0.79</td>
<td></td>
</tr>
<tr>
<td>150–180 Dysplasia</td>
<td>1.18±0.17</td>
<td>1.32±0.28</td>
<td>1.38±0.31</td>
<td>1.55±0.43</td>
<td>1.77±0.61</td>
<td>1.97±0.74</td>
<td></td>
</tr>
<tr>
<td>180–210 Normal</td>
<td>1.52±0.43</td>
<td>1.82±0.51</td>
<td>1.98±0.57</td>
<td>2.39±0.78</td>
<td>2.78±0.95</td>
<td>2.82±0.77</td>
<td></td>
</tr>
<tr>
<td>180–210 Dysplasia</td>
<td>1.19±0.15</td>
<td>1.21±0.15</td>
<td>1.32±0.24</td>
<td>1.41±0.31</td>
<td>1.49±0.44</td>
<td>1.41±0.15</td>
<td></td>
</tr>
<tr>
<td>210–240 Normal</td>
<td>1.49±0.41</td>
<td>1.80±0.51</td>
<td>2.08±0.70</td>
<td>2.61±1.16</td>
<td>3.03±1.58</td>
<td>2.70±0.80</td>
<td></td>
</tr>
<tr>
<td>210–240 Dysplasia</td>
<td>1.18±0.13</td>
<td>1.15±0.11</td>
<td>1.25±0.28</td>
<td>1.28±0.24</td>
<td>1.37±0.24</td>
<td>1.44±0.32</td>
<td></td>
</tr>
<tr>
<td>240–270 Normal</td>
<td>1.43±0.31</td>
<td>1.62±0.53</td>
<td>1.79±0.71</td>
<td>2.15±1.36</td>
<td>2.32±1.23</td>
<td>1.88±0.55</td>
<td></td>
</tr>
<tr>
<td>240–270 Dysplasia</td>
<td>1.20±0.13</td>
<td>1.17±0.13</td>
<td>1.30±0.26</td>
<td>1.30±0.22</td>
<td>1.32±0.19</td>
<td>1.34±0.16</td>
<td></td>
</tr>
</tbody>
</table>

Values are means (mm) ± standard deviation.

\(^{*/**}\)Statistical significant difference in comparison between the normal and dysplastic hips at each row of region with the same longitude using repeated-measure analysis of variance; \(^{*}P<0.05\), \(^{**}P<0.005\).
of 120–150, 150–180 and 180–210° was significantly greater than the row with longitude of 240–270° (Fig. 3). In the normal hips, there was no significant difference among the row of region with any longitude categories. Cartilage thickness maps revealed this general tendency for cartilage thickness distribution with focal gradients at the superolateral area, especially in the dysplastic hips (Fig. 4). In comparison between the normal and dysplastic hips at each row of region with the same longitude, the row with longitude of 150–180, 180–210, and 210–240° in the dysplastic hips showed significantly greater cartilage thickness than the corresponding row of region in the normal hips (Table I).

**Discussion**

Advancements in MR hardware technology and optimization of MR pulse sequences allow direct, non-invasive evaluation of articular cartilage, which is difficult on plain radiographs. Recent studies have focused on detailed, quantitative assessment of 3D cartilage volume and thickness for detection of small, focal change of cartilage morphology and monitoring of osteoarthritic progression. However, accuracy and reproducibility of quantitative cartilage thickness evaluations are largely dependent on techniques for image segmentation of cartilage boundaries and algorithms for calculation of cartilage thickness. Segmentation of cartilage with threshold setting and region-growing techniques with additional interactive manual tracing offer relatively reliable reproducibility and accuracy in the knee. However, they require considerable time and effort (human interaction), and can produce intra- and interobserver errors. Several investigators have developed sophisticated semi-automated or automated computer algorithms with snakes or deformable active shape models. These algorithms produce robust segmentation with little human interaction, and produce accurate and reproducible measurements of the articular cartilage in the knee joint. Using an algorithm based on B-spline snakes, Stammberger et al. obtained interobserver reproducibility ranging from 3.3% to 4.1% for maximal cartilage thickness measurements and reproducibility ranging from 5.6% to 10.8% for cartilage volume measurements; i.e., 1.1 to 3.6 times greater than those obtained with manual segmentation techniques. Cohen et al. obtained superior accuracy (mean error, 0.31 mm) for cartilage thickness measurements of cadaveric knees using a B-spline curve fitting technique, and using stereophotogrammetric measurements as the standard of reference.

There have been few studies of quantification of articular cartilage thickness and volume in the hip joint from SPGR MR imaging. In several such studies by McGibbon et al., using computational segmentation programs and human manual interaction, satisfactory accuracy was obtained for cartilage thickness measurements of femoral head specimens. However, to our knowledge, there has been no study concerning quantification of in vivo MR imaging of the hip joint, presumably due to inferior spatial resolution that can be achieved and difficulty of automated or semi-automated segmentation of acetabular and femoral cartilage, which are in close contact with each other in living joints. High reproducibility of measurements of cartilage volume and thickness was obtained in the knee joint using in vivo MR images with in-plane resolution of about...
0.3 mm, however, in-plane resolution of in vivo MR imaging in the hip joint seemed to be limited to about 0.6 mm at a good tradeoff between the image resolution and acceptable signal-to-noise ratio, due to difficulties in using small surface coils. If much manual tracing or pointing is required to discriminate between acetabular and femoral cartilage on MR images over a wide area of cartilage surface, accuracy and reproducibility of measurements become unreliable. In the present study, this difficulty was overcome using two novel techniques. First, persistent leg traction during MR imaging provided a continuum of joint fluid between acetabular and femoral cartilage, with clear signal contrast, and facilitated subsequent computational segmentation. Second, our custom-written program, which searches radially for inner and outer cartilage edges with directional second-order derivatives after interpolation of discrete MR data to 1/10 of the original voxel, allowed fully automated segmentation of the acetabular cartilage at the weight-bearing area in all cases, with visual confirmation of the original MR images. Using this segmentation algorithm, we obtained a mean error of 0.28 mm in measurements of the cartilage thickness of cadavers, and reproducibility of 3.9% in repeated measurements of patients and volunteers. These accuracy and reproducibility values were comparable with those reported by Stammberger et al. and Cohen et al. in the knee cartilage.

In the present study, overall acetabular cartilage thickness in the normal hips averaged 1.34 mm, and ranged from 0.91 mm to 3.4 mm. This is consistent with previous studies evaluating cadaveric human hip joint. The following acetabular cartilage thickness distribution ranges have been reported: 1.0–3.3 mm, by Kurrat et al., using a needle probe system; 1.1–3.6 mm, by Eckstein et al., using an ultrasound system. In those three studies, bony hip joint structure and cartilage surface were assumed to be normal. In the present study, the cartilage thickness of the normal hips had some regional variation, with a general trend for thickness to increase around superolateral regions at 10–30° latitude and 150–210° longitude (Fig. 3); this is consistent with previous cadaveric studies.

An interesting finding of the present study is the significant difference in average cartilage thickness and cartilage thickness distribution patterns between the dysplastic hips and normal hips. Average cartilage thickness of the dysplastic hips was 1.3 times greater than that of the normal hips, and the difference in cartilage thickness was particularly pronounced around the superolateral acetabular regions. For cartilage of the posterior part of the acetabulum at 90–120° longitude and the anterior part at 240–270° longitude, there was no statistical difference in thickness among angles of latitude between the dysplastic hips and normal hips. However, for cartilage of the superior part at 150–180° and 180–210° longitude, and cartilage of the anterosuperior part at 210–240° longitude, there was a significant difference in thickness among angles of latitude between the dysplastic and normal hips (Table II). In the superolateral acetabular area, at 20–30° latitude and 180–210° longitude, cartilage thickness of the dysplastic hips was 2 times greater than that of the normal hips.

There are several possible explanations for these notable differences in cartilage thickness distribution. First, anthropometric variables such as height, weight and body mass index have significant influences on cartilage thickness in joints of the lower limb. Larger and heavier donors or patients have thicker articular cartilage in the hip, knee and ankle joints. In the present study, there was no significant difference in these anthropometric variables between the normal hips and dysplastic hips. When considering the fact that patients with dysplastic hips tended to have higher body weight and body mass index, and the analysis was conducted in a relatively small number of subjects, however, acetabular cartilage thickness in the dysplastic hips may be partly accounted for by the anthropometric effects.

Second, the present difference in cartilage thickness distribution between the normal and dysplastic hips supports the hypothesis that distribution of cartilage thickness correlates with long-term stress distribution on articular surfaces. Lequesne proposed the mechanism of the cartilage growth in response to pressure stimulation. A marked increase in biomechanical stress around the anterosuperior or superolateral area may lead to an increase in cartilage thickness at those areas.

Third, anatomical structures (bone and cartilaginous structures) of the hip joint progressively change during postnatal developmental periods, according to mechanical and physiological factors. If abnormal stress is applied to the acetabular margin due to hip instability, cartilaginous development may be prolonged, and stimulation of subsequent endochondral ossification may be impeded. This may result in abnormally thick articular cartilage in association with pelvic bone deficiency of the dysplastic hips after the childhood developmental periods are completed. To clarify the effects of the second and the third possible mechanisms on thickness distribution of the acetabular cartilage, further studies comparing 3D cartilage distribution and detailed pelvic bony structure are needed.

There are several potential limitations in the present study. First, the number of normal hips was small, compared with that of dysplastic hips. Furthermore, we defined normal hips on anteroposterior radiographs or mid-coronal MR images, however, milder forms of dysplasia with limited insufficiency of anterior or posterior acetabular roof might be undetected in the group of normal hips. Owing to a small number of normal hips and likelihood of inclusion of milder forms of dysplasia in the normal hip group, there was a possibility to fail to detect statistical significant difference for cartilage thickness distribution between the two groups. Given the similarities in cartilage thickness distribution between the present normal hip group and the findings of previous cadaveric studies, and the findings of significant differences in cartilage thickness at superior area of the acetabulum between the normal and dysplastic hip groups, we conclude that acetabular cartilage thickness distribution is reliably different between normal hips and apparent dysplastic hips on conventional radiographs.

Second, due to the strongly curved structure of acetabular cartilage, errors in cartilage thickness measurements from volume-averaging effect are likely to occur, depending on the angles between the cartilage surface and MR imaging plane. Mcibbion et al. reported errors of over 0.3 mm in out-of-plane cartilage thickness in cadaveric studies of the femoral head. Obtaining MR images with thinner slices is an effective way of minimizing volume-averaging effects, but a slice thickness of about 1 mm is probably the minimal requirement for acquiring images with sufficient signal-to-noise ratio, using current clinical MR equipment. In the present study, to minimize volume-averaging effects, 3D cartilage thickness was calculated from MR images on sagittal directions, which were orientated approximately normal to the cartilage surface at the anterior, superior and posterior areas. In the anterosuperior area of the acetabular cartilage, contact pressure was most
prominent in biomechanical studies⁴ and cartilage damage was often observed in arthroscopic studies of dysplastic hips⁵,⁶. Although the volume-averaging effects become larger at the medial cartilage area, we conclude that evaluation of articular cartilage at this area is not particularly important based on the biomechanical condition and assessment of osteoarthritis progression in the hip joint.

Third, the opposing acetabular and femoral cartilages were not in contact on the MR images used to evaluate acetabular cartilage distribution, due to our use of the traction device. The articular cartilage deforms considerably in the living joint, according to intraarticular biomechanical load. Armstrong et al.⁷ reported compression of cartilage by as much as 14% of its thickness under a load of 4–6 times body weight, in a cadaveric study of the hip joint, using arthrography examinations. Herberhold et al.⁸ found changes in cartilage thickness of between 10% and 30% during the first 10 min of static compression at 1.2–1.8 times body weight, in cadaveric studies of the femoropatellar joints, using MR imaging. We are not certain how addition of traction force altered intraarticular biomechanical stress on the cartilage surface, and changed cartilage thickness distribution of the normal and dysplastic hips. It would be of great interest to compare cartilage thickness distribution with and without leg traction devices, under various physiological conditions including supine or upright positions. However, that would require development of imaging technology with higher spatial resolution and superior tissue signal contrast, compared to current standard MRI protocols.

To our knowledge, the present study is the first to reveal characteristic patterns of cartilage thickness distribution in dysplastic hips. A larger database of articular cartilage morphology in normal and dysplastic hips is needed. However, the present finding that cartilage thickness varies considerably with respect to the location of the acetabulum in dysplastic hips, and that there is a general trend toward thick articular cartilage at the superolateral portion, may aid in assessing the cartilage condition whether cartilage thinning is related with osteoarthritic involvement or the intrinsic cartilage structure in the local area. In computational biomechanical assessment of dysplastic hips using a finite element model, incorporation of inhomogenous cartilage thickness distribution rather homogenous distribution⁹ may result in closer agreement between computational assessment and real stress distribution around articular cartilage. Furthermore, in planning periacetabular osteotomy, satisfaction cartilaginous congruency resulting from consideration of inhomogenous distribution of cartilage thickness (in addition to traditional bone morphological planning) may increase the probability of successful clinical outcome.

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References