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Cartilage thickness in the hip joint measured by MRI and stereology – a methodological study

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Abstract

Objective: The purpose of this study was to develop a precise and efficient method for estimating the thickness of the articular cartilage in the hip joint and hence three different stereologic methods were tested based on Magnetic Resonance Imaging.

Design: Twenty two females and four males with hip dysplasia underwent MRI. The thickness of the femoral and acetabular cartilage was estimated.

Results: The results for all three methods showed that the observed total variance on cartilage thickness is small. The mean thickness of the acetabular cartilage measured by the three different methods ranged between 1.15 mm and 1.46 mm. The mean thickness for the femoral cartilage measured by the three different methods ranged between 1.18 mm and 1.78 mm. The measurements took 15–20 min per hip to carry out.

Conclusion: Methods 1 and 3 are as precise but we favour method 3 because the measurements are done on images obtained through the center of the femoral head which means that the cartilage surface is intersected perpendicular and partial volume effect avoided. We suggest that this method can be advantageous for assessing the progression of osteoarthritis in dysplastic hips after periacetabular osteotomy.

Key words: Magnetic resonance imaging, Hip dysplasia, Stereology, Cartilage.

Introduction

Magnetic resonance imaging (MRI) is non-invasive and non-ionizing, thus advantageous for assessing the progression of osteoarthritis in dysplastic hips. Articular cartilage has minimal reparative potential and degeneration of the cartilage surface leads to osteoarthritis. The point at which accumulated microdamage becomes irreversible is not known[1].

Periacetabular osteotomy has been introduced to improve acetabular coverage of the femoral head and reduce the risk of secondary osteoarthritis in patients with symptomatic hip dysplasia[2,3]. When periacetabular osteotomy is performed the results of surgery are largely dependent on the degree of preoperative osteoarthritic involvement[4]. As periacetabular osteotomy is performed on dysplastic hips to prevent osteoarthritic progression, changes in the thickness of the articular cartilage is a central variable to follow over time. When periacetabular osteotomy is performed and contact pressure on cartilage is reduced, additional joint degeneration is assumed to be slowed or prevented unless irreparable damage to the cartilage has happened at the time periacetabular osteotomy is performed. Studies have described different methods based on MRI to visualize and quantify articular cartilage thickness[5–7]. In order to develop an unbiased and precise method to quantify cartilage thickness, stereologic methods are useful. Stereologic methods are used to obtain quantitative information about three-dimensional structures based on observations from section planes or projections.

The purpose of this study was to develop a precise and efficient method for estimating the thickness of the articular cartilage in the hip joint and hence three different stereologic methods based on MRI were investigated. Such a stereologic method can be used to evaluate the effect of periacetabular osteotomy and give a better indication for surgery.

Material and method

The study was accepted by the local ethical committee. After signed consent, 22 females and four males presenting 26 dysplastic hips were studied. Median age was 39 (19–53) years and all patients had spherical femoral heads. The patients were scheduled for periacetabular osteotomy and had the following radiologic and clinical characteristics: center-edge angle of Wiberg was 24° or less[8], osteoarthritis degree 0 or 1 according to the classification of Tönnis[9], closed growth zones in the pelvis, symptomatic/painful hip and

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minimum 110° flexion in the hip joint. Excluded from the study were patients with metal implants, cases where the dysplasia might have been caused by neurological illnesses, Legg–Calvé–Perthes disease or sequelae after earlier hip surgery. Also, patients where an intertrochanteric femoral osteotomy was necessary were excluded from the study.

MAGNETIC RESONANCE IMAGING

The examinations were performed on a 1.5 Tesla MRI scanner (Siemens, Erlangen, Germany) using a body array surface coil. A fat suppressed three-dimensional FLASH sequence was used. The imaging matrix was 256 × 256, field of view 220 × 220 mm with a section thickness of 1.5 mm, TR/TE 60.0/11.0, with a flip-angle of 50° and time of acquisition was 9.38 min. To show the acetabular and femoral cartilages separately, an ankle traction device was used during MRI. This device pulled the leg distally with a load of 10 kg.

DOUBLE EXAMINATIONS

The first 13 patients were examined twice within a few minutes, with complete repositioning of the patient and set-up in order to obtain an estimate of precision of the method used.

STEREOLOGIC METHODS

Three different stereologic methods to measure the thickness of cartilage were tested and evaluated for precision and efficiency. The assumption of using these principles is either to use isotropic images or to deal with a spherical surface. Based on X-rays of all included patients, we assumed that the femoral heads were spherical. We opened the MR images and measured the cartilage thickness in a software (Grain 32, Dimac and KT Algorithms) designed for stereological purposes. The measurements were performed manually by one person without knowledge of clinical data or results of other examinations. The interface between femoral and acetabular cartilage was identified as a result of the traction device used during MRI. The interface between cartilage and bone was uncomplicated to discriminate in most images.

Method 1: On the sagittal images of the hip joint every third image per series was sampled which added up to four to five images. In the software a grid of approximately 15 vertical test lines was selected and located on the images and where the test lines intercepted the cartilage, the orthogonal distance through the cartilage was manually measured (Fig. 1). Approximately 60–80 measured distances were summed and the mean distance/thickness of the acetabular and femoral cartilage, respectively, was calculated[10].

Method 2: On the sagittal images of the hip joint every third image per series was sampled which added up to four to five images. A grid of approximately 15 vertical test lines was selected and located on the images and where the test lines intercepted the cartilage, the distance following the direction of the test line through the cartilage was manually measured (Fig. 2). Approximately 60–80 measured distances were summed[11] and the mean distance/thickness of the acetabular and femoral cartilage, respectively, was calculated.

Method 3: Four reconstructed images through the center of the femoral head were used (Fig. 3). This consisted of a sagittal, a coronal and two images placed 45° between coronal and sagittal. On each of the four images a grid of 15–20 radial test lines was selected and located on the images and where the test lines intercepted the cartilage, the orthogonal distance through the cartilage was manually measured [Fig. 4(a–d)]. Approximately 60–80 measured distances were summed and the mean distance/thickness of the acetabular and femoral cartilage, respectively, was calculated.

The precision of the estimates depends on the methods used and the objects investigated[12]. In addition to calculate the observed total variation (CV = SD/mean) of the cartilage thickness, it can also be determined if the variation stems primarily from the stereologic procedure or from the biological variation of cartilage thickness. This can be done by

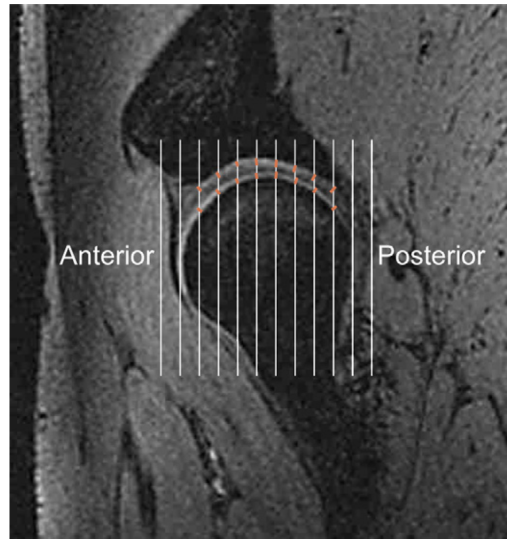

Fig. 1. A grid of vertical test lines was placed on the images and where the test lines intercepted the cartilage, the orthogonal distance through the cartilage was measured.

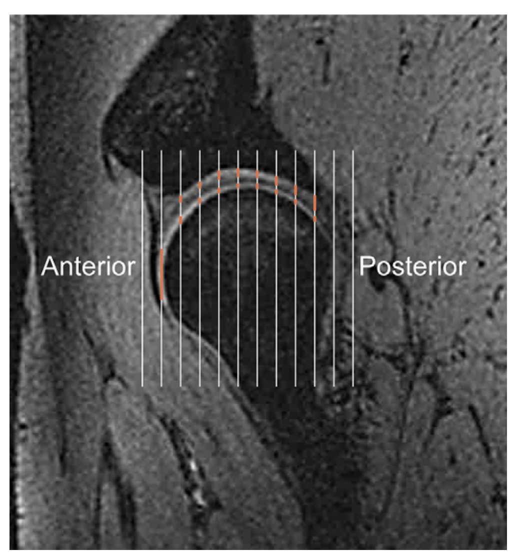

Fig. 2. A grid of vertical test lines was placed on the images and where the test lines intercepted the cartilage, the distance following the direction of the test line through the cartilage was measured.

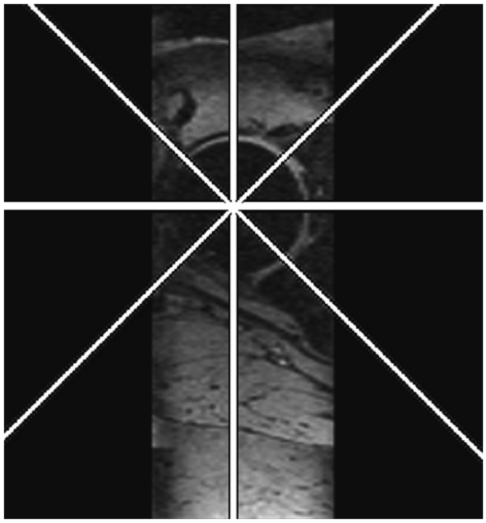

Fig. 3. Axial slice of the femoral head showing how the Four reconstructed MR images through the center of the femoral head are positioned.

calculating the error variance (CE = SEM/mean) which is an estimate of the variation of the stereologic procedure and knowing that we also can identify the influence of the stereologic procedure on the total variation. We estimated the precision of the methods by performing double measurements on images of 13 patients who had the MRI procedure repeated within few minutes with complete repositioning of the patient and set-up. After double measurements the coefficient of variance (CV) and the coefficient of error of the stereologic procedure (CE) were estimated for the thickness of the acetabular and femoral cartilage[12,13].

Results

The mean thickness for the acetabular and femoral cartilage estimated with the three described methods is shown in Table I. The observed total variation was highest for method 2 which makes the least precise method of the three. Methods 1 and 3 do equally well in relation to total variation and error variance. The two methods are quite similar but the estimations in method 1 are based on sagittal images whereas the measurements in method 3 are performed on center images. All three methods took 15–20 min per hip to carry out.

The effect on error variance of method 3 if sampling fewer measurements is shown in Fig. 5.

Discussion

All the three methods (1–3) tested in this study were swift and reproducible, but produced different mean cartilage thickness estimates. The stereologic sampling procedure deployed in method 2 yielded a CV^2 twice as high as methods 1 and 3 in the same patients.

Precision was equally good in methods 1 and 3; but we favour the former because it deploys images obtained through the centre of the femoral head allowing perpendicular cartilage surface intersection. We thereby avoid the potential bias (partial volume effect) that may otherwise arise from oblique intersection of the cartilage of the femoral head because of its spherical form and the parallel nature of the imaging planes.

The results for all three methods showed that the observed total variance (coefficient of variation, CV) on cartilage thickness is small. CV includes the biological variation, CV(bio), and error variance of the method (coefficient of error of the mean, CE). The following relationship exists: $CV^2 = CV^2(bio) + CE^2$. Normally, a study is designed such that $CE^2/CV^2 \sim 0.2–0.5$, because the CE will then only have a limited influence on the total variation (CV)[12]. In this study, $CE^2/CV^2 = 0.08$ for method 1, $CE^2/CV^2 = 0.06$ for method 2 and $CE^2/CV^2 = 0.08$ for method 3. This means that the methodological error variance has basically no influence on CV.

We also studied the effect on CE at a lower number of measurements to test the effect of reducing the overall time consumed by these methods.

Using one half of the measurements for cartilage thickness estimation produced a CE of 0.03. With 1/4 of the measurements, the CE was 0.05, with 1/8 0.08 and with 1/16 0.11.

Based on CE, sampling of 1/8 of the measurements (no. approx. 10) will produce an acceptable error variance of the method and time consumption will drop to about 5 min per hip. However, given the heterogeneity of cartilage loss in osteoarthritis caused by hip dysplasia it is likely that the dependency of measurement precision on sampling increases with the severity of disease. It is also possible that the relative performance of the three methods varies with the severity, heterogeneity and distribution of cartilage loss. In the first place we have tested these methods for precision. The next move is to refine method 3 in order to make it possible to measure cartilage thickness in four quadrants. This will enable us to identify the distribution of cartilage loss.

Joint space narrowing in the weight-bearing area is a well-known radiological finding in hip osteoarthritis indicative of articular cartilage wear in the weight-bearing area[14]. However, the threshold of clinical relevance[15] of such narrowing is difficult to establish because it is often classified qualitatively[16]. A subjective qualitative assessment of joint space narrowing is not sufficient for drawing conclusions about cartilage thickness as joint space narrowing does not appear before osteoarthritis has progressed as shown by Nishii *et al.*[17] who detected a high prevalence of cartilage abnormalities in 70 dysplastic hips without joint space narrowing. For that reason estimating the cartilage thickness by the presented stereologic methods based on MRI may be used as a means of early diagnosis of osteoarthritis before the radiographic change is evident. MRI and traction can be applied to patients with hip dysplasia in order to evaluate the cartilage thickness before deciding to perform a periacetabular osteotomy. If the articular cartilage is shown obviously thin and irregular on MRI, periacetabular osteotomy may be avoided[18].

In addition, MRI and traction can evaluate cartilage abnormalities of the acetabulum and femoral head separately. Nishii *et al.*[19] conducted MRI evaluations in patients with hip dysplasia and found that abnormalities of the acetabular cartilage seemed to occur earlier than those of the femoral cartilage in general. Hasegawa *et al.*[16] reported on the basis of MRI that acetabular sclerosis preceded femoral head sclerosis in dysplastic hips and another study disclosed a significant tendency for more frequent occurrences of cysts in the acetabulum than in the femoral head[20]. This might be due to the limited area where the main load transfer occurs in the acetabular cartilage as compared with the femoral cartilage during gait and stairs climbing in the

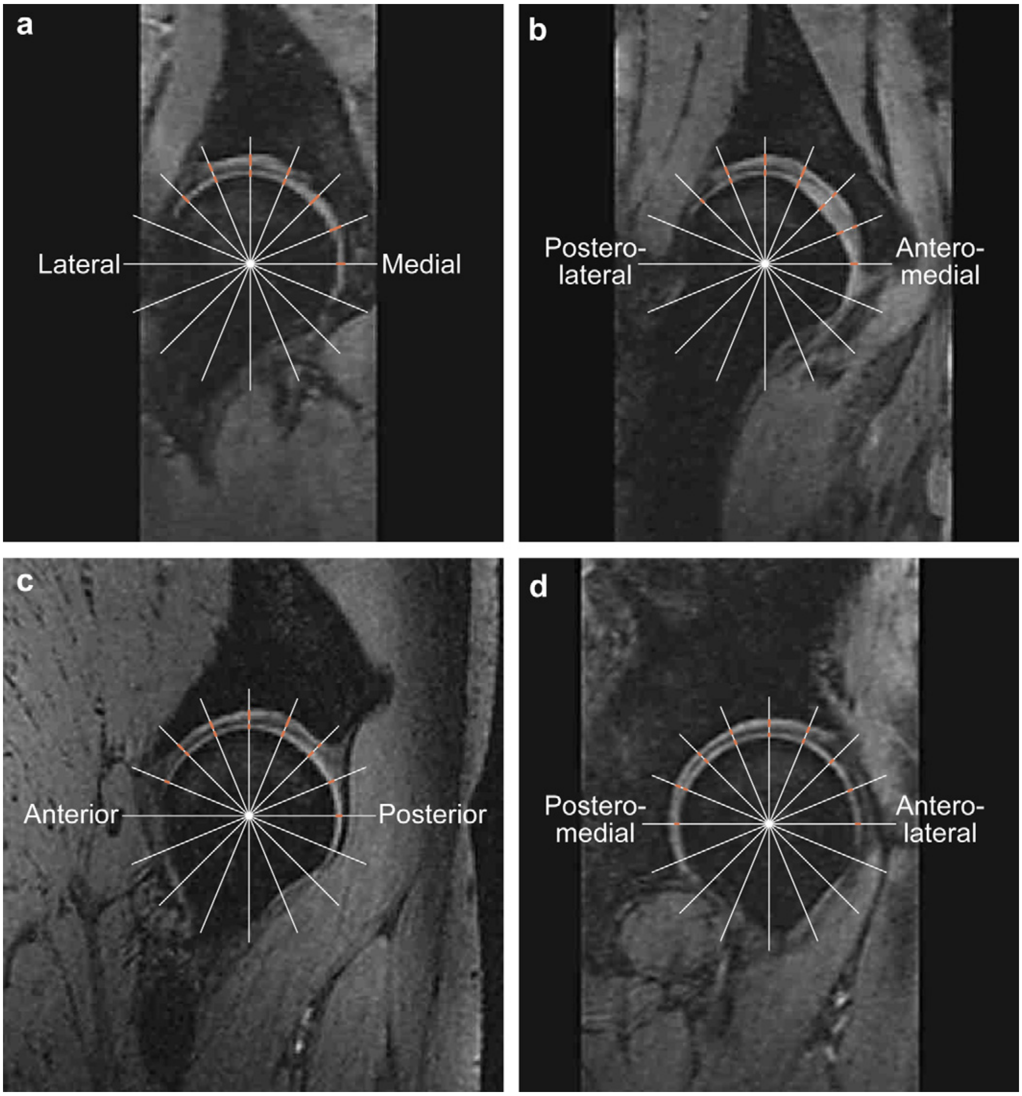

Fig. 4. (a–d) On each of the four images a grid of radial test lines was placed and where the test lines intercepted the cartilage, the orthogonal distance through the cartilage was measured.

patient with hip dysplasia[19]. Biomechanical analysis of the dysplastic hip joint has shown that the compressive stress is extremely high at the anterosuperior portion of the weight-bearing area[21,22]. Several clinical studies on dysplastic hips support these results by showing that articular cartilage degeneration appears mainly in the anterosuperior part of the weight-bearing area of the femoral head and acetabulum[17,23,14].

Nakanishi *et al.* measured cartilage thickness of the femoral head with MRI and traction on 10 normal volunteers[24]. They found the cartilage to be thickest in the central portion around the ligamentum teres (mean 2.8 mm). The medial and the lateral portions were almost of the same thickness (medial 1.3 mm, lateral 1.1 mm). Nishii *et al.* made computational analysis of MRI and found average cartilage thickness to be significantly greater in dysplastic hips than in normal hips (1.77 mm vs 1.34 mm)[25]. In another study the cartilage thickness of the femoral head on six cadavers was measured using different MRI pulse sequences and in that study the measured mean thickness of the cartilage

Table I

Thickness of acetabular and femoral cartilage, standard deviation (SD), coefficient of variation (CV) and coefficient of error of the mean (CE)

Acetabular cartilage					Femoral cartilage				
Method	Thickness (mm)	SD (mm)	CV	CE	Method	Thickness (mm)	SD (mm)	CV	CE
1	1.15	0.05	0.05	0.01	1	1.22	0.06	0.05	0.01
2	1.46	0.17	0.11	0.03	2	1.78	0.20	0.11	0.03
3	1.26	0.04	0.03	0.01	3	1.18	0.06	0.05	0.02

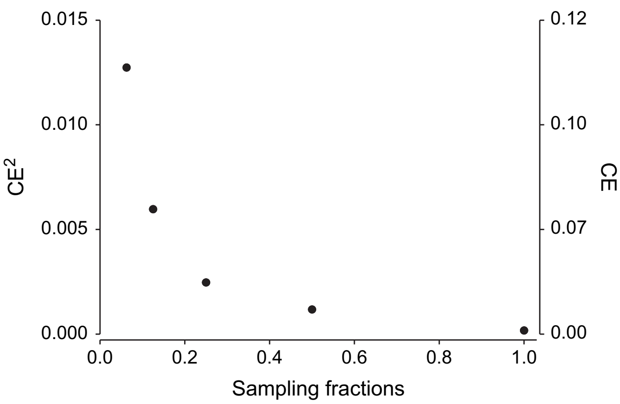

Fig. 5. The effect on error variance of method 3 when sampling fewer measurements.

ranged between 1.36 mm and 1.70 mm.[26] These measurements of cartilage thickness are not directly comparable to our results but they seem to be somehow greater than what we found in this study. The cause of this discrepancy is not based on chemical-shift as we used fat-suppression which eliminates this phenomenon.

Also, we have investigated if metallic artefacts from the screws inserted in the pelvis at periacetabular osteotomy pose a potential problem for these methods used. There are only minor artefacts from the titanium screws and these do not interfere with the measurements of cartilage thickness.

In conclusion, methods 1 and 3 were as precise but we favour method 3 sampling four reconstructed images through the center of the femoral head and using radial test lines because using this method we avoid partial volume effect. We suggest that the method can be advantageous for assessing the progression of osteoarthritis in dysplastic hips after periacetabular osteotomy.

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