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Patterns of joint damage seen on MRI in early hip osteoarthritis due to structural hip deformities

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SUMMARY

Objective: The aim of this study was to evaluate differences in damage patterns assessed using magnetic resonance imaging (MRI) between hips with femoroacetabular impingement (FAI) and developmental dysplasia of the hip (DDH) as well as to correlate MRI findings with delayed Gadolinium enhanced MRI of cartilage (dGEMRIC) and with patient pain.
Design: This retrospective study included 40 patients (mean age 28.6 ± 11.2 years) who underwent dGEMRIC and morphological MRI of the hip. Twenty-one hips with FAI and 19 with DDH were investigated. A self-developed morphological grading (MRI score) and dGEMRIC evaluation were done on seven radial reformats obtained from an isotropic 3D True-fast imaging with steady state precession (FISP) sequence and an isotropic T1-mapping sequence. The observed damage patterns were summed up into sub-scores and a total MRI score.
Results: Labrum damage, paralabral cysts, and acetabular rim bone cysts were more common in DDH patients than in FAI patients. No significant differences were seen in the occurrence of cartilage damage, bone cysts, or osteophytes. In DDH (but not in FAI), the dGEMRIC index demonstrated a tendency for lower values in areas next to cartilage defects. There was no association between labrum damage and dGEMRIC index. A moderate correlation was seen between Western Ontario and McMaster Universities (WOMAC) pain score and cartilage damage, paralabral cysts, and the total MRI score.
Conclusions: This study confirms a higher prevalence of labrum damage but not cartilage damage in patients with DDH in comparison to patients with FAI. In addition, our data suggests an association of cartilage damage and paralabral cysts with patient reported pain.

Introduction

Osteoarthritis (OA) of the hip joint is prevalent in 1–6% of the adult population, with the rates varying between countries and gender[1]. The social and economic burden associated with this disease[2] demands a better understanding of its etiology and the need to find means for its prevention. Early OA of the hip joint is known to be mainly secondary to anatomical abnormalities as found in developmental dysplasia of the hip (DDH) and femoroacetabular impingement (FAI). While in DDH, cartilage damage derives from insufficient acetabular coverage and subsequently increased axial joint load[3], in FAI the cartilage damage is caused by the abutment of an aspheric femoral head against the acetabular rim[4]. Surgical techniques to correct the underlying anatomical abnormalities were developed to relieve symptoms but also with the ultimate goal to stop or delay the degeneration of the hip joint[5,6]. There is data demonstrating that the amount of pre-existing joint damage will influence the surgical outcome[7]. Hence, non-invasive imaging techniques such as magnetic resonance imaging (MRI) has been of clinical interest to stage the amount of joint damage in these hips[8].

Plain radiography is the standard method by which we assess the structural anatomy of the hip. Additionally, it is utilized to assess the extent of OA; however, it is known that it is insensitive to early stages of OA[9,10]. MRI on the other hand is able to directly visualize soft tissue structures, including labrum and cartilage. Not

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only morphological, but also quantitative imaging approaches like delayed Gadolinium enhanced MRI of cartilage (dGEMRIC) may allow the early detection of joint damage before gross structural changes to the tissue[11]. Powerful three-dimensional (3D) isotropic MR sequences for morphological imaging and quantitative T1 mapping (used for dGEMRIC) are now available and allow image reconstruction and readings in arbitrary planes[12,13]. MRI readings on isotropic datasets in combination with adequate 3D viewing software allows the radiologist to assess the hip joint comprehensively[14]. In a spherical structure such as the hip joint, the disadvantages of 2D MR sequences like imaging gaps or partial volume effects are minimized using 3D isotropic sequences.

To date, there are no reports comparing morphological damage patterns in FAI and DDH using 3D isotropic sequences. Furthermore, it is not known how findings on 3D isotropic sequences of the hip correspond to dGEMRIC values in the same location.

The primary aims of this study were (1) to investigate whether there are differences in damage patterns in bone, cartilage, and labrum as seen on MRI between DDH and FAI and (2) whether dGEMRIC correlates to cartilage and labrum assessment in those patients. A secondary aim was to correlate these MRI findings with patient reported pain. Our primary hypotheses were (1) that differences in distribution of labral damage, bone cysts and osteophytes are present between DDH and FAI, and (2) that dGEMRIC index is different when morphological MRI findings are present.

Materials and methods

Study population

Institutional review board approval was obtained for this retrospective study. A waiver of informed consent was granted. Sixty-one consecutive hip patients (71 hips) undergoing MRI between November 2006 and December 2007 were screened. Forty patients met our inclusion criteria, which were the following: presence of structural deformity (either DDH or FAI), MRI scan that included dGEMRIC and morphological MRI, age greater than 10 years, intact joint space (Tönnis grade 0–I[15]) and a completed Western Ontario and McMaster Universities (WOMAC) pain questionnaire. DDH was diagnosed in patients when the lateral center edge (LCE) angle was less than or equal to 25° or Tönnis angle >15° on the anterior–posterior (AP) pelvic radiographs. FAI was diagnosed based on clinical examination findings (positive anterior impingement sign[16]) in combination with radiographic features of cam deformity (alpha-angle ≥55° on 45°-Dunn or cross table lateral view[17]) or pincer deformity (positive cross over sign and/or posterior wall sign)[18]. Exclusion criteria were advanced OA (Tönnis grade II or more), prior hip surgery, history of hip trauma, neuromuscular disorders able to affect the hip joint, chromosomal abnormalities and any other known hip disease. Cases with both acetabular deficiency and impingement within the same hip were also not included. In patients with bilateral disease only the right hip was analyzed for our study.

From this patient population, 19 patients (19 hips) with DDH (male/female 0/19) and 21 patients (21 hips) with FAI (male/female 9/12) were selected. The FAI hips were classified as mixed in 11, cam in 7, and pincer impingement in 3 cases. The mean age was 29.0 years (standard deviation SD: 11.5 years, range: 13–52 years). The patient characteristics of both groups (DDH and FAI) are shown in Table I.

WOMAC Index

Patients were asked about presence of pain and scored accordingly using the pain portion of the WOMAC questionnaire[19].

Table I
Patient characteristics

	DDH	FAI	P for difference
Number of patients/hips	19/19	21/21	
Age (years)	27.2 ± 10.8	30.7 ± 12.1	0.33
Gender (female/male)	19/0	12/9	<0.001
JSW (mm)	4.5 ± 1.1	3.9 ± 0.6	0.03
WOMAC pain score	8.1 ± 5.0	6.3 ± 4.7	0.26
Tönnis grade 0/I	11/8	11/10	0.55

Patient characteristics are shown as mean ± SD. P-values for differences between DDH and FAI are given.

The sum of the Likert scale was used with a possible minimum score of 0 (no pain) and a maximum score of 20 (worst pain) for the diseased hip.

Plain radiographic evaluation

Standard AP pelvic radiographs taken within 1 year of the MRI were used for radiographic assessment. The minimal joint space width (JSW) at the central weight-bearing zone was measured on digitalized radiographs using the Synapse® PACS System (Fujifilm Medical Systems USA, Inc., Stamford, CT, USA). The Tönnis grading system was also utilized to grade the amount of radiographic OA[8]. This analysis was conducted by an orthopedic surgeon (YY) with 5 years of experience in musculoskeletal image evaluation and was blinded to patient history and MRI findings during the readings.

MRI

In all cases, MRI was performed after intra-venous gadolinium injection, followed by 15 min of exercise. Each patient received 0.4 ml per kg body weight of the FDA approved contrast agent gadopentetate dimeglumine (Magnevist®, Bayer HealthCare, Berlin, Germany) approximately 30 min prior to MRI (~45 min prior to T1 mapping).

All MR images were obtained using a 1.5 T system (Avanto®, Siemens Healthcare, Erlangen, Germany) and a dedicated flexible surface coil. The 3D isotropic True-fast imaging with steady state precession (FISP) sequence was used for morphological grading of labrum, cartilage, and bone. The True-FISP sequence was previously used and compared to standard 2D imaging for morphological grading in knee and shoulder joints[12,20,21]. For dGEMRIC, a 3D isotropic dual flip angle volume interpolated breath-hold examination (VIBE) T1 mapping sequence (gradient echo based) was used, which was described in prior studies[13,22]. The MR parameters are shown in Table II.

Table II
MR parameters

Sequence	3D iso True-FISP	3D iso VIBE T1 map
Repetition time (ms)	12.57	15
Echo time (ms)	5.48	3.27
Field of view (mm)	160 × 160	160 × 160
Matrix	256 × 256	192 × 192
Voxel size (mm)	0.63 × 0.63 × 0.63	0.83 × 0.83 × 0.83
Slice thickness (mm)	0.63	0.8
Interslice gap (mm)	0.13	0.16
Number of slices	144	96
Bandwidth (Hz/Px)	140	130
Flip angles (°)	–	4.1/23.5
Fat suppression	Yes	No
Examination time (min)	7:45	6:51

MR sequence parameters are given. iso: isotropic.

Morphological MRI evaluation

The MRI analysis included morphological grading of labrum, cartilage, and bone, and was performed by the primary reader (IK, 5 years of experience) for all patients. Inter-observer variability was assessed by having 10 randomly selected patients re-graded by a musculoskeletal radiologist with more than 15 years of experience (SW). Intraobserver agreement was assessed by re-reading images 3 weeks apart.

The 3D True-FISP data set was reconstructed using a multi-planar reconstruction software (Syngo®, Siemens Healthcare, Erlangen, Germany) to create six radial reformats (slice thickness 0.63 mm) rotating around the femoral head–neck axis in 30° steps (Fig. 1). Thereby, the radial reformats enabled assessment of the upper hemisphere of the hip joint, at seven consecutive regions: (1) anterior, (2) anterior–superior, (3) superior–anterior, (4) superior, (5) superior–posterior, (6) posterior–superior, (7) posterior (same reformat used as for anterior assessment). In these regions, labrum, cartilage and bone were evaluated with a scoring system developed for the purpose of this study.

The labrum was classified based upon severity of lesions (0 = normal, 1 = partial tear, 2 = full-thickness tear/complete detachment from acetabular rim) as described by Leunig *et al.*[23]. The acetabular cartilage damage was graded as: 0 = normal, 1 = focal defect, 2 = generalized defect (larger than 10 mm in length and at least partially full-thickness lesions). If cartilage delamination was clearly identified on MRI it was classified depending on the size as

focal or generalized defect. Both labrum and cartilage damage were graded on all seven radial positions. The presence of paralabral cysts, bone cysts in the femoral head, acetabular center, and acetabular rim, osteophytes of the femoral head and acetabular rim were recorded on all seven radial reformats. The presence of each type of lesion on one of the reformats was noted as 1, the absence was noted as 0.

Eight sum scores for each type of MRI finding ("cartilage damage", "labrum damage", "paralabral cyst", "acetabular rim bone cyst", "acetabular center bone cyst", "femoral bone cyst", "acetabular rim osteophyte", "femoral osteophyte") and a "total MRI score" for all morphological findings were calculated. The maximum achievable total MRI score was 70 (worst MRI outcome), the minimum possible score was 0 (best MRI outcome). An overview of our scoring system is given in Fig. 2 and Table III.

dGEMRIC evaluation

The reformats for the dGEMRIC evaluation were obtained in the same radial imaging planes as the imaging planes for morphologic grading. Seven radial reformats ranging from anterior to posterior (reformat number 1–7) were assessed. On every reconstructed T1 image, two equally sized regions of interest (ROIs) for the peripheral and central articular cartilage were selected. The lateral border of the ROI was defined by the acetabular rim and labral–chondral junction and the medial border was defined by the acetabular fossa (Fig. 3). Both cartilage surfaces (femoral and acetabular) were selected within one ROI; however, care was taken
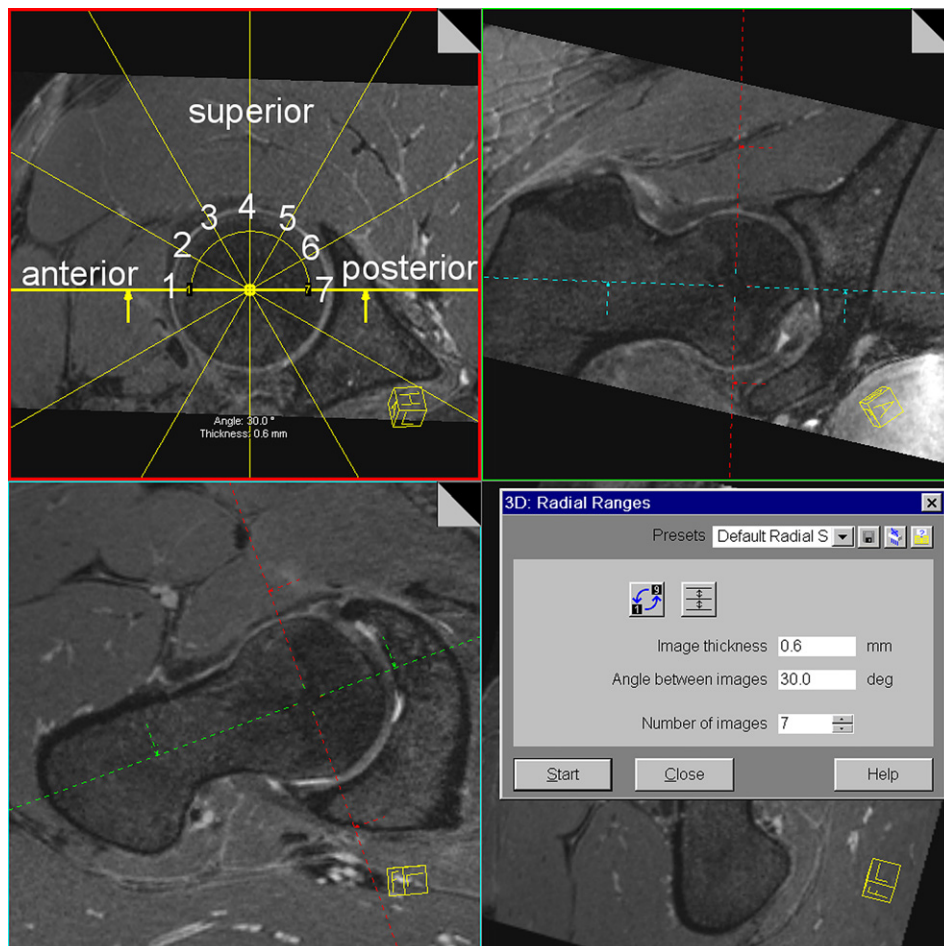
Fig. 1. Acquisition of radial reformats obtained from an isotropic 3D True-FISP sequence. Seven radial reformats around the femoral neck axis were obtained from the anterior to the superior and the posterior orientation (first and last were the same).
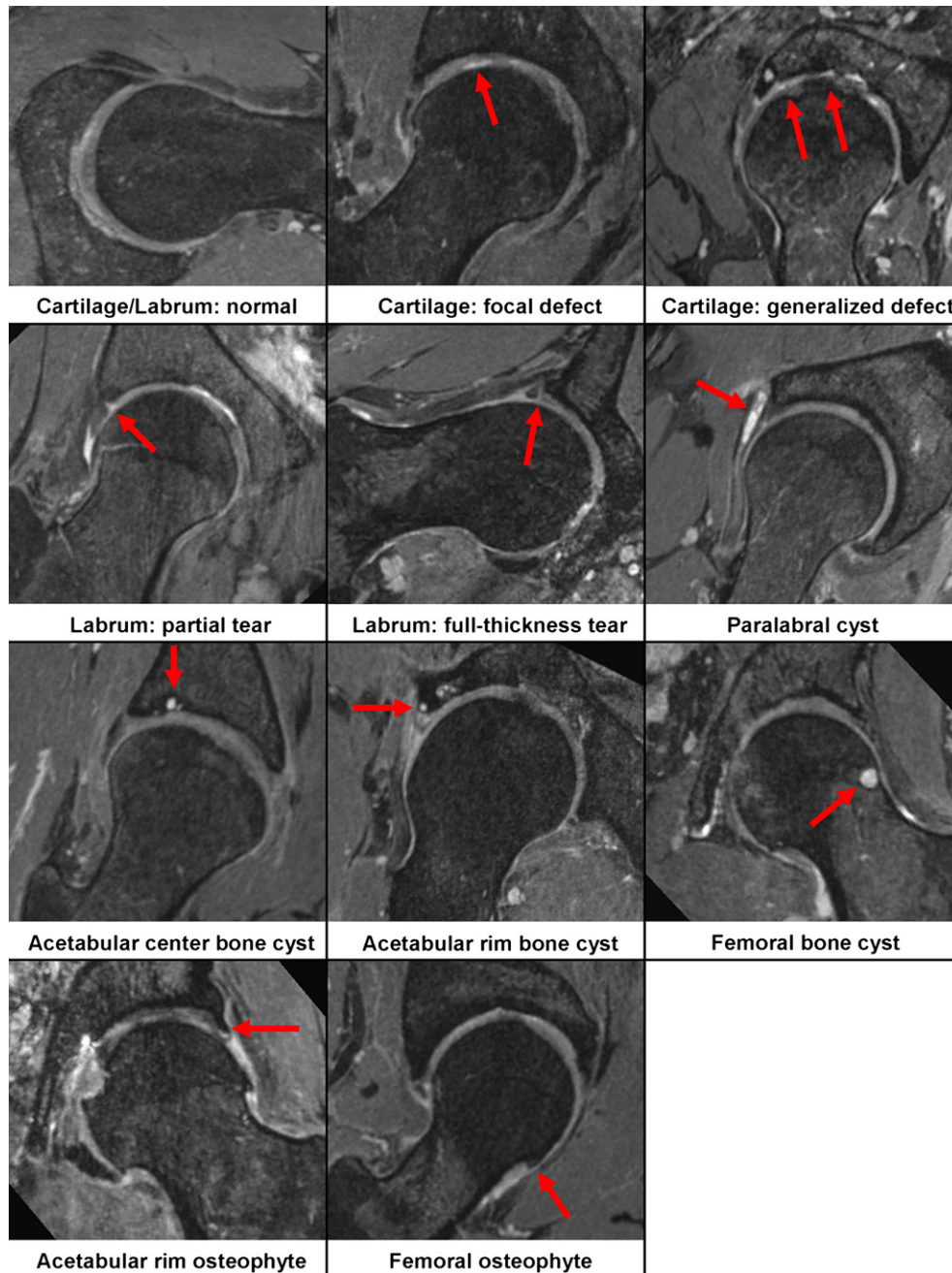
Fig. 2. Examples for the morphological MRI scoring are shown. See Table III for point scoring system.

not to include joint fluid (e.g., cartilage defects) into the ROI. Similar to other authors[11], corresponding morphological images were used to ensure correct ROI selection. This type of ROI evaluation has demonstrated excellent inter- and intraobserver agreement with intraclass correlation coefficients above 0.95[22,24]. Since peripheral and central dGEMRIC values were fairly similar, the mean of both regions was used for our statistics.

Two out of 161 reformats in the DDH group could not be evaluated because of MRI artifacts. All 175 reformats for the FAI group were evaluated.

Statistical analysis

Statistical analysis was done using PASW Statistics 18.0 (SPSS Inc., IBM, Chicago, Illinois, USA). Descriptive statistics for each type of hip lesion are presented as mean and SD for parametric data, and median and interquartile range (IQR) for non-parametric data. For comparison of ordinal and non-normal data (morphological MRI scoring), the non-parametric Mann–Whitney U test was used and for binary data the Chi-square test was used. Normally distributed "mean per patient" data (dGEMRIC index, WOMAC pain score) was compared with two-tailed independent sample t-tests. For the comparison of the dGEMRIC index between DDH and FAI hips the mean dGEMRIC index per hip (including all seven reformats) was calculated.

For the comparison of dGEMRIC (mean per MRI reformat) with morphological MRI findings a repeated measures ANOVA was performed, to account for the multiple measures per patient.

For correlation analyses, Spearman's Rho (ρ) was used for non-parametric data (morphological MRI vs WOMAC), and Pearson's

Table III
Morphological MRI scoring system

	Criterion	Position							Max. score
		Ant	Ant-sup	Sup-ant	Sup	Sup-post	Post-sup	Post	
Assessment of soft tissues									
Labrum damage	Normal	0	0	0	0	0	0	0	**14**
	Intralabral tear	1	1	1	1	1	1	1	
	Full-thickness tear	2	2	2	2	2	2	2	
Paralabral cysts	No	0	0	0	0	0	0	0	**7**
	Yes	1	1	1	1	1	1	1	
Assessment of articular cartilage									
Cartilage damage	Normal	0	0	0	0	0	0	0	**14**
	Focal defect	1	1	1	1	1	1	1	
	Generalized defect	2	2	2	2	2	2	2	
Assessment of bone									
Acetabular center bone cysts	No	0	0	0	0	0	0	0	**7**
	Yes	1	1	1	1	1	1	1	
Acetabular rim bone cysts	No	0	0	0	0	0	0	0	**7**
	Yes	1	1	1	1	1	1	1	
Femoral bone cysts	No	0	0	0	0	0	0	0	**7**
	Yes	1	1	1	1	1	1	1	
Acetabular rim osteophytes	No	0	0	0	0	0	0	0	**7**
	Yes	1	1	1	1	1	1	1	
Femoral osteophytes	No	0	0	0	0	0	0	0	**7**
	Yes	1	1	1	1	1	1	1	
Total									**70**

The morphological MRI scoring consisted of eight items. Single choice was allowed for each item in each location (worst pathologic finding). For each item a sum score of the seven radial slices (anterior to posterior) was calculated. The "total MRI score" was the sum of each item sum score. The maximum achievable total MRI score was 70 (worst MRI outcome), the minimum possible score was 0 (best MRI outcome). Ant: anterior, sup: superior, post: posterior. Max. score: Maximum achievable score for sub-scores and total MRI score.

method (r) was used for parametric data (e.g., dGEMRIC vs cartilage damage, dGEMRIC vs labrum damage). The correlation was considered weak when the correlation coefficient r or ρ was between 0.2 and 0.4, moderate between 0.4 and 0.6, strong between 0.6 and 0.8 and very strong above 0.8.

Eight patients had bilateral hip disease (four DDH and four FAI patients). Since the degree of disease between the right and left hip was fairly similar in all bilateral cases, we decided to evaluate only the right hip to avoid within-subject statistical dependence.

For inter- and intraobserver statistics Cohen's kappa was used[25]. According to Landis et al. kappa values from 0.41 to 0.60 were considered as moderate, 0.61 to 0.80 as substantial, and values

above 0.80 as excellent agreement[26]. A P-value of 0.05 was considered statistically significant.
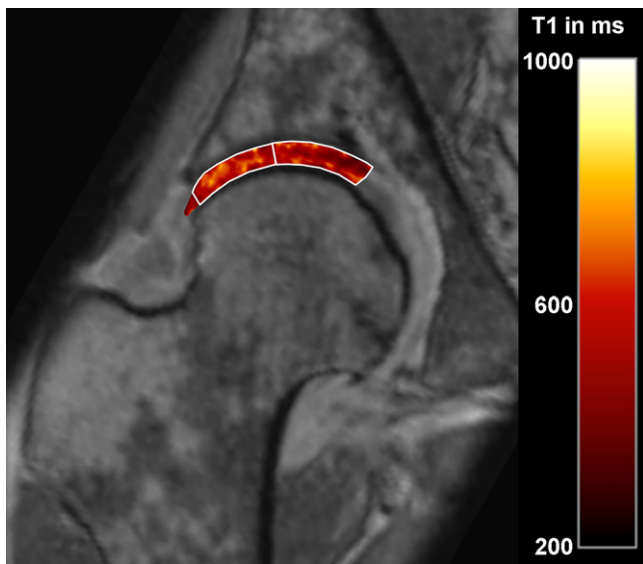
Results

Cohort characteristics

The cohort characteristics of the DDH and FAI patients are shown in Table I. Twenty-two hips had Tönnis grade 0 on radiographs [11 in DDH (57.9%) vs 11 (52.4%) in FAI]. Eighteen hips had Tönnis grade I OA on radiographs [eight in DDH (42.1%) vs 10 in FAI (47.6%)]. There were no statistical differences in the distribution of hips with differing radiographic OA between hips with DDH and FAI ($P = 0.55$; Table I). The mean age in patients with Tönnis grade 0 was 25.8 years (SD 10.3, range 15–52 years). In patients with Tönnis grade I it was 32.6 years (SD 11.9, range 13–52 years). The measurement of JSW shows a mean value of 4.5 mm (SD 1.1, range 3.4–6.9 mm) in DDH and 3.9 mm (SD 0.6, range 3.1–5.0 mm) in FAI. JSW was significantly higher in the DDH group ($P = 0.03$). The mean WOMAC pain score was 7.2 (SD 4.8, range 0–20). In DDH hips it was 8.1 (SD 5.0, range 0–20) vs 6.3 (SD 4.7, range 0–20) in FAI hips. There was no significant difference of the WOMAC pain score between DDH and FAI ($P = 0.26$; Table I).

Morphologic evaluation

The detailed results of the morphologic MRI evaluation are shown in Table IV. The total MRI score was higher in patients with Tönnis grade 1 than with Tönnis grade 0 (median 13 vs 10, $P = 0.04$).

Paralabral cysts were seen only in DDH patients (six hips) and not in FAI patients ($P = 0.006$). Labrum damage was more severe in DDH patients (median 4; IQR 3, 6) than in FAI patients (median 2; IQR 1, 4; $P = 0.006$). Also, full-thickness labral tears were more common in the DDH group (DDH: 12 of 19; FAI six of 21; $P = 0.05$). In dysplasia patients, acetabular rim bone cysts were more common than in FAI (10 vs 4 hips; $P = 0.03$). No significant

Fig. 3. Example figure showing manual ROI selection on T1 maps for central and peripheral regions of articular cartilage. Each ROI comprised both cartilage surfaces (femoral and acetabular).

Table IV
Results of morphological MRI scoring

MRI findings	DDH				FAI				P-value*
	Mean	# of hips	% of hips	95% CI	Mean	# of hips	% of hips	95% CI	
Labrum damage	4.7	19	100.0%	3.7/5.7	2.9	21	100.0%	2.0/3.7	0.006**
Paralabral cysts	0.6	6	31.6%	0.1/1.2	0.0	0	0.0%	−	0.006**
Cartilage damage	4.7	19	100.0%	3.4/6.0	4.5	21	100.0%	3.5/5.6	0.81
Acetabular center bone cysts	0.8	5	26.3%	0.0/1.7	0.2	3	14.3%	−0.1/0.5	0.30
Acetabular rim bone cysts	1.0	10	52.6%	0.4/1.5	0.3	4	19.0%	0.0/0.6	0.03**
Femoral bone cysts	0.0	0	0.0%	−	0.1	1	4.8%	−0.1/0.3	0.81
Acetabular rim osteophytes	1.5	13	68.4%	0.8/2.2	1.0	11	52.4%	0.4/1.5	0.18
Femoral osteophytes	1.5	13	68.4%	0.7/2.2	1.6	15	71.4%	1.0/2.2	0.58
Total MRI score	14.8	n.a.	n.a.	11.6/18.0	10.5	n.a.	n.a.	8.3/12.8	0.16

Morphological MRI findings are shown as the mean of the single scores, the number of hips and the percentage of hips showing that findings. *The P-values represent the results of Mann−Whitney U testing on the MRI scores (DDH vs FAI). **Significant differences are marked

differences were seen in cartilage damage, acetabular center bone cysts, femoral bone cysts, acetabular rim osteophytes, and femoral osteophytes between DDH and FAI (Table IV).

Morphological MRI vs dGEMRIC findings

The total MRI score was moderately correlated to the mean dGEMRIC index (overall per hip mean; $r = -0.488$; $P = 0.001$). As one would expect, the higher the total MRI score, the lower was the dGEMRIC index (and proteoglycan content). The overall mean dGEMRIC index (mean of all seven slices in all hips) in DDH hips was slightly lower than in FAI hips (527.0 ± 102.4 ms vs 557.4 ± 70.1 ms), however, not significantly different ($P = 0.28$). These slightly higher mean dGEMRIC values in FAI patients were noted in peripheral and central zones alike (FAI vs DDH: 546.3 vs 514.2 ms for peripheral, and 568.6 vs 539.7 ms for central; both $P > 0.05$).

In DDH patients, the dGEMRIC index (mean per MRI reformat) was higher in morphologically normal cartilage compared to "intact" cartilage in areas with focal defects. However, this was not statistically significant with mean values of 571.3 ms and 509.9 ms respectively [$P = 0.08$; see Table V for confidence intervals (CIs)]. In FAI patients the dGEMRIC index was similar in healthy areas (569.1 ms) and in areas with focal defects (557.5; $P = 0.40$). The detailed results showing peripheral and central dGEMRIC values separately are shown in Table V.

We did not see a significant association between dGEMRIC index (mean per MRI reformat) and labral damage. For example, the dGEMRIC index of DDH hips with full-thickness labrum tears was not much lower than in hips without labrum changes (518.9 ms vs 545.2 ms; $P = 0.31$). The same was true for hips with FAI. See Table V for details. Similarly, the presence of paralabral cysts did not significantly change the dGEMRIC index: 546.9 ms without and 532.5 ms with paralabral cysts ($P = 0.49$).

There were lower dGEMRIC indices (mean per MRI reformat) in areas with acetabular rim osteophytes (505.8 vs 553.0 ms), femoral bone cysts (450.1 vs 546.4 ms) and femoral osteophytes (484.7 vs 557.0 ms). Also in the presence of acetabular center bone cysts (495.7 vs 549.9 ms) a tendency for lower dGEMRIC indices was observed. Acetabular rim bone cysts appeared to have only minor effects on dGEMRIC values in our study (534.8 vs 548.3 ms). See Table VI.

Correlation of MRI to WOMAC pain score

The correlation of the WOMAC pain score to morphological MRI features in the total cohort ($N = 40$) shows moderate correlation to cartilage damage ($\rho = 0.437$; $P = 0.005$) and weak correlation to paralabral cysts ($\rho = 0.372$; $P = 0.018$). It also shows a weak

correlation to the total MRI score ($\rho = 0.382$; $P = 0.015$). Analysis of the DDH patient cohort alone showed moderate correlations for those parameters with the WOMAC pain score: Cartilage damage ($\rho = 0.457$; $P = 0.049$) and paralabral cysts ($\rho = 0.500$; $P = 0.029$). Only cartilage damage ($\rho = 0.528$; 0.014), but no other MRI parameter, did correlate with the WOMAC pain score in the FAI patients. No other significant correlations with the WOMAC pain score were found. Labrum damage did not correlate with the WOMAC pain score. When comparing patients with full-thickness labral tears to those without full-thickness tears, there was no difference in WOMAC pain score (6.83 vs 7.45; $P = 0.70$). Also, none of the subgroups (FAI and DDH) showed a difference in pain with full-thickness tears.

Inter- and intraobserver variation

The interobserver agreement was excellent for acetabular center bone cysts, acetabular rim bone cysts, paralabral cysts, femoral bone cysts, substantial for cartilage damage, and moderate for,

Table V
dGEMRIC index in comparison to different stages of cartilage and labrum grading. There is a tendency for lower dGEMRIC index in areas with focal cartilage damage as seen on morphological MRI. Remarkably, no decreased dGEMRIC index was observed in FAI patients with focal defects (the cartilage areas next to defects were measured, not the defect itself). For labrum changes there was no difference in mean dGEMRIC index between the single grading stages

		Cartilage grade	N	Cartilage mean T1	95% CI		P-value
DDH	dGEMRIC mean	Normal	59	571.3	544.2	598.4	0.080
		Focal defect	55	509.9	483.6	536.3	
	dGEMRIC peripheral	Normal	59	556.2	530.8	581.6	0.070
		Focal defect	55	494.6	470.0	519.3	
	dGEMRIC central	Normal	59	586.4	555.7	617.1	0.093
		Focal defect	55	525.3	495.5	555.1	
FAI	dGEMRIC mean	Normal	64	569.1	545.5	592.8	0.403
		Focal defect	71	557.5	538.2	576.7	
	dGEMRIC peripheral	Normal	64	562.6	537.0	588.2	0.169
		Focal defect	71	542.9	522.1	563.8	
	dGEMRIC central	Normal	64	575.7	550.7	600.7	0.744
		Focal defect	71	572.0	551.7	592.4	

	Labrum grade	N	Cartilage mean T1	95% CI		P-value
DDH	Normal	64	545.2	520.0	570.5	0.308
	Partial tear	46	521.0	492.0	550.0	
	Full-thickness tear	21	518.9	464.7	573.1	
	Total	131	532.5	514.7	550.3	
FAI	Normal	95	560.4	543.9	576.9	0.823
	Partial tear	44	551.9	526.1	577.6	
	Full-thickness tear	8	552.9	506.5	599.3	
	Total	147	557.4	544.3	570.6	

N represents the number of radial reformats (areas). P-values were obtained from the one-way repeated measures ANOVA.

Table VI
dGEMRIC index in comparison with the MRI findings paralabral cysts, bone cysts and osteophytes

MRI finding		Mean T1	95% CI		*P*-value
Paralabral cysts	No	546.9	535.5	558.2	0.490
	Yes	532.5	473.6	591.5	
Acetabular center bone cysts	No	549.9	538.6	561.2	0.056
	Yes	495.7	454.3	537.0	
Acetabular rim bone cysts	No	548.3	536.8	559.9	0.601
	Yes	534.8	486.5	583.1	
Femoral bone cysts	No	546.4	535.3	557.4	0.032*
	Yes	450.1	320.3	579.9	
Acetabular rim osteophytes	No	553.0	541.0	564.9	0.009*
	Yes	505.8	477.8	533.8	
Femoral osteophytes	No	557.0	544.6	569.3	0.001*
	Yes	484.7	455.2	514.2	

labral damage, acetabular rim osteophytes and femoral osteophytes. Kappa values are shown in Table VII.

The intraobserver agreement was substantial for cartilage and labral damage, and was excellent for paralabral cysts, acetabular center bone cysts, acetabular rim bone cysts, femoral bone cysts, acetabular rim osteophytes and femoral osteophytes (Table VII).

Discussion

In this study, we compared the DDH and FAI damage patterns as seen on morphological MRI. Although the two cohorts of patients were comparable in basic characteristics, they showed differences in labrum damage, i.e., higher sum scores for labrum damage in the DDH group (median FAI 2, DDH 4). Furthermore, we found a higher incidence of full-thickness labral tears in DDH (63% in DDH; 29% in FAI), which is different to the findings in the study of Leunig *et al.*, who found no difference[27]. However, similar to the data by Leunig *et al.*, we found a higher rate of hypertrophy and degenerative changes in the labra of DDH patients and higher incidence of paralabral cysts[27]. Clinicians should be aware that in adolescents and young adults labral tears can be expected more often in DDH than with FAI in early disease stages. In accordance with labrum changes, acetabular rim bone cysts were more common in DDH patients than in FAI patients. This can likely be attributed to increased loading at the acetabular rim in DDH.

We found no differences in the occurrence of acetabular center bone cysts, femoral bone cysts, acetabular rim osteophytes, and femoral osteophytes between DDH and FAI hips. This is interesting since differing pathomechanisms are supposed to be responsible for OA in DDH and FAI[28–30]. However, the numbers of these lesions were low in this early OA population.

The correlation between the dGEMRIC index and MRI total morphological score suggests that dGEMRIC is a valid measure of joint damage. In DDH hips, local dGEMRIC indices in the remaining cartilage of areas with focal cartilage damage showed a tendency

Table VII
Inter- and intraobserver statistics

MRI findings	Interobserver agreement kappa	Intraobserver agreement kappa
Cartilage damage	0.71	0.66
Labrum damage	0.44	0.79
Acetabular center bone cysts	1.00	1.00
Acetabular rim bone cysts	0.87	1.00
Paralabral cysts	1.00	1.00
Femoral bone cysts	1.00	1.00
Acetabular rim osteophytes	0.45	1.00
Femoral osteophytes	0.55	1.00

The kappa values for inter- and intraobserver agreement are shown for each type of MRI finding.

for lower values in comparison to areas with morphologically normal cartilage (as assessed on True-FISP MRI). Interestingly, this was not the case in FAI hips where local dGEMRIC indices of the tissue surrounding the defect appear to be less affected (showing less or no proteoglycan loss). This suggests that cartilage defects in FAI might be of a true focal nature and do not affect the surrounding cartilage. In contrast, cartilage defects in DDH appear to be associated with more generalized proteoglycan loss, i.e., also in areas surrounding the defects[31]. One has to keep in mind that areas with cartilage defects (filled with joint fluid) were not included within the dGEMRIC ROIs, but only tissue surrounding the defects was measured. These values reflect the dGEMRIC index in immediate proximity to defect areas. This finding might indicate that orthopedic surgeons removing cartilage from damaged areas in FAI patients can expect the surrounding cartilage to be healthy, whereas in DDH one could suspect a more generalized cartilage disease if defects are present. This information could help the surgeon in the planning of hip impingement surgery. However, this relationship has to be confirmed in further studies. Additionally, we did not have sufficient resolution to separate the femoral and acetabular cartilages. Therefore, with higher resolution scans, we may be able to detect more localized cartilage damage.

We did not find a significant association between labrum damage and the dGEMRIC index of nearby articular cartilage. As a potential limitation, we may not have had sufficient power to demonstrate a difference. McCarthy *et al.* analyzed a large arthroscopy cohort and found that severe cartilage damage (Outerbridge grade III and IV) is present in 49% of patients with labral tears but only 24% of patients without labral tears[32]. However, their patients were on average 10 years older than our cohort. On the other hand, femoral bone cysts were associated with lower cartilage proteoglycan content. This is consistent with the hypothesis that degenerative cysts are secondary to cartilage damage[33]. Osteophytes were associated with a significant decrease in dGEMRIC indices (decrease in proteoglycan content). This supports the observation of osteophytes as an indicator for cartilage disease[34].

The correlation of morphological changes to pain suggests that the clinical symptoms of DDH and FAI patients are associated with the degree of cartilage damage and further lends validity to our radiologic findings. Since the articular cartilage itself is an aneural structure, it is unlikely that this is the direct cause for pain[35]. However, it is believed that the synovium, the joint capsule and the subchondral bone are responsible for pain generation associated with cartilage damage[35,36]. It can be assumed that these proposed mechanisms are also responsible for pain in our patients. We found no correlation between labral damage and WOMAC pain score, though labral tears are widely recognized as a cause for pain in the hip joint[32,37–41]. However, there is evidence that labral tears are common in asymptomatic hip joints[42]. Interestingly, there was a correlation between paralabral cysts and WOMAC pain score in DDH patients.

A limitation of this study is the small number of patients. This could affect our results in particular concerning rare findings like femoral bone cysts and acetabular center bone cysts. Further limitations are the lack of a healthy control group and the fact that the MRI findings were not validated with intraoperative findings. Furthermore, predominantly female subjects were part of our study in both groups. While this is in concordance to epidemiological data for DDH[29,43], this is uncommon for FAI, where male predominance would be expected[44]. Thus, our results may be more valid for female patients with FAI than for male patients. We did not include "mixed cases", presenting with FAI and DDH within the same hip. It is hypothetical to interpolate our results for such patients, but they might present with a mix of additive FAI and DDH effects, that could lead to even earlier joint damage.

The exclusion of patients with more than minimal radiographic OA changes potentially resulted in relatively high dGEMRIC indices in our patient cohorts. However, the detection of even early proteoglycan loss represents a major advantage of hip joint dGEMRIC scans. There might be undetected cases of acetabular cartilage delamination having influence on our dGEMRIC results. This is hard to validate, since we have no surgical confirmation for these patients and MRI is reported to have low sensitivity for delamination[45].

In conclusion we found that a higher degree of labrum degeneration and associated paralabral cysts can be seen in DDH than in FAI. Cartilage defects are associated with a decrease in dGEMRIC index of the surrounding cartilage in many DDH hips, but not in FAI, suggesting more diffuse damage in DDH. Furthermore, our data suggests a relationship between the patient's pain and cartilage damage on MRI.

Author contributions

All authors contributed to a considerable extent to the conception and design of the study, or acquisition of data, or analysis and interpretation of data and the drafting of the article or the critical revision for important intellectual content. The final manuscript version to be submitted was approved by all authors.

One or more authors contributed to the provision of study materials or patients (YK, MM, SB), statistical expertise (YK, DS, TM), obtaining of funding (YK, TM), and collection and assembly of data (IK, DS, SW, SB).

The corresponding author and the first author (YK, DS) take responsibility for the integrity of the work as a whole.

Ethics approval

The procedures followed in this study were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000. This study was approved by the Committee on Clinical Investigation (institutional review board) of the Children's Hospital Boston/Harvard Medical School (Boston, MA, USA).

Role of funding source

Conflict of interest

YK received research funding from Siemens Healthcare. TM was paid consultant for Siemens Healthcare and Merck Serono.

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