Three-Dimensional Cartilage Thickness Distribution of Dysplastic Hips with and without Osteoarthritis: Assessment with a Fully Automated Computer Analysis from 3D MR Imaging

T. Nishii\textsuperscript{1}, Y. Sato\textsuperscript{2}, H. Tanaka\textsuperscript{3}, N. Sugano\textsuperscript{4}, H. Miki\textsuperscript{5}

\textsuperscript{1}Department of Orthopaedic Surgery, Osaka University Medical School, Suita, Osaka, Japan, \textsuperscript{2}Division of Interdisciplinary Image Analysis, Osaka University Medical School, Suita, Osaka, Japan, \textsuperscript{3}Department of Radiology, Osaka University Medical School, Suita, Osaka, Japan

Abstract
Acetabular cartilage thickness distribution in dysplastic hips and normal hips were compared three-dimensionally using a fully automated computational analysis from 3D MR images. In dysplastic hips before osteoarthritic changes, specific trend of thick cartilage distribution was observed at the anterosuperior portion, however, in dysplastic hips with osteoarthritic changes, such specific trend disappeared and decrease of cartilage thickness was found at the anterosuperior portion. The precise quantitative assessment of cartilage thickness may be effective in discriminating inherent cartilage morphology of dysplastic hips, monitoring subtle change of cartilage in longitudinal studies, and performing periacetabular osteotomy to achieve satisfactory cartilaginous congruency.

Introduction
Three-dimensional (3D) assessment of articular cartilage thickness distribution is important for localization of osteoarthritic development and determination of subsequent surgical therapy. Among various imaging modalities, magnetic resonance (MR) imaging with fat-suppressed gradient-echo sequences showed a high degree of accuracy for evaluation of cartilage in knee joints\textsuperscript{[1]}, however, few investigations have been conducted in hip joints. The purpose of this study is to evaluate 3D distribution of acetabular articular cartilage thickness in patients with hip dysplasia before and after onset of osteoarthritic change, and clarify the mechanism of osteoarthritic development, using MR imaging. To perform accurate and reproducible assessment of cartilage thickness, a fully automated computer analysis system in cartilage segmentation and subvoxel measurements of imaging resolution has been developed.

Material and Methods
Twenty-two dysplastic hips of 18 patients and 5 normal volunteer hips were studied. On anteroposterior radiographs of the patients, center edge (CE) angle ranged from \textdegree{–4} to 22\textdegree. Fifteen hips showed no joint space narrowing (without osteoarthritis), and 7 hips showed mild to moderate joint space narrowing (with osteoarthritis). All patients and volunteers were female, and average age of the volunteers, patients without osteoarthritis and patients with osteoarthritis was 29, 27, 39 years, respectively. Informed consent was obtained from all patients.

MR imaging was obtained with 3D fast SPGR (TR/TE: 24/4/5.7ms, 1.5mm thickness, 16 cm FOV, 256X192 matrix) with fat saturation in sagittal planes (Fig. 1) using a 1.5-T MR system (SIGNA, GE). To allow separate acetabular and femoral cartilage detection, continuous leg traction technique was used during MR imaging. Automated method for acetabular cartilage thickness measurements from 3D MR data: The method consisted of the following four steps. 1) The center of a sphere that approximates the femoral head was automatically determined using the Hough transform, based on the properties 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. 3) Acetabular cartilage was automatically detected from the radial directional derivative images using adaptive thresholding. 4) A subvoxel zero-crossing search was performed along the radial directions, and the thickness of the acetabular cartilage was measured from the distance between the inner and outer cartilage edge positions.

To demonstrate the acetabular cartilage thickness distribution, the global coordinate system was used for the acetabulum: the center point of the globe was the center of the femoral head. The acetabular fossa corresponded to 90\textdegree of latitude (the North pole), the lateral pole of acetabulum to 0\textdegree of latitude and 180\textdegree of longitude, and the anterior pole of the acetabulum to 0\textdegree of longitude and 270\textdegree of longitude. The acetabular cartilage thickness distribution was compared between pre-osteoarthritic hips, advanced osteoarthritic hips, and normal hips.

Results
Average acetabular cartilage thickness of the volunteers, patients without osteoarthritis, and patients with osteoarthritis was 1.3mm, 1.7mm, and 1.8mm, respectively. All normal hips showed almost homogenous cartilage thickness over the entire acetabular cartilage area (Fig. 2). Dysplastic hips without osteoarthritis, on the contrary, showed a characteristic distribution of cartilage thickness: Cartilage thickness increased remarkably around the area of 180 to 230 degrees of longitude and the 15 to 30 degrees of longitude (anterosuperior portion of the acetabulum). However, those remarkable increases of cartilage thickness were not observed after advancement of osteoarthritis in dysplastic hips. Maximal cartilage thickness of the volunteers, patients without osteoarthritis, and patients with osteoarthritis was 2.1 mm, 4.7 mm, and 3.4 mm, respectively. There were statistically significant differences between the volunteers and patients without osteoarthritis (p<0.05, Scheffe test).

Discussion
Distribution of cartilage thickness of the hip joint had been studied in cadavers using a needle probe or ultrasound\textsuperscript{[2,3]}, however, assessment in vivo hip joints, especially in dysplastic hips, had been difficult. In the present study, detailed distribution of cartilage thickness could be evaluated using non-invasive 3D imaging and a custom-made automated computer analytic technique. From this study, several important findings were obtained. First, cartilage thickness varied considerably with respect to the location of the acetabulum in dysplastic hips, and there were a general trend of thick articular cartilage at the anterosuperior portion. Second, decrease of cartilage thickness was likely to occur at the anterosuperior portion, as the osteoarthritic change progressed. These findings suggested that observation of cartilage abnormality change is most important in evaluation of osteoarthritic change for dysplastic hips. Further, inhomogenous distribution of cartilage thickness may be taken into account to achieve satisfactory cartilaginous congruency when periacetabular osteotomy is performed.

References:

Fig. 1: Original Sagittal MR images in patients with a dysplastic hip

Fig. 2: (Left) Cartilage distribution of normal hips. (Right) Cartilage distribution of dysplastic hips without osteoarthritis. Horizontal axis: longitude degrees, Vertical axis: latitude degrees.