Peer reviewed article

Comparison of MRI graded cartilage and MRI based volume measurement in knee osteoarthritis

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Summary

Objectives: The aim of this study was to investigate the relationship between the femoral, tibial and patellar cartilage volume and MRI grading of the articular cartilage in patients with knee OA.

Methods: Articular cartilage volumes of 65 postmenopausal women were determined by processing images acquired in the sagittal plane using a fast spin echo proton density-weighted sequence. The articular cartilages were divided into 5 compartments including lateral and medial tibial, lateral and medial femoral and patellar compartments. The articular cartilages were graded using a modified Outerbridge classification. Grade 0 indicated intact cartilage, grade 1 chondral softening with normal contour, grade 2 superficial fraying, grade 3 surface irregularity and thinning and grade 4 full thickness cartilage loss. The grades of articular cartilage were compared with cartilage volume measurements.

Results: In medial femoral cartilage, grade 1 had more volume compared to grade 0 cartilage (p: 0.017). In medial tibial cartilage, grade 1 had more volume compared to grade 0 and grade 2 cartilage (p: 0.045 and p: 0.027, respectively). In patellar cartilage, grade 1 cartilage had significantly more volume than grade 0 cartilage (p: 0.007). In lateral tibial and femoral cartilages, no significant difference was observed between grade 0 and grade 1 cartilage.

Conclusions: Cartilage volume correlates well with MR grading of articular cartilage. The higher the grade of the cartilage the less the volume, with the exception of grade 1 lesions. Grade 1, reflects oedema in the cartilage and has a conflicting effect on volume measurement. The combination of MRI based volume measurement and grading of articular cartilage may provide an accurate method for the non-invasive evaluation and follow-up of articular cartilage.

Key words: knee; cartilage; volume; grade; MRI

Introduction

OA is the major cause of disability in people over 65 [1]. OA is a group of clinically heterogeneous disorders unified by the pathological features of hyaline cartilage loss and subchondral bone reaction. The prevalence of OA in women and men is similar until about the age of 50, but thereafter the disease becomes more prevalent, severe and generalized in women [2, 3]. The most common joints affected include the knees and the hips [4]. Development of treatments for OA is limited by the lack of a non-invasive method that is reproducible and accurate which can be used to measure progression of disease. Until recently, conventional radiology was the only available, validated, non-invasive method of measuring pro-

Abbreviations

OA:	osteoarthritis
MRI:	magnetic resonance imaging
BMI:	body mass index
LFC:	lateral femoral cartilage
MFC:	medial femoral cartilage
LTC:	lateral tibial cartilage
MTC:	medial tibial cartilage
PC:	patellar cartilage
JSN:	joint space narrowing

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gression of OA [5]. Cartilage degeneration is commonly considered to be the initial pathological defect in OA [6].

MRI is the only imaging modality that can delineate articular cartilage directly and noninvasively [7]. MRI is a simple, safe, non-invasive and reproducible technique for measuring knee cartilage thickness and volume in vivo. There has been increasing interest in the use of MRI in the measurement of knee cartilage volume as a possible outcome measure in arthritis. Although radiological joint space narrowing is the current "gold standard", cartilage volume as measured by MRI has been increasingly investigated in OA [7–10]. MRI techniques, allowing articular cartilage to be quantified with sufficient precision and accuracy to be applicable to longitudinal evaluations of disease activity and treatment response in patients with arthritis, have been described [7, 10–12, 13]. Although a good correlation with articular cartilage volume and radiological grading of JSN has been reported [14], to our knowledge, no previous work has correlated MRI cartilage volume measurements with MRI grading.

In this study we compared the femoral, tibial and patellar cartilage volume with MRI grading of the articular cartilage in patients with knee OA.

Methods

A total of 67 postmenopausal women participating in a hormone study of OA were recruited into this study. Two patients were excluded from the study because of severe degradation of the images, caused by motion of the patient. Criteria for entry to the study included current use-related pain in the index knee to be studied, crepitus in that knee, age >40 and radiographic evidence of OA. Age at menopause was defined as last recalled regular menses or oophorectomy. The exclusion criteria were previous knee joint replacement, inflammatory arthritis, malignancy, knee injury or a contraindication to MRI (pacemaker, history of potentially ferromagnetic material in a strategic location).

Since weight, height, BMI and femoral bone size have been regarded as potential confounding factors for patellar, femoral and tibial cartilage volumes [8, 9], these variables were measured.

Weight was measured to the nearest 0.1 kg (shoes and bulky clothing removed) using a single pair of electronic scales. Height was measured to the nearest 0.1 cm (shoes removed) using a stadiometer. Body mass index (BMI) (weight [kg]/height [m^2]) was calculated. For each subject, MRI examination of the dominant knee, defined as the limb from which she leads off when walking, was performed.

MRI method

MRI of the knee was performed in the sagittal plane with a 1.5-T magnet (Gyroscan Intera Master, Philips) and a knee coil. Scanning parameters for the sagittal proton density-weighted sequence were TR/TE 1275/15, field of view 18 cm, slice thickness 1.5 mm, interslice gap 0 mm, matrix 512×512 pixels and 2 acquisitions with a total imaging time of 4 min 25 sec.

Grading of cartilage with MRI

Five articular surfaces were assessed: patellar facet, the medial and lateral femoral condyles, and the medial and lateral tibial plateaus. Two senior radiologists graded the cartilage. The articular cartilage was graded on the magnetic resonance images with a modification of the classification system of Outerbridge. Grade 0 indicated intact cartilage, grade 1 chondral softening or blistering with an intact surface, grade 2 shallow superficial ulceration, fibrillation, or fissuring involving less than 50 per cent of the depth of the articular surface, grade 3 deep ulceration, fibrillation, fissuring or a chondral flap involving 50 per cent or more of the depth of the articular cartilage without exposure of subchondral bone and grade 4, full-thickness chondral wear with exposure of subchondral bone [12, 15–17].

Quantification of cartilage volume with MRI

We used the method previously described by Peterfy et al. [10]. Articulate cartilage volumes were determined by means of 3D image processing on an independent work station. In this technique, the image data were transferred to the work station and an isotropic voxel size was then obtained by a trilinear interpolation routine. The volume of individual cartilage plates was isolated from the total volume by manually drawing disarticulation contours around the cartilage boundaries on a section by section basis. These data were then resampled by means of bilinear and cubic interpolation for the final 3D rendering. The volume of the particular cartilage plate was then determined by summing all the pertinent voxels within the resultant binary volume. This was done by a single observer (TB). An index of bone size was calculated by measuring femoral condylar volume in each subject. This was done using the same method as for cartilage volume. Contours were drawn around the femoral condyle in images on sagittal views. In each section the anterior, posterior and lower border corresponded to the bone-cartilage junction. The superior border was delineated by drawing a straight line connecting the superior limits of the anterior and posterior contours in each image (figure 2).

The intraobserver reproducibility of the MRI cartilage volume estimate was tested on 20 knees randomly selected and read twice three weeks apart.

Statistics

The variables were given as mean ± SD (Standard Deviation). The cartilage volumes were adjusted for femoral bone size, weight, height and BMI. Linear regression was used to examine the effect of weight, height, BMI and femoral condyle bone volume (as a measure of bone size) on femoral, patella and tibial cartilage volumes in univariate analyses and in a multivariate model. Results are presented as regression coefficients that represent differences in cartilage volume per unit change in the relevant explanatory factor, while other factors are held constant (i.e. controlled for).

The correlation between volume measurements and MR grading was investigated. A p value of less than 0.05 was regarded as significant. Kruskal-Wallis one way ANOVA and LSD (Least Significant Difference) test were used to compare the articular cartilage grades and volume measurements. Reproducibility was tested by using Kappa coefficient.

Results

A total of 65 patients met the criteria for inclusion in the study. The mean ages of the patients were 53.1 ± 7.0 years (45–75). The weight and height of the patients were 70.6 ± 11.3 kg (52–105) and 156 ± 5.1 cm (146–170), respectively. The BMI values were 28.8 ± 3.9 kg/m^2 (19.3–38.1).

Univariate analyses showed minimal effect of age, BMI and bone size on cartilage volume. The crude and adjusted values of cartilage volumes are given in table 1.

Grade 1 lesions were mostly seen in lateral tibial cartilage (LTC) and medial tibial cartilage (MTC) compartments respectively. Grade 1 lesions were minimally seen in lateral femoral cartilage (LFC) compartment. Grade 0 cartilages were mostly seen in patellar cartilage (PC), MTC and LFC compartments respectively. We did not observe grade 3 in LTC, MTC and PC. Also grade 4 cartilage was not observed in any compartment (figure 1).

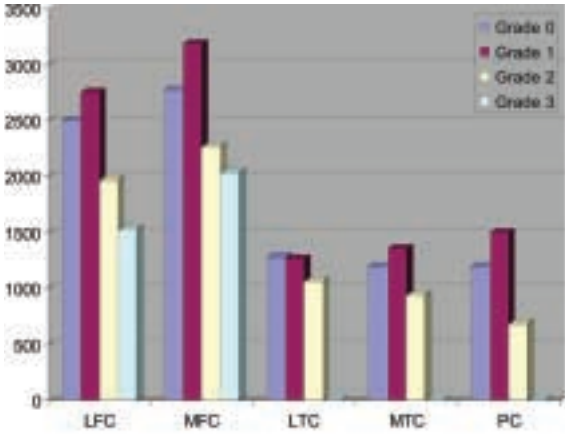

Figure 1

The distribution of MR grades in lateral femoral, medial femoral, lateral tibial, medial tibial and patellar cartilage and their relationship with volume measurement. LFC: lateral femoral cartilage; MFC: medial femoral cartilage; LTC: lateral tibial cartilage; MTC: medial tibial cartilage; PC: patellar cartilage.

Table 1

The crude and adjusted total femoral, tibial and patellar cartilage volumes.

	Volume (mean ± SD) mm^3	
	Crude	**Adjusted**
Lateral Femoral Cartilage	2246 ± 705	2246 ± 120
Medial Femoral Cartilage	2726 ± 665	2725 ± 196
Total Femoral Cartilage	4972 ± 1177	4972 ± 315
Lateral Tibial Cartilage	1252 ± 260	1253 ± 15
Medial Tibial Cartilage	1264 ± 316	1265 ± 43
Total Tibial Cartilage	2517 ± 511	2519 ± 57
Patellar Cartilage	1234 ± 404	1235 ± 73

Table 2

Number and mean volume measurements of MR-graded articular cartilages in the tibiofemoral and patellofemoral joints.

	n	**Volume (Mean ± SD) (mm^3)**
Lateral Femur Cartilage		
Grade 0	34	2503 ± 568
Grade 1	6	2755 ± 769
Grade 2	18	1967 ± 666
Grade 3	7	1531 ± 544
Medial Femur Cartilage		
Grade 0	36	2770 ± 536
Grade 1	15	3190 ± 618
Grade 2	9	2268 ± 527
Grade 3	5	2033 ± 617
Lateral Tibial Cartilage		
Grade 0	5	1279 ± 352
Grade 1	56	1266 ± 258
Grade 2	4	1060 ± 173
Medial Tibial Cartilage		
Grade 0	29	1197 ± 236
Grade 1	33	1356 ± 359
Grade 2	3	939 ± 181
Patellar Cartilage		
Grade 0	46	1196 ± 332
Grade 1	15	1497 ± 420
Grade 2	4	682 ± 474

In LFC no significant difference was observed between grade 0 and grade 1 cartilage (p: 0.39). Grade 0 cartilage had significantly more volume than grade 2 and grade 3 cartilages (p: 0.003 and p: 0.000 respectively). Grade 1 cartilage had significantly more volume than grade 2 and grade 3 cartilages (p: 0.013 and p: 0.001 respectively).

In MFC grade 1 had more volume compared to grade 0 cartilage (p: 0.017). Grade 0 cartilage had significantly more volume than grade 2 and grade 3 cartilage (p: 0.025 and p: 0.008 respectively). Grade 1 cartilage had significantly more volume than grade 2 and grade 3 cartilages (p: 0.000 and p: 0.000 respectively).

In LTC no significant difference was observed between grade 0 and grade 1 cartilage. Although grade 2 cartilage had less volume than grade 0 and grade 1 cartilage, this was not statistically significant.

In MTC grade 1 had more volume compared to grade 0 and grade 2 cartilage (p: 0.045 and p: 0.027 respectively). No significant difference was observed between grade 0 and grade 2 cartilage (p: 0.167).

In PC while grade 0 cartilage had significantly more volume than grade 2 cartilage (p: 0.008), grade 1 cartilage had significantly more volume than grade 0 cartilage (p: 0.007). Grade 2 cartilage had significantly less volume than grade 1 cartilage (p: 0.000). The MR volume measurements correlated with MR grades are seen in table 2.

The intraobserver reproducibility was 0.92 for volume measurements and interobserver reproducibility was 0.93 for cartilage grading.

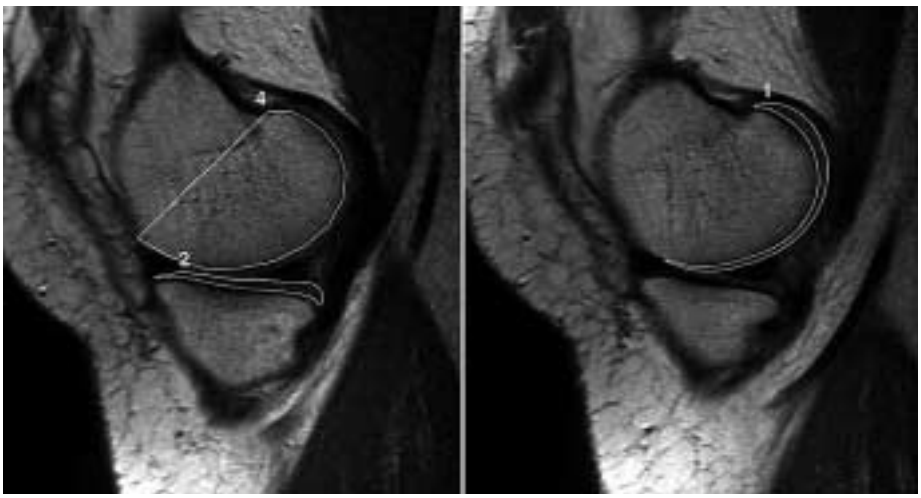

Figure 2

a. Single fast spin-echo proton density-weighted sagittal image of a study subject's knee with a typical outline of the bone contour and tibial cartilage used in the calculation of the bone volume and tibial cartilage volume, respectively.
b. Another image with the femoral cartilage outlined during segmentation on the work station.

Discussion

In both epidemiological studies and clinical trials, the traditional radiographic method of assessing OA progression is done by estimating cartilage loss as measured by narrowing joint space [8, 14, 18]. In plain knee radiographs, small positional changes from one examination to the next may affect the reproducibility of joint space narrowing, particularly in longitudinal studies [14]. Measurements of joint space width on radiographs can not differentiate between femoral and tibial cartilage loss and do not reveal the distribution pattern of tissue degradation throughout the joint surface [7].

MRI, by virtue of its superior soft-tissue contrast, lack of ionizing radiation and multiplanar capabilities, is superior to more conventional techniques for the evaluation of articular cartilage [12, 19]. Unlike radiography, MRI can provide direct visualization of the hyaline cartilage (as well as the meniscus and bone) and has the potential to provide accurate quantification with sensitivity to change [10]. MR imaging is considered an accurate means of detecting and grading moderate and advanced cartilage lesions in the knee joint and is thus useful in the evaluation of knee OA [20, 21]. MRI is also less subject to positional change, which is a particular problem in the interpretation of small changes in radiological measures in longitudinal studies [14].

A major difference in the way in which X-ray and MRI image the joint is that the former is done with weight bearing and the latter without. If one of the major causes for cartilage thinning in OA is increased deformability on weight-bearing then one might expect a major discrepancy between volume measurements on MRI and JSN assessed on weight-bearing X-rays. However, conventional pathological studies of OA suggests that the major loss of structural elements of the cartilage occurs in the focal areas that are most affected [22].

Methods to quantify cartilage volume from MRI have been available for over 10 years [23]. A number of publications exist which show that the method is highly reproducible and reflects cartilage volume measured directly from postoperative or cadaveric samples [24, 25]. Cartilage volume measurement studies have increased in importance because of the prevalence of cartilage injury and degeneration and the development of new techniques to treat damaged cartilage [26].

Optimized MR imaging techniques allow articular cartilage to be noninvasively quantified with sufficient precision and accuracy to be applicable to longitudinal evaluations of disease activity and treatment response in patients with arthritis [7, 9, 11]. Although cartilage volume has been reported to correlate well with radiological grading of joint space narrowing, a clear difference in cartilage volume of radiological grade 0 and grade 1 JSN could not be shown [14]. Using the cartilage volume quantification method no significant loss of total cartilage volume had been found in 11 patients with knee OA studied over a 3-year period [22]. These data appear to challenge the face validity for the use of total cartilage volume to assess structural changes in OA.

Several recent publications have described the use of fat suppressed three-dimensional spoil gradient-recalled sequences for the evaluation of knee hyaline cartilage, with greater sensitivity and specificity for hyaline cartilage defects [11, 12, 27–30]. However, these sequences generally require long acquisition times and additional time for off-line manipulation to create images in planes different from that in which the images were acquired. In fast spin-echo proton density-weighted images, the resulting tissue contrast between articular cartilage and adjacent fluid and cortical bone provides a useful window in which to visualize the integrity of the hyaline articular cartilage and other structures of the knee [11, 12]. We used a fast spin-echo proton density-weighted sequence to assess the morphology and thickness of the hya-

line articular cartilage of the knee. In a specialized MR study of the knee articular cartilage, grade 1 was considered disease negative status because of its relatively limited clinical importance and a suspected higher subjectivity of establishing its presence at arthroscopy [12]. Grade 1 has indicated chondral softening or oedema with an intact surface [15]. When the results of MRI and arthroscopy were compared, there appeared to be a tendency for the readers of the MR images to overdiagnose grade 1 lesions. It is unclear if this finding suggests that MRI has superior sensitivity with regard to the detection of oedema in the cartilage or if it represents an imaging artifact [12]. This possible imaging artifact is minimized with our technique by virtue of the relatively small pixel size and the high resolution matrix. According to the MRI grading system, we expected a decrease in volume as the grade increased. Our results revealed that, in general, the higher the grade of the articular cartilage, the less the volume was, with the exception of grade 1 cartilage. We found that grade 1 articular cartilages had significantly more volume compared to other cartilage grades including grade 0 intact cartilages.

Several possible reasons have been reported for the lack of change in total cartilage volume of the knee joint (measured from MRI) in the face of disease progression in OA. The most obvious explanation has been reported to be that OA is a focal disease and cartilage change is usually concentrated on small areas of the joint subjected to maximal loading. Assessment of total cartilage volumes will dilute any change in these areas. Another likely explanation for this finding is offered by data from other studies using histology, MRI or arthroscopy, which have shown that some parts of the articular cartilage increase in volume (grade 1) due to excess hydration in the early phases of OA. It is quite possible that progression of OA in whole joints will result in thickening of cartilage in some areas and loss of cartilage volume in others resulting in no measurable change in total cartilage volume. Specifically, progression of relatively advance lesions in one compartment might be accompanied by earlier changes in swelling of the cartilage in another compartment [22]. Similarly, our results revealed different stages of cartilage degeneration in different compartments of the same knee.

In our study, synchronous evaluation of articular cartilage by means of MR grading revealed that grade 1 articular cartilage has negative effect on the accuracy of articular cartilage volume measurements for follow-up of OA. These data appear to challenge the face validity for the independent use of cartilage volume to assess structural changes in OA.

In conclusion, we have shown that cartilage volume correlates well with MR grading of articular cartilage. The higher the grade of the cartilage, the less the volume, with the exception of grade 1 lesions. Grade 1, which reflects oedema in the cartilage, has a conflicting effect on volume measurement. We believe that, MRI based volume measurement and grading of articular cartilage together may provide an accurate method for the non-invasive evaluation and follow-up of articular cartilage pathology.

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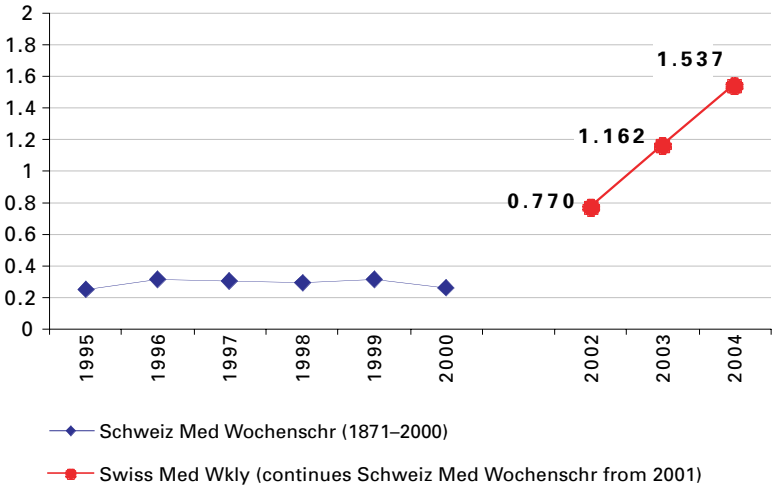

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