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Validation of scoring hip osteoarthritis with MRI (SHOMRI) scores using hip arthroscopy as a standard of reference

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Abstract

Purpose To validate SHOMRI gradings in preoperative hip magnetic resonance imaging (MRI) with intra-arthroscopic evaluation of intraarticular hip abnormalities.

Methods Preoperative non-arthrographic 3.0-T MRIs of 40 hips in 39 patients (1 patient with bilateral hip surgery) with femoroacetabular impingement (FAI) syndrome (mean age, 34.7 years ± 9.0; n = 16 females), refractory to conservative measures, that underwent hip arthroscopy were retrospectively assessed by two radiologists for chondrolabral abnormalities and compared with intra-arthroscopic findings as the standard of reference. Arthroscopically accessible regions were compared with the corresponding SHOMRI subregions and assessed for the presence and grade of cartilaginous pathologies in the acetabulum and femoral head. The acetabular labrum was assessed for the presence or absence of labral tears. For the statistical analysis sensitivity and specificity as well as intraclass correlation (ICC) for interobserver agreement were calculated.

Results Regarding chondral abnormalities, 58.8% of the surgical cases showed chondral defects. SHOMRI scoring showed a sensitivity of 95.7% and specificity of 84.8% in detecting cartilage lesions. Moreover, all cases with full-thickness defects (n = 9) were identified correctly, and in n = 6 cases (out of n = 36 with partial-thickness defects) the defective cartilage was identified but the actual depth overestimated. Labral tears were present in all cases and the MR readers identified 92.5% correctly. ICC showed a good interobserver agreement with 86.3% (95% CI 80.0, 90.6%)

Conclusion Using arthroscopic correlation, SHOMRI grading of the hip proves to be a reliable and precise method to assess chondrolabral hip joint abnormalities.

Key Points

• *Assessment of hip abnormalities using MRI with surgical correlation.*
• *Comparing surgery and MRI by creating a hybrid anatomic map that covers both modalities.*
• *Non-arthrographic use of 3.0-T MRI provides detailed information on cartilage and labral abnormalities in hip joints.*

Keywords Magnetic resonance imaging · Evaluation studies · Hip joint · Arthroscopy · Chondrolabral injuries

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Abbreviations

FAI	Femoroacetabular impingement
ICC	Intraclass correlation
MRI	Magnetic resonance imaging
NPV	Negative predictive value
OA	Osteoarthritis
PPV	Positive predictive value
SD	Standard deviation
SHOMRI	Scoring hip osteoarthritis with MRI

Introduction

Osteoarthritis (OA) is a well-known global challenge for today's health care system with a far-reaching economic burden to society and consequences for each individual affected by this disease [1, 2]. Moreover, there is no known cure and no proven pharmacologic intervention available to treat OA [3, 4]. Because the progressive process of joint degeneration is directly associated with the aging population [5, 6], the prevalence of OA is anticipated to continually increase, resulting in OA as the leading cause of musculoskeletal disability in the elderly [7]. Hip OA in particular demonstrates rising incidence and prevalence with 7.4% of older individuals, aged 60 to 90 years, being affected [8]. Nonetheless, hip OA is also found in younger patients, whereas especially femoroacetabular impingement (FAI) is a frequent source for hip joint degeneration [9]. Along with the OA-related clinical features of pain and immobility, the crux lies in its irreversible progressive nature: gradual cartilage loss, accompanied by degeneration of other joint tissues, ultimately results in altered bone structure and joint destruction. Knowing this, it is not surprising that hip replacement procedures have doubled over the last decades, with 306,600 hip arthroplasties performed in 2011 in the USA alone [10]. To prevent late stage hip OA, precise imaging tools are necessary to assess morphologic changes within the joints, to identify patients at risk of developing severe OA and to prevent further damage to the joint.

Magnetic resonance imaging (MRI) plays a critical role in assessing disease burden and monitoring progression of joint abnormalities in the setting of OA. Therefore, MRI has become indispensable for clinical detection of joint alterations. However, the interpretation of hip MR images is challenging. Semiquantitative MR-based hip OA evaluation systems have been introduced, such as the Scoring Hip Osteoarthritis with MRI (SHOMRI) grading system [11]. SHOMRI grades tissues and abnormalities involved in the degenerative process of hip OA, and it has been shown to significantly correlate with radiographic and clinical scores [11]. However, to date, SHOMRI has not been validated using an intra-arthroscopic evaluation as a standard of reference, which would provide information on the accuracy of this MR imaging-based grading compared with intraoperative-proven hip defects. We hypothesize that SHOMRI grading of the hip is an accurate method for scoring intraarticular abnormalities of the hip using non-arthrographic 3.0-T MRI.

Therefore, the purpose of this study was to correlate SHOMRI gradings in preoperative hip MRI with intra-arthroscopic evaluation of hip abnormalities. Using a hybrid map that overlays the geographical zones used in hip arthroscopy on top of the MR-defined subregions provided by SHOMRI, we assessed the presence and grade of cartilaginous pathologies as well as labral abnormalities.

Methods

Participants

All patients in our study cohort were prospectively enrolled from the hip preservation clinic at our institution. Throughout the recruitment, participants were initially examined by a sports medicine fellowship-trained orthopedic surgeon, and the data (including patient demographics, questionnaires and image acquisitions) were collected prior to hip arthroscopy. In total, 40 hips in 39 patients (1 patient underwent surgery on both hips) with clinical and morphologic signs of FAI were eligible for a surgical treatment and underwent hip arthroscopy. Patients were eligible for surgery if they were between the ages of 18 to 50 years, had a BMI < 30 kg/m^2 and presented with functionally limiting hip pain due to cam-type or cam-predominant mixed-type FAI morphology that was refractory to conservative measures including physical therapy and/or corticosteroid injections. Preoperative radiographs were obtained in all subjects. Cam morphologies were defined as an alpha angle ≥ 55 degrees on a 45-degree Dunn lateral radiograph [12, 13]. Only patients with no or mild signs of osteoarthritis (grade 0-1; Tönnis classification [14] of OA by radiographic changes) were included. Exclusion criteria included evidence of moderate to severe arthritic changes (Tönnis grade 2 or higher) on preoperative radiographs or prior history of hip surgery. Furthermore, the initial planning MRI for each patient was required to be within 6 weeks prior to the actual surgery.

This study was approved by the institutional Committee on Human Research, and all patients provided written consent.

Image acquisition

Preoperative imaging of the hip undergoing arthroscopic surgery was performed in all 39 patients. The 3.0-T MRIs (GE Discovery MR750) were acquired using a 16-channel large flex array coil. All patients were scanned in the same position, with both feet taped together and rotated inwards. First, a three-plane localizer centered on the greater trochanter was obtained. The MRI protocol included triplanar 2D fat-suppressed fast spin-echo (echo time 60 ms, repetition time 2400 to 3700 ms, FOV 18.0 cm, slice thickness 4 mm) and 3D FOCUS fat-suppressed fast spin-echo, reformatted in in coronal, sagittal and oblique axial FOCUS (TE 20.0 ms, TR 1200.0 ms, FOV 15.3 cm, slice thickness 4.0 mm) sequences.

Scoring chondrolabral lesions of the hip using MRI and arthroscopy

Using the SHOMRI scoring system, the MR images were retrospectively reviewed independently by two musculoskeletal radiologists (BJS, JN), both blinded to the clinical and arthroscopic information. Each patient received a complete SHOMRI analysis [11], whereas, the current analysis focused on cartilage and labrum abnormalities since other features (bone marrow edema, subarticular cysts) are due to the nature of the abnormality not suitable for an arthroscopic correlation. Labral abnormalities were scored on a simplified two-point SHOMRI rating scale: no labral abnormalities or labral tear present. Articular cartilage lesions were graded on a three-point rating scale: no cartilage lesions, partial-thickness defects or full-thickness defects. Acetabular and femoral arthroscopically accessible cartilage regions (femur: anterior, superomedial and superolateral; acetabulum: anterior, superomedial and superolateral) were scored separately for each patient.

Diagnostic arthroscopy served as the standard of reference for the evaluation of intraoperative hip abnormalities. A two-portal access was used for dynamic arthroscopic examination. Arthroscopic evaluation was assessed by a sports medicine fellowship-trained orthopedic surgeon with a focus on hip arthroscopy surgery (ALZ) and graded the femoral and acetabular cartilage lesions based on the Outerbridge and Beck classifications, respectively [15] (Table 1).

Evaluation of combined geographic zones of SHOMRI and arthroscopy

Both SHOMRI and arthroscopy use analogous geographic zones for evaluating intraarticular hip pathologies. SHOMRI uses a sagittal and coronal sequence to divide the femoral head and the acetabular articular surface into six and four subregions, respectively. Arthroscopic measurement of hip joint abnormalities relies on a similar zone-based system, recently published by Ilizaliturri et al [16]. To define the areas of agreement between the arthroscopic zone-based system and SHOMRI subregions, five training cases were retrospectively reviewed by an experienced orthopedic surgeon (ALZ) and an experienced musculoskeletal radiologist (TML). The training cases included arthroscopic videos, obtained during surgery, and preoperative MRIs. Through the training cases, we created a hybrid map of surgical and MRI-based zones to define the matching regions (Fig. 1). To compare both modalities, we combined cartilage lesions that were located in the SHOMRI subregions, acetabulum anterior (AA), acetabulum superolateral (ASL) and acetabulum superomedial (ASM), and the arthroscopic zones,anterior-inferior region (zone 1), anterior-superior region (zone 2) and mid-superior region (zone 3). The same system was applied to the femoral head, where we combined the SHOMRI subregions, femur anterior (FA), femur superolateral (FSL) and femur superomedial (FSM), and the arthroscopic zones, anterior-inferior region (zone 1), anterior-superior region (zone 2) and mid-superior region (zone 3). Since access with arthroscopic instrumentation is limited in certain areas, the posterior regions of the acetabulum and femoral head (zones 4 and 5) were excluded from the analysis because of limited access. The mid-inferior region (zone 6, acetabular fossa) was also excluded since this area is not covered by cartilage [17]. For the case that several lesions were visible in the same region, the more severe lesions were used for correlation. Furthermore, if cartilage lesions detected by the MRI could not be clearly assigned to the corresponding arthroscopic zone, the cases were reviewed, using intraoperative arthroscopy video recordings, to identify the corresponding regions and to improve clarity.

Agreement of chondrolabral lesions using SHOMRI and arthroscopy

For both modalities, in a first step cartilage defects were graded as either present or not present and the agreement between MRI and arthroscopy for this dichotomous categorization was assessed. In a second step, if cartilage defects were present, they were graded as either (1) partial-thickness or (2) full-thickness defects, and the agreement for this categorization was assessed separately. This was done separately for all acetabular and femoral subregions included in this analysis. If cartilage defects were correctly detected by MRI but the grade (partial- versus full-thickness defects) was scored differently during arthroscopy, the results were reported as (3) a cartilage lesion overestimated by MRI (a partial-thickness defect that was described as a full-thickness defect) or (4) a lesion underestimated by MRI (a full-thickness defect that was described as a partial-thickness defect). The interpretation of labral defects were scored in agreement if labral tears were present or absent. For all categories and comparisons of agreement, the lesions documented in the surgical reports served as standard of reference.

Statistical analysis

Statistical analysis was performed using SPSS statistical package version 23 (IBM; Armonk, NY, USA). The number of true-positive (TP), false-positive (FP), true-negative (TN) and false-negative (FN) test results was calculated for each category (chondral and labral lesions) using two-by-two tables. Using these data, sensitivity and specificity were calculated against intra-arthroscopic evaluation as the reference standard. Inter- and intraclass correlation (ICC) estimates and their 95% confidence intervals were calculated based on a mean rating (k = 2), absolute agreement, two-way mixed-effects model, where ICC values < 0.5 indicated poor reliability, values between 0.5 and 0.75 indicated moderate reliability, values between 0.75 and 0.9 indicated good reliability, and values > 0.90 indicated excellent reliability [18].

Table 1 Arthroscopic evaluation of chondrolabral lesions

Grading of the acetabular cartilage	
SHOMRI 0 - No damage to the cartilage surface	
Beck grade 0	Macroscopically sound cartilage with no morphologic defects
Beck grade 1	Softening/malacia of the cartilage
*Beck grade 2**	*Debonding with loss of fixation of the cartilage to the acetabular bone*
SHOMRI 1 - Partial-thickness defect of the articular surface	
Beck grade 3	Partial-thickness defects with fraying and tearing of the chondral surface
SHOMRI 2 - Full-thickness defect of the articular surface	
Beck grade 4	Full-thickness defects to the subchondral bone
Grading of the femoral head cartilage	
SHOMRI 0 - No damage to the cartilage surface	
Outerbridge grade 0	Macroscopically sound cartilage with no morphologic defects
Outerbridge grade 1	Softening/malacia of the cartilage
SHOMRI 1 - Partial-thickness defect of the articular surface	
Outerbridge grade 2	Partial-thickness defects with fragmentation or tearing of the articular surface < 0.5 inches
Outerbridge grade 3	Partial-thickness defects with fragmentation or tearing of the articular surface > 0.5 inches
SHOMRI 2 - Full-thickness defect of the articular surface	
Outerbridge grade 4	Full-thickness defect featuring erosion of the cartilage down to the bone
Grading of the chondro-labral junction	
No labral tear	Inspection and probing of the chondro-labral junction shows no abnormalities
Labral tear	Inspection and probing of the chondro-labral junction shows presence of a labral tear

The table shows the arthroscopic evaluation of chondrolabral lesions in the hip. *Since acetabular delamination (Beck grade 2) is not included in the SHOMRI grading, these findings were not part of the analysis

Results

Patient demographics

Thirty-nine patients with clinical and morphologic signs of FAI were included in our study. Of these, one patient had bilateral hip MR imaging, resulting in a total of $n = 40$ hip cases. For each case, the cartilage of the acetabulum and femur were scored separately, resulting in a total of $n = 80$ regions with $n = 40$ acetabular and $n = 40$ femoral regions. The average age of all study participants was 34.7 years [standard deviation (SD) 9.0]. Our study cohort consisted of $n = 16$ females (41.0%) and $n = 23$ males (59.0%). The average time between the preoperative MR imaging study and hip surgery was 7.8 days (SD 8.2). The detailed patient characteristics are summarized in Table 2.

Inter-/intrareader reliability

Interreader ICC between the readers for all chondrolabral readings showed a good agreement with 0.863 and a 95% confidence interval from 0.800 to 0.906 ($p < 0.001$). Subcategorized into the readings for chondral abnormalities of the femoral head, the acetabulum, and labral tears, the ICC ranged from 0.740 to 0.859. The average ICC for cartilage lesions in the acetabulum was 0.859 with a 95% confidence interval from 0.735 to 0.925 ($p < 0.001$) and 0.777 in the femoral head with a 95% confidence interval from 0.627 to 0.866 ($p < .001$). For labral tears the ICC was 0.905 with a 95% confidence interval from 0.800 to 0.955 ($p < 0.001$).

Intrareader reliability for both readers was good to excellent. The ICCs for intrareader agreement for reader 1 were as follows: all chondrolabral readings, 0.957 with a confidence interval from 0.936 to 0.970 ($p < 0.001$); chondral abnormalities of the femoral head, 0.803 with a confidence interval from 0.667 to 0.883 ($p < 0.001$); chondral abnormalities of the acetabulum, 0.852 with a confidence interval from 0.720 to 0.922 ($p < 0.001$); labral tears, 0.979 with a confidence interval from 0.957 to 0.990 ($p < 0.001$). The ICCs for intrareader agreement for reader 2 were as follows: all chondrolabral readings, 0.923 with a confidence interval from 0.891 to 0.945 ($p < 0.001$); chondral abnormalities of the femoral head, 0.852 with a confidence interval from 0.753 to 0.911 ($p < 0.001$); chondral abnormalities of the acetabulum, 0.753 with a confidence interval from 0.535 to 0.869 ($p < 0.001$); labral tears, 0.890 with a confidence interval from 0.641 to 0.956 ($p < 0.001$).

Surgical hip evaluation

Out of the 80 identified hip regions, arthroscopic evaluation revealed cartilage defects in 47 (58.8%) cases, with 9 full-

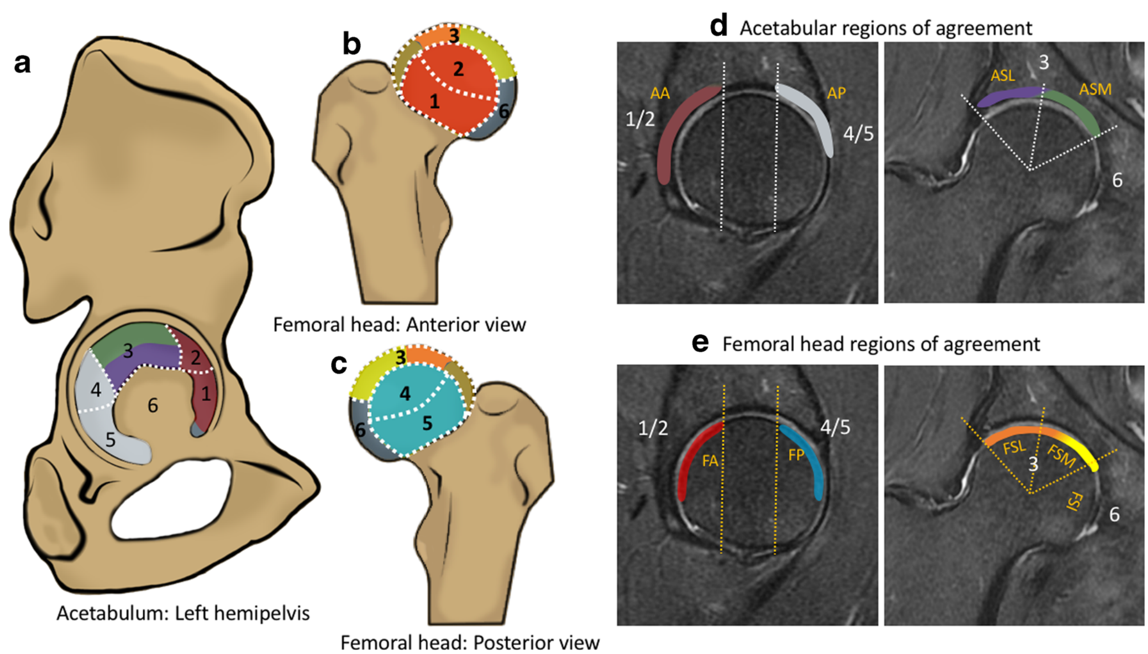

Fig. 1 Evaluation of combined geographic zones of SHOMRI and arthroscopy. Illustration of the left hemipelvis (**a**), anterior (**b**) and posterior (**c**) view of the femoral head. Arabic numerals within the dotted white lines refer to the different geographical zones as introduced by Ilizaliturri, whereas colored areas refer to the subregions as used in SHOMRI scoring. (**d**) and (**e**) arabic numerals and colored SHOMRI regions both overlaid on a coronal and sagittal 2D T2 fat-suppressed FSE sequence. **d** Areas of agreement for the acetabulum, whereas (**e**) shows the areas of agreement for the femoral head. Please note that when using SHOMRI cartilage lesions in the anterior and posterior region are assessed on a sagittal view and lesions in the center region are assessed in the coronal view. AA = acetabulum anterior, AP = acetabulum posterior, ASL = acetabulum superior lateral, ASM = acetabulum superior medial, FA = femoral head anterior, FP = femoral head posterior, FSL = femoral head superior lateral, FSM = femoral head superior medial, FSI = femoral head superior inferior

thickness defects (11.3%) and 38 partial-thickness defects (47.5%). Thirty-three regions (41.2%) showed no cartilage defects. Interestingly, eight out of nine full-thickness defects were found in at the acetabular region (Figs. 2 and 3). Partial-thickness defects were also more prevalent in the acetabular cartilage (Fig. 4) than at the femoral head, with 23 and 15 cases of partial thickness, respectively. With respect to labral abnormalities, all 40 hips showed labral tears.

Table 2 Patient demographics

Demographics	
Mean age (years) of all patients	34.7 ± 9.0
BMI (kg/m^2) of all patients	24.1 ± 3.1
Females [*n* (%)]	16 (41.0%)
Males [*n* (%)]	23 (59.0%)
Surgery left hip [*n* (%)]	22 (55.0%)
Surgery right hip [*n* (%)]	18 (45.0%)
Average time between imaging and surgery (days)	7.8 ± 8.2

In total, 39 patients were included and 40 hips were scanned since 1 patient had surgery on both hips. Continuous data are expressed as mean ± SD. Categorical data are presented in numbers of participants with percentage in parentheses

SHOMRI evaluation

SHOMRI scoring showed a sensitivity of 95.7% and a specificity of 84.8% in determining if cartilage lesions were present in all scored regions (Table 3). Positive and negative predictive values (PPV, NPV) also showed good results (90% and 93%, respectively). Of 47 arthroscopically proven cartilage defects, 45 cases were correctly detected by the MR readers, and 28 cases (out of 33) were correctly identified as having no chondral defects.

When comparing the results for the acetabulum and the femoral head separately, the sensitivity was higher at the acetabulum with 100%, and a PPV of 93.9%, than in the femoral head with 87.5%, and a PPV of 82.4%. However, specificity was higher in the femoral head than in the acetabular region, showing 87.5% and 77.8%, respectively.

Within the 45 cases with cartilage defects correctly identified by the MR readers, all cases with arthroscopically proven full-thickness defects ($n = 9$, 20%) were correctly described as full-thickness defects using SHOMRI. Furthermore, 30 (66.67%) cases were correctly described as partial-thickness defects. The remaining six (13.34%) cases also showed arthroscopically proven partial-thickness defect, whereas the MR readers overestimated the actual depth of the lesions and scored them as full-thickness defects (Table 4). Only 2 of the

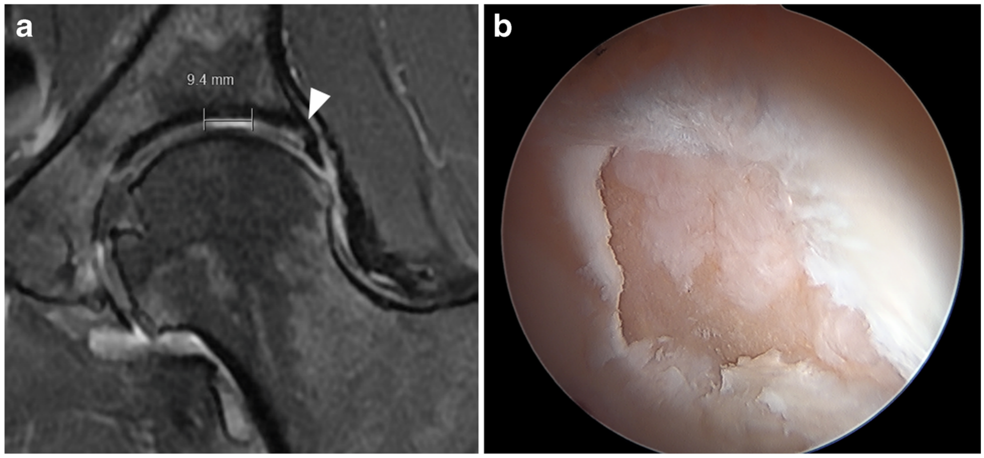

Fig. 2 Full-thickness defect of the acetabular cartilage. MRI (coronal 2D T2 fat-suppressed FSE) of the left hip in a 40-year-old female patient (**a**) shows a 9.4-mm full-thickness defect in the center of the superior acetabulum and a labral tear superior-lateral (white arrowhead). The arthroscopy image (**b**), 9 days after the preoperative hip MRI, confirmed the full-thickness defect of the articular cartilage

47 arthroscopically proven cartilage defects were missed by the radiologists. In five cases, readers described partial-thickness defects that were not confirmed during arthroscopy, leaving a total of $n = 7$ cases identified as false-positive ($n = 5$) or false-negative ($n = 2$) readings. All patients in this study presented with intraoperative labral tears, and the radiologists only missed three tears (sensitivity = 92.5%). Table 4 summarizes the results of comparisons between SHOMRI gradings and arthroscopic evaluation.

Discussion

This is the first study validating the semiquantitative MRI hip osteoarthritis SHOMRI grading concerning intraarticular hip abnormalities using arthroscopic correlation. We validated SHOMRI scores using intraoperative evaluation as the standard of reference and were able to show both high sensitivity and specificity in detecting chondral lesions and high sensitivity in detecting labral tears. Based on our findings, SHOMRI scoring of the hip is a precise and reliable method to evaluate hip cartilage and labral abnormalities.

MRI has been shown to be highly sensitive and specific for characterization and assessment of musculoskeletal disorders [19–23] and especially in the setting of joint pathologies several MR-based scoring methods have been introduced [11, 19, 24–28], all with the common purpose to provide practice guidelines in describing and quantifying radiologic findings and to minimize subjectivity. Moreover, the accurate and systematic classification of MRI using a standardized terminology of reporting creates reproducibility that is ideally reflected in high intra- and interrater reliability of each method.

The complex anatomy and mechanical conditions of the hip joint present a unique challenge for a standardized and reproducible image assessment. The closely apposed articular surfaces of the femoral head and the acetabulum, in an already small intraarticular volume, require a well-elaborated imaging

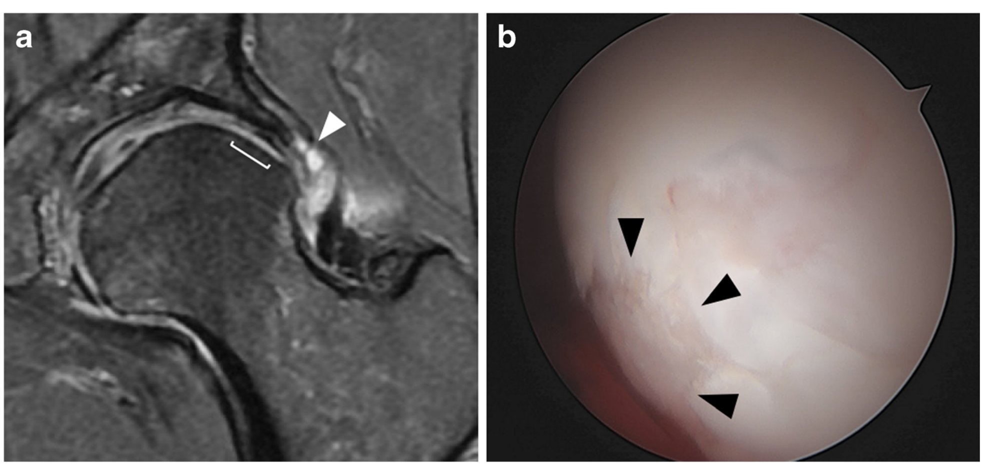

Fig. 3 Full-thickness defect of the superior lateral femoral head. Hip MRI (coronal 2D T2 fat-suppressed FSE) of a 53-year-old female patient with advanced degeneration of the left hip. The labrum was torn with associated paralabral cysts (**a**, white arrowhead). Moreover, the patient presented a full-thickness defect in the superior lateral region of the femoral head (**a**, white brackets). The femoral full-thickness cartilage defect is nicely seen in the arthroscopy (**b**) 5 days after the MRI with erosions of the cartilage to the bone (**b**, black arrowheads)

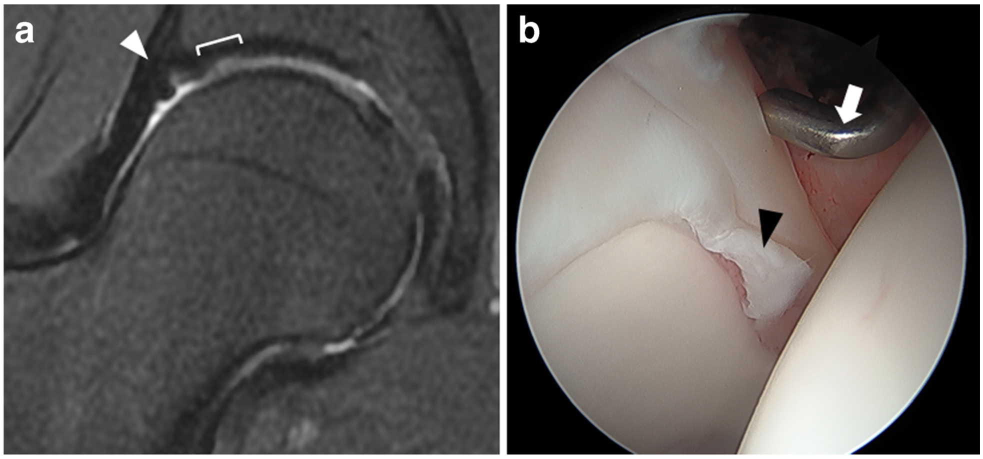

Fig. 4 Torn labrum and partial-thickness loss of the acetabular cartilage. Right hip MRI (coronal 2D T2 fat-suppressed FSE) of a 24-year-old male patient (**a**) with intra-arthroscopic evaluation (**b**) of the same hip 4 days after the MRI. The labrum was torn at the chondrolabral junction (**a**, white arrow head) with a partial-thickness defect in the anterior superolateral region of the acetabulum (**a**, white bracket). Arthroscopy (**b**) shows the partial-thickness defect with the probe on the labrum (white arrow) and the partial-thickness defect of the acetabulum (**b**, black arrowhead)

protocol for optimal visualization of the hip joint. To better differentiate the cartilage layers, Schmaranzer et al used traction MR arthrography in 73 patients who underwent arthroscopy afterwards [29]. While this technique improves the visualization of articular cartilage layers as two distinct layers, and as shown by the authors of this study, also allows an accurate detection of chondrolabral abnormalities, in the clinical setting it assumes a certain level of comfort and might carry the risk of patient discomfort and eventually development of pain. Furthermore, as pointed out by the authors, a direct comparison of conventional MR arthrography and traction MR arthrography is still needed to determine if either of these techniques is superior to the other.

So far, only a few studies have focused on the evaluation of MR-based hip scoring methods [24–26]; moreover, only one of these studies used the complete study cohort for correlation with surgical reports [26]. Overall, these studies showed a good performance evaluation hip MRI with surgical correlation. However, the complete imaging protocol required either an MRI arthrogram [24, 26] or administration of intravenous contrast [25]. In contrast, by using SHORMI, the assessment of hip joint abnormalities in our investigation was performed with a non-arthrographic 3.0-T system. Still, we were also able to show high sensitivity and specificity for the assessment of hip joints by means of MRI.

Generally, in an effort to optimize image quality while maintaining scan time efficiency, the use of MR arthrography challenges the conventional non-enhanced MRI. However, although several studies have reported a higher accuracy for MR arthrography in the detection of chondrolabral lesions [17, 30, 31], the use of intraarticular contrast might not be logistically feasible in a larger study trial and/or in clinical

Table 3 Results for evaluation of cartilage and labral lesions using SHOMRI readings with intra-arthroscopic standard of reference

TP	TN	FN	FP	Sens.	Spec.	PPV	NPV	Acc.	Total cases
Combined analysis of chondral defects at the acetabulum and femoral head									
45	28	2	5	0.957	0.848	0.90	0.933	0.913	80
Separate analysis of chondral lesions at the acetabulum									
31	7	0	2	0.100	0.778	0.939	0.10	0.950	40
Separate analysis of chondral lesions at the femoral head									
14	21	2	3	0.875	0.875	0.824	0.913	0.875	40
Analysis of labral tears									
37	*#n/a*	3	0	0.925	*#n/a*	0.100	*#n/a*	*#n/a*	40

Data show the correlation of SHOMRI readings with intra-arthroscopic evaluation of chondral and labral lesions in the hip. Combined analysis of chondral defects at the acetabulum and femoral head shows the combined results for any cartilage lesion present in the acetabulum and/or femoral head. Separate analyses of chondral lesions at the acetabulum/femoral head each show results for any cartilage lesions present only in the acetabulum or femoral head

TP true positive, *TN* true negative, *FN* false negative, *FP* false positive, *Sens.* sensitivity, *Spec.* specificity, *PPV* positive predictive value, *NPV* negative predictive value, *Acc.* accuracy, *Total readings* total readings included in the analysis

Table 4 Cross table performance of SHOMRI readings with intra-arthroscopic evaluation

		Arthroscopy				
		No chondral lesion	Full-thickness defect	Partial-thickness defect	Labral tear	No labral tear
SHOMRI	No chondral lesions	28	0	2		
	Full-thickness defect	0	9	6		
	Partial-thickness defect	5	0	30		
	Labral tear				37	0
	No labral tear				3	0

The 5 × 5 cross table performance of all SHOMRI readings with intra-arthroscopic evaluation of chondral and labral lesions in the hip. Data in the first three columns/rows show the agreement of both modalities with respect to grading of cartilage lesions, whereas, the least two columns/rows show the agreement of both modalities with respect to the labrum. Gray cells show lesions correctly identified using SHOMRI

routine [32], and, more importantly, for the majority of these studies, a 1.5-T MRI system was used. In this context, recent studies have shown that the use of a high-resolution, non-arthrographic 3-T MRI is capable of detecting chondral and labral abnormalities with high accuracy [20, 33, 34] and therefore may obviate the need for intraarticular contrast.

One of the primary characteristics of our study design was the feasibility of SHOMRI to detect cartilage lesions with surgical reports as the standard of reference. Naturally, other findings in the adjacent bone that are also involved in the process of joint degeneration (bone marrow edema patterns or subarticular cysts) are not visible on macroscopic examination during surgical interventions [24, 26] and were therefore not part of our investigation. Cartilage deterioration, as the main characteristic of joint degeneration, is usually at some point accompanied by changes in the subchondral bone, and therefore both can be seen as a continuously challenged functional unit when involved in degeneration [35]. However, studies have indicated a possible protective effect of the cartilage layer on the functional and structural changes in the subjacent bone, such as the bone marrow pattern and subarticular cysts [36–38]. Therefore, especially the accurate identification of cartilage lesions will be of great benefit in the setting of a preoperative hip evaluation using MRI.

We acknowledge that our study has several limitations. First, all of our study participants showed an acetabular labral tear; therefore, no specificity was computed during analysis of the SHOMRI scores. However, because FAI is the predominant cause of labral tears in nondysplastic hips [39, 40] and all of our patients were eligible for surgery, it is expected to find a high prevalence of labral tears in such a cohort. Second, our readings were only performed on patients with FAI syndrome, and no patients without clinical or morphological signs of FAI were included. Due to the purpose of our study, evaluation of hip abnormalities with intraoperative correlation, a surgical report was needed; thus, to extend this study design to include controls without indication for surgical treatment is not feasible. Finally, although arthroscopy is the choice of treatment for patients with FAI and no to mild radiographic changes (Tönnis 0 – 1) [41], the access of the arthroscopic instrumentation is limited, especially in the posterior regions of the hip joint; thus, we did not include the posterior cartilage regions in our investigation.

In conclusion, the semiquantitative MR-based scoring system, SHOMRI, is a useful evaluation method for hip abnormalities with good to excellent reliability [11]. In the current study, we evaluated SHOMRI scores with arthroscopic correlation as a standard of reference. We were able to show a high sensitivity and specificity for chondral assessment at the acetabulum and femoral head in patients with FAI syndrome. Additionally, our results also showed a high sensitivity in detecting labral tears. Within the arthroscopically accessible regions, SHOMRI grading proved to be a reliable and precise method to assess chondrolabral abnormalities in the hip joint.

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Compliance with ethical standards

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Conflict of interest The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

Statistics and biometry One of the authors has significant statistical expertise.

Informed consent Written informed consent was obtained from all subjects (patients) in this study.

Ethical approval Institutional Review Board approval was obtained.

Methodology
• prospective
• diagnostic study
• performed at one institution

References

1. United States Bone and Joint Initiative: The Burden of Musculoskeletal Diseases in the United States (BMUS), Third Edition, 2014. Rosemont, IL. Available at http://www.boneandjointburden.org. Accessed on December 8, 2017
2. Turkiewicz A, Petersson IF, Björk J et al (2014) Current and future impact of osteoarthritis on health care: a population-based study with projections to year 2032. Osteoarthritis Cartilage 22(11):1826–1832
3. Yusuf E (2016) Pharmacologic and non-pharmacologic treatment of osteoarthritis. Curr Treat Options Rheumatol 2(2):111–125
4. Karsdal MA, Michaelis M, Ladel C et al (2016) Disease-modifying treatments for osteoarthritis (DMOADs) of the knee and hip: lessons learned from failures and opportunities for the future. Osteoarthritis Cartilage 24(12):2013–2021
5. Vita AJ, Terry RB, Hubert HB, Fries JF (1998) Aging, health risks, and cumulative disability. N Engl J Med 338(15):1035–1041
6. Peffers MJ, Balaskas P, Smagul A (2018) Osteoarthritis year in review 2017: genetics and epigenetics. Osteoarthritis Cartilage 26(3):304–311
7. Felson DT, Lawrence RC, Dieppe PA et al (2000) Osteoarthritis: new insights. Part 1: the disease and its risk factors. Ann Intern Med 133(8):635–646
8. Quintana JM, Arostegui I, Escobar A et al (2008) Prevalence of knee and hip osteoarthritis and the appropriateness of joint replacement in an older population. Arch Intern Med 168(14):1576–1584
9. Agricola R, Waarsing JH, Arden NK et al (2013) Cam impingement of the hip: a risk factor for hip osteoarthritis. Nat Rev Rheumatol 9(10):630–634
10. Department of Research & Scientific Affairs (2014), American Academy of Orthopaedic Surgeons. Annual Incidence of Common Musculoskeletal Procedures and Treatment. Available via http://www.aaos.org/research/stats/CommonProceduresTreatments-March2014.pdf Accessed 2 Jan 2018
11. Lee S, Nardo L, Kumar D et al (2015) Scoring hip osteoarthritis with MRI (SHOMRI): a whole joint osteoarthritis evaluation system. J Magn Reson Imaging 41(6):1549–1557
12. Hipfl C, Titz M, Chiari C et al (2017) Detecting cam-type deformities on plain radiographs: what is the optimal lateral view? Arch Orthop Trauma Surg 137(12):1699–1705
13. Nötzli HP, Wyss TF, Stoecklin CH et al (2002) The contour of the femoral head-neck junction as a predictor for the risk of anterior impingement. J Bone Joint Surg Br 84(4):556–560
14. Busse J, Gasteiger W, Tönnis D (1972) Eine neue Methode zur röntgenologischen Beurteilung eines Hüftgelenkes — Der Hüftwert. Archiv für orthopädische und Unfall-Chirurgie, mit besonderer Berücksichtigung der Frakturenlehre und der orthopädisch-chirurgischen Technik 72(1):1–9
15. Amenabar T, Piriz J, Mella C et al (2015) Reliability of 3 different arthroscopic classifications for chondral damage of the acetabulum. Arthroscopy 31(8):1492–1496
16. Ilizaliturri VM, Byrd JWT, Sampson TG et al (2008) A geographic zone method to describe intra-articular pathology in hip arthroscopy: cadaveric study and preliminary report. Arthroscopy 24(5):534–539
17. Petersilge CA (2000) From the RSNA Refresher Courses. Radiological Society of North America. Chronic adult hip pain: MR arthrography of the hip. Radiographics 20:43–52
18. Portney LG, Watkins MP (2009) Foundations of Clinical Research: Applications to Practice, 3rd edn. Prentice Hall, Upper Saddle River
19. Peterfy CG, Guermazi A, Zaim S et al (2004) Whole-Organ Magnetic Resonance Imaging Score (WORMS) of the knee in osteoarthritis. Osteoarthritis Cartilage 12:177–190
20. Linda DD, Naraghi A, Murnaghan L et al (2017) Accuracy of non-arthrographic 3T MR imaging in evaluation of intra-articular pathology of the hip in femoroacetabular impingement. Skeletal Radiol 46(3):299–308
21. Woertler K, Waldt S (2006) MR imaging in sports-related glenohumeral instability. Eur Radiol 16(12):2622–2636
22. Hobby JL, Dixon AK, Bearcroft PW et al (2001) MR imaging of the wrist: effect on clinical diagnosis and patient care. Radiology 220(3):589–593
23. Van Dyck P, Gielen JL, Vanhoenacker FM et al (2012) Diagnostic performance of 3D SPACE for comprehensive knee joint assessment at 3 T. Insights Imaging 3(6):603–610
24. Neumann G, Mendicuti AD, Zou KH et al (2007) Prevalence of labral tears and cartilage loss in patients with mechanical symptoms of the hip: evaluation using MR arthrography. Osteoarthritis Cartilage 15(8):909–917
25. Roemer FW, Hunter DJ, Winterstein A et al (2011) Hip Osteoarthritis MRI Scoring System (HOAMS): reliability and associations with radiographic and clinical findings. Osteoarthritis Cartilage 19(8):946–962
26. Schmid MR, Nötzli HP, Zanetti M et al (2003) Cartilage lesions in the hip: diagnostic effectiveness of MR arthrography. Radiology 226(2):382–386
27. Hunter DJ, Guermazi A, Lo GH et al (2011) Evolution of semi-quantitative whole joint assessment of knee OA: MOAKS (MRI Osteoarthritis Knee Score). Osteoarthritis Cartilage 19(8):990–1002
28. Hunter DJ, Lo GH, Gale D et al (2008) The reliability of a new scoring system for knee osteoarthritis MRI and the validity of bone marrow lesion assessment: BLOKS (Boston Leeds Osteoarthritis Knee Score). Ann Rheum Dis 67(2):206–211
29. Schmaranzer F, Klauser A, Kogler M et al (2015) Diagnostic performance of direct traction MR arthrography of the hip: detection of chondral and labral lesions with arthroscopic comparison. Eur Radiol 25(6):1721–1730
30. Sutter R, Zubler V, Hoffmann A et al (2014) Hip MRI: how useful is intraarticular contrast material for evaluating surgically proven

lesions of the labrum and articular cartilage? AJR Am J Roentgenol 202(1):160–169
31. Smith TO, Hilton G, Toms AP et al (2011) The diagnostic accuracy of acetabular labral tears using magnetic resonance imaging and magnetic resonance arthrography: a meta-analysis. Eur Radiol 21(4):863–874
32. Steinbach LS, Palmer WE, Schweitzer ME (2002) Special focus session. MR arthrography. Radiographics 22(5):1223–1246
33. Naraghi A, White LM (2015) MRI of labral and chondral lesions of the hip. AJR Am J Roentgenol 205(3):479–490
34. Chopra A, Grainger AJ, Dube B et al (2018) Comparative reliability and diagnostic performance of conventional 3T magnetic resonance imaging and 1.5T magnetic resonance arthrography for the evaluation of internal derangement of the hip. Eur Radiol 28(3):963–971
35. Lories RJ, Luyten FP (2011) The bone-cartilage unit in osteoarthritis. Nat Rev Rheumatol 7(1):43–49
36. Maas O, Joseph GB, Sommer G et al (2015) Association between cartilage degeneration and subchondral bone remodeling in patients with knee osteoarthritis comparing MRI and (99m)Tc-DPD-SPECT/CT. Osteoarthritis Cartilage 23(10):1713–1720
37. Tanamas SK, Wluka AE, Pelletier J-P et al (2010) The association between subchondral bone cysts and tibial cartilage volume and risk of joint replacement in people with knee osteoarthritis: a longitudinal study. Arthrit Res Ther 12(2):R58
38. Marra MD, Crema MD, Chung M et al (2008) MRI features of cystic lesions around the knee. Knee 15(6):423–438
39. Ganz R, Parvizi J, Beck M et al (2003) Femoroacetabular impingement: a cause for osteoarthritis of the hip. Clin Orthop Relat Res (417): 112–120
40. Lavigne M, Parvizi J, Beck M et al (2004) Anterior femoroacetabular impingement: part I. Techniques of joint preserving surgery. Clin Orthop Relat Res (418): 61–66.
41. Dall'Oca C, Trivellin G, D'Orazio L et al (2016) Hip arthroscopy in osteoarthritis consequent to FAI. Acta Biomed 87(Suppl 1):46–52