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Radial dGEMRIC in developmental dysplasia of the hip and in femoroacetabular impingement: preliminary results

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SUMMARY

Objective: To assess the pattern of cartilage damage in symptomatic cases of developmental dysplasia of the hip (DDH) and of femoroacetabular impingement (FAI) with a novel three-dimensional (3D) delayed Gadolinium enhanced magnetic resonance imaging of cartilage (dGEMRIC) technique.
Methods: After clinical diagnosis with conventional radiographs, two consecutive series of each 20 patients with DDH or FAI were assessed with 3D dGEMRIC. Radial T1 maps were reconstructed and region of interest analysis of the central and peripheral cartilage was carried out.
Results: The dGEMRIC index was mean 531 ± 92.7 (391–729) ms in DDH and 551 ± 95.7 (372–694) ms in FAI, respectively ($P = 0.507$). Subgroup analysis showed higher T1 in the weight-bearing areas and significantly higher values in the central areas (DDH $P < 0.0001$, $N = 11$; FAI $P = 0.036$, $N = 14$) of the acetabulum in pre-arthritic cases (dGEMRIC index > 500 ms) both in DDH and FAI. A breakdown of this distribution was found both in DDH and FAI cases with dGEMRIC index < 500 ms. Pearson correlation analysis demonstrated the dGEMRIC index had a poor predictive value for the anterior-superior quadrant of the hip joint in FAI ($r = 0.482$, $P = 0.031$, $r^2 = 0.233$).
Conclusion: Radial dGEMRIC allows for the assessment of cartilage damage in the entire hip; different patterns of T1 distribution are found in DDH and FAI at progressed stages. The assessment of the anterior-superior quadrant of the acetabulum can be considered a fundamental advantage of the 3D dGEMRIC protocol.

Introduction

Osteoarthritis (OA) of the hip is a major cause of disability in the elderly population; although the exact mechanisms are not fully understood, aberrant hip anatomy as found in developmental dysplasia (DDH) or femoroacetabular impingement (FAI) has been recognized as a cause for early OA[1]. In DDH, a reduced load-transferring area and subsequently extensive stresses on the cartilage due to the shallow acetabulum lead to early OA. The lateral center edge angle (LCE) and anterior center edge angle (ACE) are prognostic for OA and thus used to assess DDH severity[2]. In FAI, either a decreased offset of the femoral head (cam) or acetabular overcoverage (pincer) causes an abutment of the head–neck junction against the acetabulum that may result in cartilage damage and eventually leads to OA[3]. The alpha angle has been introduced as a measure of the severity of the femoral deformity in impingement[4]. Approximately 50° is considered as a threshold for pathologic anatomy, however the extent of physical activity is thought to play an additional role[4]. Surgical treatments are designed to correct the underlying bony deformity at an early stage of OA, since outcome depends on the extent of cartilage damage at the time of surgery[5,6].

Due to its ability to assess the soft tissues and cartilage that are damaged in early OA, magnetic resonance imaging (MRI) has become the preferred diagnostic tool in pre-operative assessment in hip preservation surgery[7]. Delayed Gadolinium enhanced MRI of cartilage (dGEMRIC) has been found to be specific for early cartilage glycosaminoglycan (GAG) loss[8–10]. Briefly, dGEMRIC is based on the principle that negatively charged contrast agent ($GdDTPA^{2-}$) will partition in an inversely proportional manner to the negative fixed charge density (FCD) of the extracellular matrix. FCD in turn directly correlates with cartilage GAG content[11]. T1 mapping of cartilage after contrast administration allows for an estimate of

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$GdDTPA^{2-}$ concentration, which will reflect the underlying charge density of cartilage. Since the loss of GAG is considered to be an early event in the development of hip OA[12], its direct visualization by dGEMRIC has considerable potential for the monitoring of joint-preserving hip surgery[13].

Several studies on DDH and FAI have demonstrated the value of the dGEMRIC index as a metric for OA and its ability to predict surgical outcome[12–15]. Previously, the dGEMRIC index was measured with an inversion recovery sequence which limited the examination to a few slices in the coronal plane due to the lengthy imaging time[12–14,16,17]. Hence, anterior cartilage damage as found in FAI[6,18] may be missed. A novel[19] three-dimensional (3D) dual flip angle T1 mapping sequence has been validated for 1.5 T dGEMRIC scans in the hip and was found to have sufficient accuracy for clinical use[20]. Briefly, a flip angle combination optimized for center T1 values between 756 and 955 ms yielded excellent agreement with T1 measured with the inversion recovery technique in the range of 200–900 ms in phantoms. Additional *in vivo* validation was carried out in 26 hips, which showed good correlation ($r^2 = 0.74$) with inversion recovery results and no systematic bias.

A preliminary series of radial dGEMRIC studies on hips with FAI has confirmed that decreased T1, suggesting cartilage damage, in magnetic resonance (MR) correlated with the patterns of damage found in intra-operative assessment[6,15,21,22]. Based on these findings, we hypothesized that radial dGEMRIC would demonstrate different patterns of cartilage damage in DDH and FAI due to the different biomechanical abnormality in these two conditions. The aims of this study are (1) to perform a direct comparison of cartilage damage patterns, as seen on 3D dGEMRIC scan, in cases of DDH and FAI and (2) to determine if radial dGEMRIC will yield additional information regarding early cartilage damage in these hips compared to the 2D imaging performed in the coronal plane.

Materials and methods

Study design and patients

This retrospective study was approved by the institutional review board with waiver of informed consent. Symptomatic cases that had been assessed both with radiographs in two planes (DDH: anteroposterior pelvic view and false profile, FAI: anteroposterior pelvic view and cross-table lateral view) and with the 3D dGEMRIC protocol were eligible[23]. We included DDH cases if the LCE was below 25° or if the ACE was below 20°, and FAI cases if there was a markedly decreased head–neck offset in the cross-table lateral view radiographs which could be verified in the radial MRI (alpha angle larger than 55°). Only those cases eligible for joint-preserving hip surgery had an MRI performed hence all cases had no or only mild loss of joint space on radiographs[23]. Exclusion criteria were prior hip surgery, history of hip trauma, cases with slipped capital femoral epiphysis, Legg–Calve–Perthes disease or prior femoral neck fractures, rheumatoid arthritis, high dose corticosteroids use,

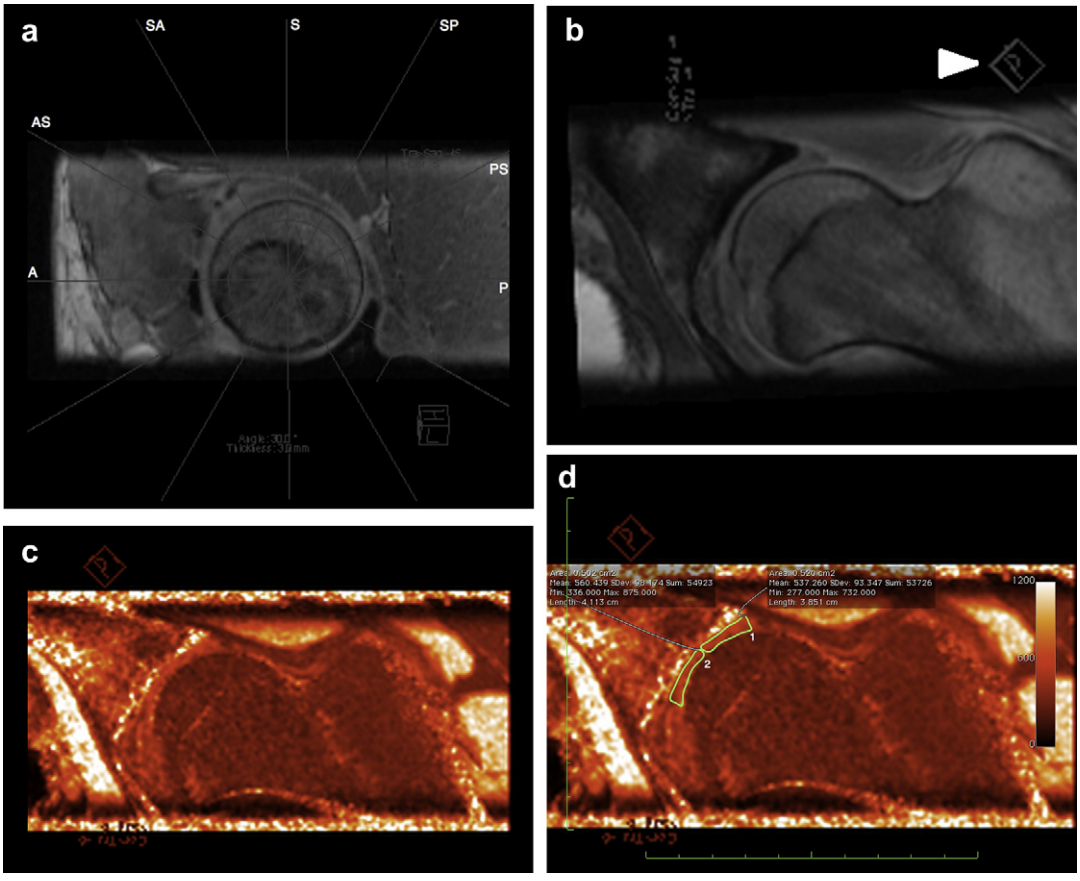

Fig. 1. Radial reconstruction of the T1 maps. After alignment of the femoral head–neck axis in the 3D viewer, the radial reconstruction tool is used in the oblique sagittal view (a) to define the orientation, intervals and slice thickness of the reformats in the Volumetric interpolated breath-hold examination (VIBE) sequence (A – anterior, AS – anterior-superior, SA – superior-anterior, S – superior, SP – superior-posterior, PS – posterior-superior, P – posterior). The orientation of the reformats is verified by a virtual cube embedded in the 3D dataset (b, white arrow) and is then transferred to the T1 map dataset (c – corresponding T1 map). The original VIBE reformat is used as a reference for the ROI analysis to ensure the cartilage layer is assessed without inclusion of subchondral bone. The acetabular and femoral cartilage layers cannot be reliably separated at 1.5 T due to limitations in resolution, however peripheral (ROI 1) and central (ROI 2) can be distinguished (d). Radial ROIs can be calculated under consideration of the number of pixels.

Table I
Baseline clinical and radiographic characteristics

		ACE (degrees)	LCE (degrees)	Alpha angle (degrees)	Toennis angle (degrees)	Age (years)	BMI (kg/m^2)	JSW (mm)	WOMAC
DDH ($N = 20$)	Mean	18.1	11.9	47.3	18.9	26.6	22.8	4.5	7.5
	SD	15.3	9.0	5.2	9.0	10.0	3.6	1.0	5.5
	Min	−23.0	−8.4	31.0	6.0	13.0	17.0	3.4	0.0
	Max	39.5	24.9	53.0	36.0	43.0	29.3	6.9	20.0
FAI ($N = 20$)	Mean		29.1	71.7	4.8	29.6	25.1	3.8	5.8
	SD		3.9	8.1	3.2	11.7	4.3	0.5	4.7
	Min		22.8	61.0	−1.9	15.0	19.4	3.1	0.0
	Max		40.6	86.0	9.8	52.0	33.6	4.7	15.0

avascular necrosis and contra-indications to MRI or the use of contrast agent.

DDH and FAI cohorts consisted of 20 consecutive cases each. The mean age was 28.1 ± 10.9 (13–52) years and the mean joint space width (JSW) 4.1 ± 0.9 (3.1–6.9) mm. The Tönnis grade was 0 in 21, 1 in 17, and 2 in 2 cases, respectively. The Western Ontario and McMaster Universities (WOMAC) index for pain[18] was assessed in all patients at the time of MRI and was mean 6.6 ± 5.1 range 0–20. The mean body-mass index (BMI) was 24.0 ± 4.07 range 17.0–33.6 kg/m^2. 33 cases were female and seven male.

MRI protocols

MR images were obtained using a 1.5 T system (Avanto, Siemens Medical Solutions, Erlangen, Germany) with a flexible surface coil. A standardized protocol was used for dGEMRIC[17,24]: after the intravenous (iv) administration of the contrast agent (0.2 mM/kg Gd-DTPA^{2-}; Magnevist, Berlex Laboratories, Wayne, New Jersey) patients walked for 15 min to ensure the distribution into cartilage. The scans were obtained minimum of 30 min after administration. The 3D isotropic dual flip angle T1 sequence that had been evaluated in a prior study[20] was used to measure the T1 maps. The parameters were TR = 15 ms, TE = 3.27 ms, flip angles of 4.1 and 23.5°, a matrix size of 192/192 in a 16 × 16 cm field of view and a 96 slice slab resulting in an isotropic dataset with a voxel size of 0.83 mm^3. The scan time was 8 min 37 s.

Radial reconstruction and region of interest (ROI) analysis

The 3D T1 dataset reconstruction was carried out using a Leonardo workstation (Siemens, Erlangen, Germany). Based on the clock-face orientation reported in literature[6], we reconstructed seven radial reformats rotating around the femoral head–neck axis with a slice thickness of 3 mm at 30° intervals: (1) anterior, (2) anterior-superior, (3) superior-anterior, (4) superior, (5) superior-posterior, (6) posterior-superior, (7) posterior [Fig. 1(a)].

The ROI analyses were performed by a trained reader (IK) blinded to the clinical diagnosis of the cases. Inter-observer variability was assessed by a second trained reader (JC) blinded to the clinical diagnosis using 10 randomly selected cases. The ROIs were drawn manually in each reconstructed plane. The cartilage layers between the fossa acetabuli and the rim were assessed; the border between femoral and acetabular cartilage layers could not be delineated in all cases [Fig. 1(c)] and the ROIs therefore included both cartilage layers [Fig. 1(d)]. The central and peripheral zones were assessed separately on each radial slice. The mid-point between the fossa acetabuli and the acetabular rim was defined as the border between central and peripheral in each slice [Fig. 1(d)]. The radial mean T1 (mean T1 of central and peripheral) as well as the global mean T1 (mean T1 of all seven radial T1 values) was subsequently calculated. The dGEMRIC index was assessed as the radial T1 value of the superior, weight-bearing cartilage.

Statistical analyses

Statistical analyses were carried out using SPSS 16.0 (SPSS Inc, Chicago, IL). The clinical parameters of the two cohorts were compared with the two-sided independent sample *t*-test for continuous variables and with the Chi-Square test for dichotomous variables. The ROI readings were evaluated in ten random cases (14 ROIs per case, 140 data points) with intra-class coefficient (ICC) reliability analysis to determine the inter-observer variability.

The dGEMRIC indices and global mean T1 values of the DDH and FAI cohorts were compared using unpaired two-sided *t*-tests. In order to look at the changes in the pattern of GAG distribution in these hips with differing amounts of OA, these cohorts were additionally separated into two subgroups based on the dGEMRIC index T1 value. Based on dGEMRIC values found in prior studies[10,12,13], we used a threshold of 500 ms (approximately one standard deviation below 570 ms, the mean value found in healthy volunteers)[17].

The patterns of GAG distribution in these hips were assessed by comparing the central and peripheral T1 values on the radial reformats using paired, two-sided *t*-tests. Additionally, we assessed the variation in GAG distribution between the weight-bearing portions of the joint (superior region) and areas of the joint with less weight bearing (anterior region) using paired, two-sided *t*-tests.

In order to determine if radial dGEMRIC provides additional information regarding the joint damage pattern in these hips compared to the dGEMRIC index, we performed bivariate linear correlation analyses (Pearson) comparing the dGEMRIC index with global mean T1 and with the radial mean T1 values in each cohort.

Table II
Subgroup data

Threshold		DDH		FAI	
		Global T1	dGEMRIC index	Global T1	dGEMRIC index
<500 ms	*N*	9	9	6	6
	Mean	448	445	498	445
	95% CI (lower, upper limit)	421, 475	417, 472	436, 558	383, 506
	Minimum	401	391	406	372
	Maximum	503	490	562	495
>500 ms	*N*	11	11	14	14
	Mean	577	601	573	596
	95% CI (lower, upper limit)	512, 642	562, 639	537, 608	556, 635
	Minimum	392	525	476	503
	Maximum	716	729	685	695
	N	20	20	20	20
	Mean	519	531	550	551
	95% CI (lower, upper limit)	472, 565	487, 574	518, 582	506, 595
	Minimum	154	391	372	372
	Maximum	778	729	765	695

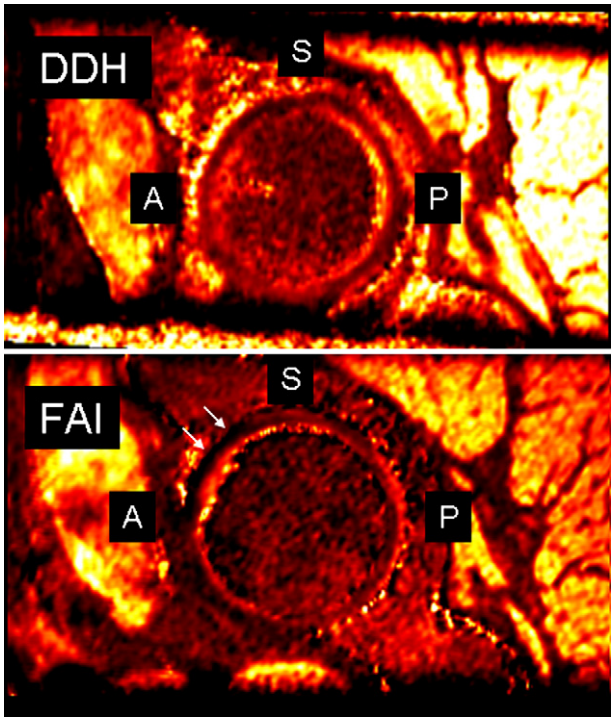

Fig. 2. Oblique sagittal reconstruction of the 3D T1 dataset in DDH and FAI. A = anterior, S = superior, P = posterior. The distribution of T1 is homogeneous in the DDH hip, whereas in the case with FAI a distinct depletion in the anterior-superior aspect of the acetabular cartilage can be seen (white arrows).

Results

As expected there were significant differences between DDH and FAI regarding radiograph analysis, however the two groups were comparable in age ($P = 0.398$), the WOMAC Score ($P = 0.300$), BMI ($P = 0.075$) and all cases had a JSW above 3 mm. The DDH cohort consisted of 20 female cases, the FAI cohort consisted of seven male and 13 female cases ($P = 0.008$). Detailed clinical parameters and radiograph evaluation data are shown in Table I. The ICC for the T1 readings was 0.926 ($P < 0.0001$).

The mean dGEMRIC indices for DDH and FAI were 531 ± 92.7 (391–729) ms and 551 ± 95.7 (372–694) ms, respectively ($P = 0.507$). The global mean T1 values (mean of all radial ROIs) were 519 ± 108.5 ms for DDH and 550 ± 81.2 for FAI ($P = 0.258$, Table II).

Subgroup analysis demonstrated varying patterns of T1 distribution based on the amount of OA. In the DDH cases ($N = 11$) and in the FAI cases ($N = 14$) with dGEMRIC index > 500 ms, the radial dGEMRIC pattern showed increased T1 in the weight-bearing areas of the acetabulum. In the DDH cases with dGEMRIC index < 500 ms ($N = 9$) a global decrease in T1 was observed. In contrast, FAI cases with dGEMRIC index < 500 ms ($N = 6$) showed a more localized decrease of T1 in the anterior-superior quadrant (Figs. 2 and 3).

The comparison of central and peripheral T1 within the two cohorts showed that peripheral T1 was significantly lower than central T1 in both cohorts (DDH: $P = 0.001$, FAI: $P = 0.046$, Table III). With respect to the subgroups, both in DDH and FAI cases with dGEMRIC index > 500 ms, central and peripheral regions showed similar T1 distributions with increased T1 in the central regions (Fig. 4). T1 of the peripheral areas was significantly lower than in the central areas ($P < 0.0001$ in DDH and $P = 0.036$ in FAI). For hips with dGEMRIC index < 500 ms, central and peripheral T1 distributions were more heterogeneous (Fig. 4). Peripheral T1 remained decreased compared to central T1 in the anterior-superior quadrant; however, in the superior-posterior quadrant the opposite was observed. DDH cases showed no significant difference between average T1 values of the central and peripheral regions ($P = 0.102$). The difference remained significant for FAI ($P = 0.0002$) because of the more localized T1 decrease in the peripheral areas.

Significant differences between superior and anterior-superior, and between superior and superior-anterior were found in the peripheral areas. In DDH > 500 ms ($N = 11$), peripheral T1 was significantly lower in the anterior-superior and in the superior-

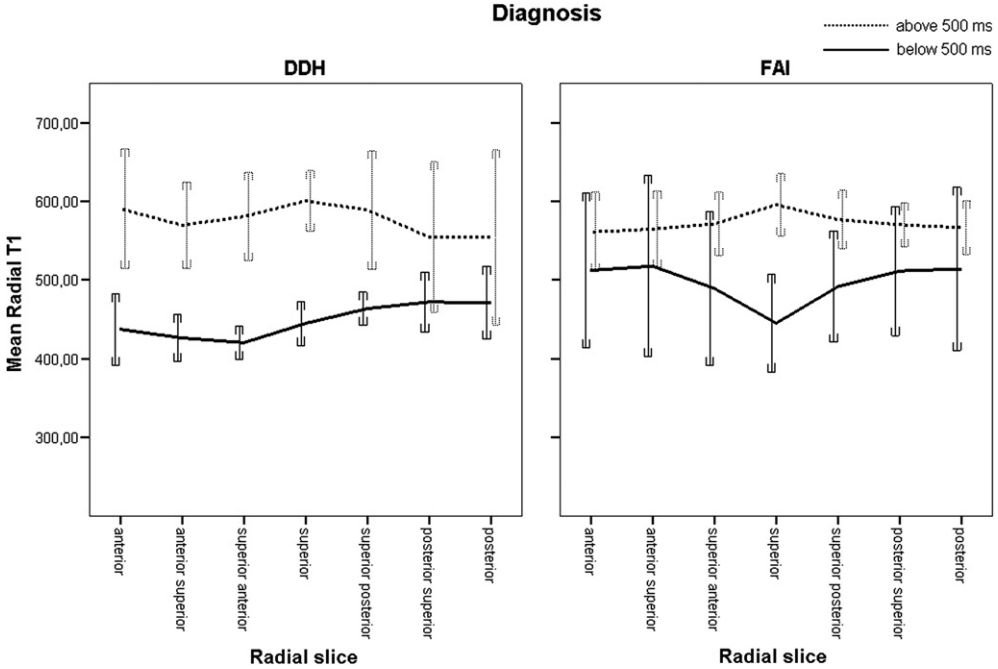

Fig. 3. Radial T1 distribution of the subgroups based on the dGEMRIC index (above 500 ms, below 500 ms). Early OA apparently affects the anterior-superior quadrants. DDH decreases in a more global pattern than FAI. The dotted lines represent the threshold of 500 ms, the error bars express 95% confidence intervals.

Table III
Mean radial (global), central and peripheral ROI analysis results

Diagnosis		dGEMRIC			*P* (central vs peripheral)
		Radial	Peripheral	Central	
DDH ($N = 20$)	Mean	521	503	539	**0.001**
	95% CI (lower, upper limit)	465, 577	449, 557	480, 599	
	Minimum	385	368	374	
	Maximum	778	747	808	
FAI ($N = 20$)	Mean	546	529	563	**0.046**
	95% CI (lower, upper limit)	504, 588	484, 575	518, 607	
	Minimum	441	399	438	
	Maximum	750	789	782	

anterior regions when compared to superior ($P = 0.042$ and $P = 0.032$). In DDH < 500 ms ($N = 9$), peripheral superior-anterior T1 was significantly lower than peripheral superior T1 ($P = 0.048$). In FAI > 500 ms ($N = 14$), peripheral T1 was significantly lower in the superior-anterior aspect when compared to peripheral superior ($P = 0.032$). In FAI < 500 ms ($N = 6$) we did not observe significant differences (Fig. 4).

Bivariate correlation analysis demonstrated strong and highly significant correlations between the global T1 values and the coronal dGEMRIC indices (Pearson correlation coefficient, $r = 0.888$, $P < 0.0001$ in DDH and $r = 0.860$, $P < 0.0001$ in FAI). Correlation of the dGEMRIC index with T1 of the anterior-superior and the superior-anterior regions yielded less agreement in FAI [Table IV and Figs. 5 and 6(a), (b)].

Discussion

Aberrant hip anatomy as found in DDH or FAI is considered to increase the risk of early OA[25]. The loss of GAG is an early event in the development of hip OA[12,26]; therefore, its direct visualization by dGEMRIC has the potential ability to demonstrate the effect of joint-preserving hip surgery on OA progression[13]. This study directly compared the patterns of T1 distribution in two cohorts of

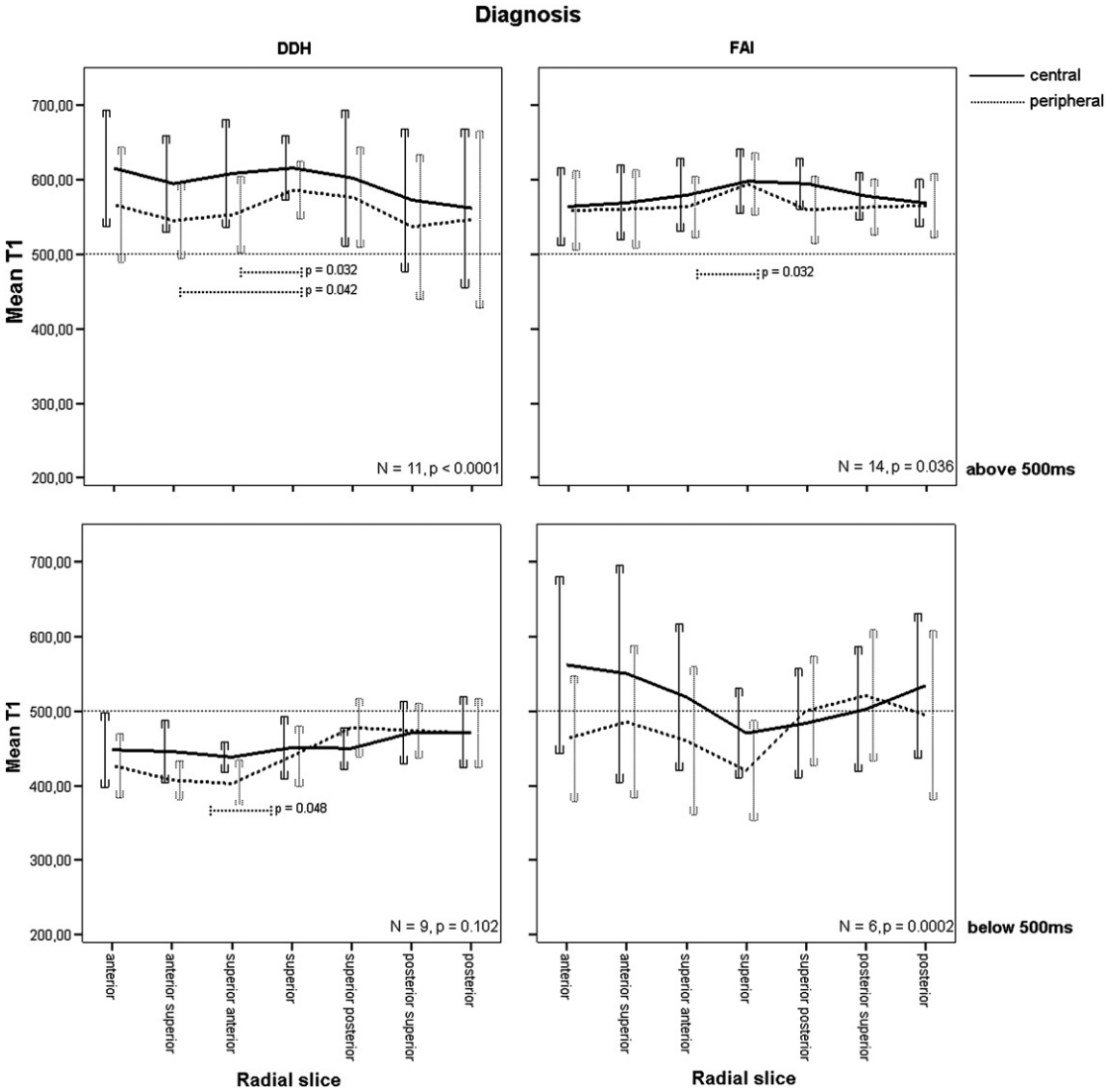

Fig. 4. Central and peripheral subgroup analysis. The pattern of central and peripheral T1 is comparable in DDH and FAI cases with dGEMRIC index > 500 ms; the highest T1 is found in the weight-bearing areas of the acetabulum. In cases with dGEMRIC index < 500 ms, a breakdown of this pattern occurs, however the most pronounced decline in T1 occurs in the periphery of the anterior-superior quadrant. The dotted lines represent the threshold of 500 ms. The dotted bars indicate a significant difference between the peripheral areas in the paired Student's *t* test, the error bars express 95% confidence intervals. The *P* values in the lower right corners concern the difference between central and peripheral T1.

Table IV
Bivariate correlation analysis of the dGEMRIC index and radial post-contrast T1 values; in FAI, the predictive value of the dGEMRIC index is markedly decreased for anterior-superior T1. Global T1 (mean of all radial regions of interest) shows a strong correlation. *$P < 0.05$, **$P < 0.001$

	Radial T1	Anterior	Anterior-superior	Superior-anterior	Superior-posterior	Posterior-superior	Posterior	Global
DDH	Pearson correlation	0.841**	0.868**	0.910**	0.840**	0.638**	0.607**	**0.888****
	Sig. (two-tailed) p	<0.0001	<0.0001	<0.0001	<0.0001	0.002	0.005	<0.0001
	N	20	20	20	20	20	20	20
FAI	Pearson correlation	0.592**	**0.482***	0.632**	0.912**	0.771**	0.630**	**0.860****
	Sig. (two-tailed) p	0.006	0.031	0.003	<0.0001	<0.0001	0.003	<0.0001
	N	20	20	20	20	20	20	20

symptomatic DDH and FAI cases with a novel 3D T1 mapping sequence. We found that the distribution of central and peripheral T1 was similar in both pathologic entities at an early stage; T1 was higher in the superior region and central areas compared to peripheral areas. This agrees with the T1 distribution in healthy volunteers[15] and with histological data on the GAG distribution in the acetabulum[27].

At more advanced stages of OA (dGEMRIC index < 500 ms) we found a breakdown of this distribution (Fig. 4) both in DDH and FAI. Interestingly, the peripheral T1 decrease was more pronounced in the anterior-superior quadrant of the acetabulum, both in DDH and FAI. In DDH the decrease followed a more global pattern than in FAI. Intra-operative findings show that cartilage damage occurs predominantly in the anterior-superior quadrant both in DDH and in cam type FAI, although the underlying mechanisms differ[3,22,28]. In cam type FAI the decreased head–neck offset causes increased joint loading; during flexion the labrum is stretched and pushed outwards and the cartilage is compressed and pushed inwards,

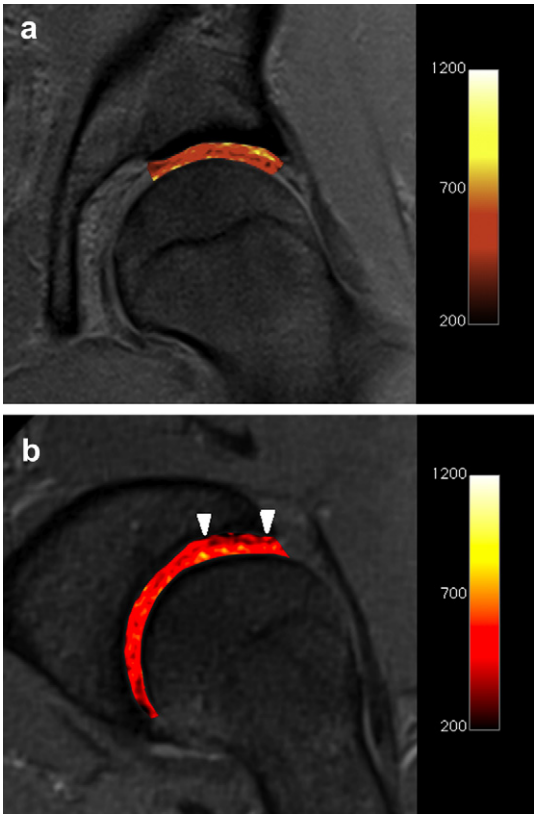

Fig. 5. Example of a case with FAI with high T1 in the coronal plane (a) and a marked T1 decrease in the peripheral anterior cartilage (white arrows – b). Cartilage damage was observed intra-operatively in this area.

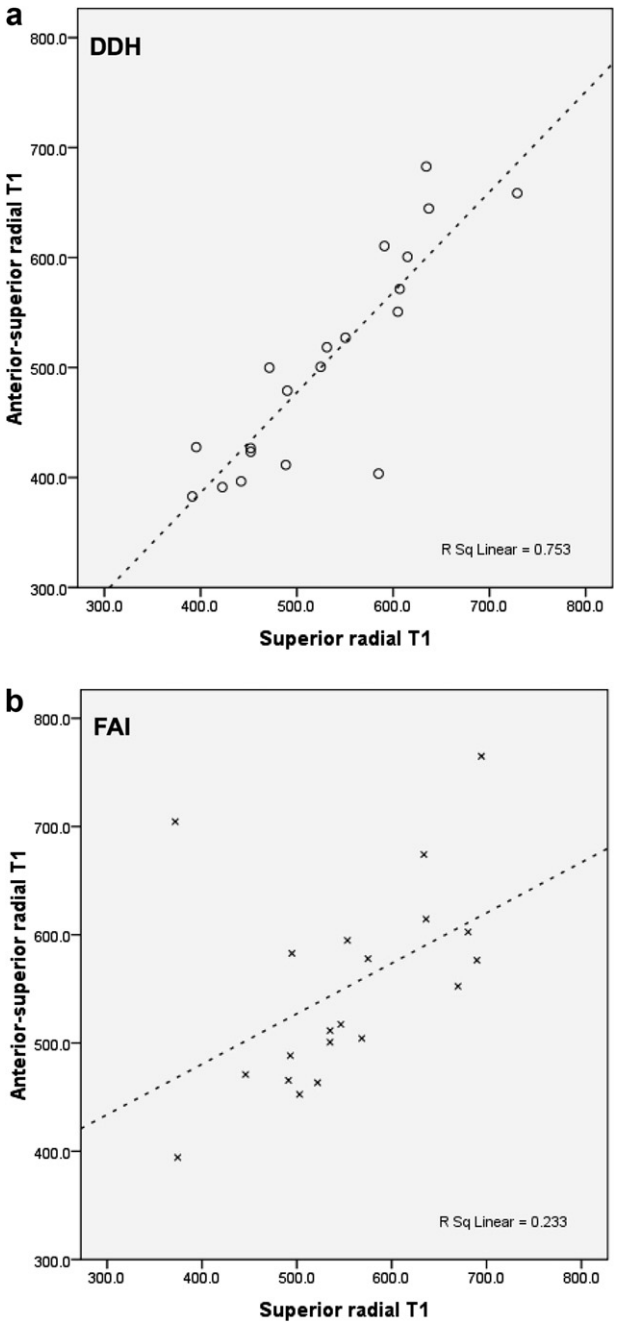

Fig. 6. Scatterplot of anterior-superior and corresponding superior radial T1 values in DDH (a) and in FAI (b); despite a more distinct decrease of peripheral T1 in the anterior-superior quadrants, strong correlation with a good predictive value is found due to the global decrease of T1 ($r = 0.868$, $P < 0.001$, $r^2 = 0.753$) in DDH. In contrast, only moderate correlation with poor predictive value is found in FAI ($r = 0.482$, $P < 0.05$, $r^2 = 0.233$). The dotted lines represent the linear regression fit.

resulting in considerable shear stress and separation of the cartilage layer from the subchondral bone and labrum[22]. Carpet phenomenon and delamination are thus frequent intra-operative findings in cam type FAI, and the location of these lesions occurs in association with femoral deformity predominantly in the anterior-superior quadrant of the acetabulum[21,29]. In DDH, the shallow acetabulum results in a reduced load-transferring articular area, resulting in abnormal load distribution and increased stress on the cartilage[30,31]. Arthroscopic studies on DDH cartilage damage have demonstrated that there is a prevalence for cartilage lesions in the acetabular anterior-superior aspect of the joint; Fujii *et al.*[32] report cartilage lesions in 77.8% in pre-arthritic cases, 61.1% of which were located in the anterior-superior part of the acetabulum in patients younger than 20 years. McCarthy *et al.*[28] report that 100 out of 170 DDH hips had chondral defects situated in the anterior quadrant (59%). Concomitant anterior labral lesions were as frequent as 66%. All acetabular lesions were found in the watershed zone near the labrum; the Outerbridge Grades reported for anterior defects were: 13% I, 23% II, 21% III and 43% IV. Labro-articular cartilage fissures initiating delamination and subsequent rapid progression of the defects due to the oscillating hydrodynamic pressure dynamics of the joint fluid were deemed to lead to the high proportion of deep defects. Contrary to impingement, anterior articular lesions are considered to be caused by torsion and shear forces in hyperextension rather than by flexion.

The patterns of damage found in this series therefore agree well with the general understanding of cartilage degeneration in the hip in DDH and FAI, as the most pronounced decline in T1 was found in the peripheral anterior-superior and superior-anterior zones. The success of surgical intervention depends on the early recognition of cartilage damage[6]; the ability to identify focal areas of damage using radial dGEMRIC may improve the diagnostic sensitivity of MR and hence may improve patient care.

Several studies have demonstrated the clinical value of dGEMRIC. Since the dGEMRIC index is more sensitive than conventional radiographs for the detection of early OA[12], it can be used as a metric measure to assess the severity of hip OA and has demonstrated to have predictive value for the outcome after surgery[13,14]. Pre-operative assessment of hips with acetabular dysplasia using dGEMRIC scans demonstrated that symptoms correlated with the dGEMRIC index ($r = -0.50$, $P < 0.001$)[12]. Additionally, the dGEMRIC index correlated with the LCE angle demonstrating even in young patients early articular cartilage changes could be seen in severely dysplastic hips. In a categorical comparison of the degree of dysplasia (mild, LCE $> 15^\circ$, moderate, LCE between 6° and 15°, severe, LCE $< 5^\circ$), the dGEMRIC indices differed significantly between all categories, while the JSW did not. A multiple logistic regression model showed the preoperative dGEMRIC value and joint subluxation prior to the surgery to be significant predictors of early postoperative failure[13]. The probability of total hip arthroplasty increased dramatically with lower dGEMRIC index (10% probability of joint replacement at 400 ms, 40% at 300 ms). The dGEMRIC index in morphologically normal hips averaged 570 ± 90 ms[17]; a dGEMRIC index of 390 ms (two standard deviations below normal) was thus defined as the threshold for OA[13,14].

These studies, however, used an inversion recovery sequence that allowed for two-dimensional T1 mapping only, and therefore reported on T1 of the weight-bearing areas derived from coronal views. Since the onset of degeneration occurs predominantly in the anterior regions of the joint, the extent of cartilage damage might be misinterpreted in the coronal plane[6,18,22]. Results of the current series confirm this notion; the predictive value of the dGEMRIC index for T1 of the anterior-superior regions was poor in FAI [Fig. 6 (b)]. In DDH, the change in T1 was more homogeneous throughout the different regions of the joint, which may indicate that biologic factors are involved in the development of OA in addition to mechanical damage.

It is worth to note that the 3D sequence does not necessitate longer scan time than the inversion recovery sequence; the use of negatively charged contrast agent, the time interval between contrast agent administration and measurement and the need for strict imaging protocols remain inherent sources of bias of the dGEMRIC technique[24]. Still, the assessment of the whole joint might help to detect cartilage degeneration at an earlier stage and enable surgeons to treat patients at early stages of OA.

Several limitations to this study should be noted. This is a non-randomized, cross-sectional study with a relatively low number of consecutive cases. The cohorts are not controlled by asymptomatic cases or by volunteers, and the retrospective design ruled out a direct comparison of dGEMRIC data and intra-operative findings. The heterogeneity of the two cohorts with respect to gender and age may be a source of bias.

In summary, radial dGEMRIC allows for the assessment of cartilage damage in the entire hip. DDH and cam type FAI in progressive stages of OA are shown to have different patterns of T1 distribution. The assessment of the anterior-superior quadrant of the acetabulum can be considered a fundamental advantage of the improved dGEMRIC technique, as this region can be missed by coronal slices in the weight-bearing zone but has the highest prevalence of cartilage lesions.

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Contributions

All authors contributed substantially to the design, execution, analysis, and write up of this study. The corresponding author (YJK) takes responsibility for the integrity of the work as a whole.

Conflict of interest

YJK and TCM receive research funding from Siemens Healthcare.

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