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Isotropic 3D MRI Determined Labral Tear Extent Correlates With Hyaline Cartilage Loss in Hip Dysplasia Patients

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Keywords: Hip dysplasia; Labrum; Cartilage; MRI; 3D MRI; PROMs.

Key Findings

1. 3D MRI can be used to reliably measure hip labral tears (ICC=0.66), which can be used as a tool to assist with diagnostic and treatment plans.
2. Labral tear lengths on 3D MRI correlate directly with worsening cartilage damage (p<.008) suggesting possible protective mechanism of the intact hip labrum.

Abstract

Objective: Hip Dysplasia (HD) presents with hip pain and/or instability. Radiographs are used for initial screening while 3D MRI added to routine 2D MRI increases the conspicuity of associated labral and cartilage lesions. This study aimed to correlate the extent of hyaline cartilage injury with the presence, location, multiplicity, and length of labral tears in HD patients, and with Patient-Reported Outcome Measures (PROMs).

Methods: Consecutive 139 pre-operative patients with a final diagnosis of HD (ages 14-68 years, both genders) were included. All had complete datasets including 2D and 3D MRIs and PROMs (EqVas Health Rating, SF12, UCLA Activity Score, VAS Pain, HOS, HOOS, iHot 12, and HHS). 3D labrum-specific reconstructions were performed, and a multi-reader study was obtained. Inter-reader (ICC) analysis and Spearman correlations were calculated with the hypothesis that longer labral tears correlate with worsening cartilage injury and PROMs.

Results: Among 156 hips from 139 patients, there were 122 hips with intact cartilage, 10 with low-grade, 6 with high-grade, and 18 with full-thickness cartilage injuries. The tear lengths were 15.38 mm+/-5.57 mm (mean+/-SD) with moderate inter-reader correlation (ICC= 0.66). Longer labral tears correlated with worsening cartilage damage (p=.008), VAS worst pain (p=.008), subchondral cysts (p<0.05), and para-labral cysts (p<0.001). No statistically significant correlations were seen between labral tear length and PROMs (p>0.05), though few correlation trends were observed.

Conclusion: Hip labral tears can be reproducibly measured on 3D MRI and larger labral tears correlate with worsening hyaline cartilage damage but not with PROMs.

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Introduction

Hip Dysplasia (HD) is a developmental condition characterized by a shallow and up sloping acetabulum and sometimes accompanied with femoral head in congruency [1]. The resultant instability of the joint if left untreated, can lead to hyaline cartilage damage, labral tears, and premature hip osteoarthritis [2]. Radiographs are used for the initial imaging screening and assessment of HD and various validated measurements like Tonnis angle, lateral center edge angle and extrusion index have been described for grading the extent of HD [3]. Following radiographic assessment, multiplanar 2D (dimensional) MR imaging with or without arthrogram is routinely performed for outlining the health of labrum and hyaline cartilage [4,5]. Recently, 3D spin echo MR imaging is being adopted for hip assessment. 3D MRI can be performed in an isotropic manner on high-field magnets (3 Tesla and newer 1.5T MRI scanners) [6,7]. Such volume imaging allows high-resolution assessment of labrum and cartilage lesions. In addition, it presents opportunities to measure the extent of labral tears with labrum specific reconstructions [8].

Although the diagnosis of HD is established primarily based on a combination of clinical presentation, physical findings, and radiographic measurements, advanced imaging (3D CT and 3D MRI) is commonly used for pre-operative planning [9]. In addition, patient reported outcome measures (PROMs) are vital in assessing the overall quality of life of the patient and how HD affects their joint health status. Common measurements included in PROMS include Eq Vas Health Rating, SF12, UCLA Activity Score, VAS Pain, HOS, HOOS, I Hot 12, and HHS (Table 1) [10-17]. Each reported outcome measure provides a unique perspective on the patient's health, which is important in establishing an overall clinical picture of the patient and can influence treatment plans.

Thus, PROMs and high-resolution MR imaging can serve as important tools to measure the HD disease burden and vital data points in building a treatment plan for the patient. However, to the authors' knowledge, there are no studies in English literature that investigated the correlation between the extent of labral injury on MRI with the hyaline cartilage damage and PROMs. This study aimed to correlate the extent of hyaline cartilage injury in HD patients with the presence, location, multiplicity, and length of labral tears in HD patients and with PROMs. Our hypothesis was that the extent of labral tears appreciated through 3D MRI techniques correlates with worsening hyaline cartilage injury and poorer PROMs.

Material and Methods

IRB approval was in place for this cross-sectional study and for the retrospective use of a patient registry consisting of radiographic images, 2D and 3D MR imaging, and PROMs gathered through a longitudinally maintained hip preservation database. All patients gave informed consent for the future use of their survey responses and data in our institutional hip preservation practice.

Patients

A total of 314 patient records with a final diagnosis of HD were initially screened for inclusion in the study from a consecutive series of patients. Inclusion criteria were ages 14-100 years, all genders, hip MRI performed at our institution with 2D and 3D MRI protocol on 1.5T and 3T magnets, and final established diagnosis of HD based on surgery and in electronic chart follow-ups. Exclusion criteria included the presence of avascular necrosis of the hip (AVN), absence of 3D MR imaging, prior arthroplasty, and the presence of implants. Ultimately, 156 hips from 139 patients were included in the study. (Figure 1). Of the 139 patients, 89 underwent surgery for their HD. Of the 89, 76 had labral tears indicated on their surgery reports, and of the 76 patients, 75 had their labral tears repaired in the same setting. Of the 89 patients who underwent surgery, 23 patients had cartilage damage indicated on 3D MRI, and 79 of the 89 had cartilage damage indicated on their surgery reports.

MR imaging protocol

All scans were performed on 1.5T (Sola, Siemens, Erlangen, Germany) and 3T (Achieva, Philips, Best, Netherlands) scanners using a cardiac multichannel coil. Multiplanar 2D MR imaging sequences in fat suppressed and nonfat-suppressed contrasts were available (parameters- repetition time, TR= 3000-3500ms; echo time, TE=36-42ms; slice thickness= 3.0-3.5mm; interslice gap= 10%; fat-suppression= frequency-selective fat suppression). 3D MRI was obtained using the following parameters, TR= 1100ms; TE=40-42ms; voxel= 0.8-0.9 mm; interslice gap= 0%, sagittal isotropic acquisition with multiplanar reconstructions available in picture archiving system). K-*space* sampling patterns to reduce pixel aliasing and overlap on reconstructed images allowed 3D isotropic imaging on 1.5T scanner.

3D MRI reconstructions and measurements

A senior MSK radiologist initially evaluated all cases with a medical student using both 2D MRI and 3D MRI mimicking the routine practice and evaluated the quality of imaging on a 1-5 scale with 5 being the best examination, and labral and cartilage lesions on Isite PACS (Philips, Best, Netherlands) using a scoring sheet (Table 2). The quality scale was as follows- 1. Not diagnostic/ 2. substantial artifacts which affect diagnostic interpretation/ 3. moderate artifacts, which may affect diagnostic interpretation/mild artifacts, which do not affect diagnostic interpretation/excellent examination. The artifacts considered were parallel imaging related streak artifacts, motion, and failure of fat suppression. Then, using an independent software (Aquarius intuition, Terarecon, Durham, NC), 3D reconstructions were created along the largest labral tear identified and were saved to the same PACS as a set of 3-5 images. The Senior MSK radiologist trained the other MSK readers on the measurement protocols on 10 images, which also formed part of the final dataset. This was done to mimic a practice where 3D recons are automatically generated in the region of labral tear and radiologist simply measures them. The labral tear was identified as a linear fluid-like signal at the chondrolabral junction communicating with the joint fluid. Additional signs included labral truncation, para-labral cyst, and subchondral cyst at the site of tear. The labral tear length- longest linear signal of the tear were subsequently independently recorded by all three readers from the 3D reconstructions created. If there were multiple tears, the largest tear was measured. The radiologists also had 2D MR images available on PACS to assess the labral tear and cartilage damage, replicating our routine practice. It was however, not practical for all readers to create 3D reconstructions on an independent software for the purposes of this study.

Patient Reported Outcome Measures (PROMs)

The PROMs for the project were initially collected from the patients via REDCap surveys during their pre-operative office visit within 4 weeks of MRI. The PROMs included EqVas Health

Rating, SF12, UCLA Activity Score, VAS Pain, HOS, HOOS, iHot 12, and HHS.

Statistical Analysis

Descriptive statistics were used for patient demographics and Body Mass Index (BMI). Spearman's rank correlation coefficients were reported with corresponding 95% confidence intervals for all variables of interest. For patients with bilateral tears, the worse side was selected for correlation calculation. Correlation coefficients were interpreted as negligible: 0-0.1, weak: 0.1-0.39, moderate 0.4-0.69, strong: 0.7-0.89 and very strong: 0.9-1. FDR (false discovery rate) adjustment was applied to p values for the correlation between labral tears measurements and PROMs. Intraclass Correlation Coefficient (ICC) was also performed to ascertain the level of agreement between the three readers. All analysis was done on R version 4.1.1 (R Core Team, Vienna, Austria).

Results

Patients

The mean patient BMI was 25.94 kg/m2, with a minimum of 17 kg/m2 and a maximum of 42.12 kg/m2. The mean patient age was 35 years, with a minimum of 16 years and a maximum of 68 years. Detailed patient demographic data is displayed in Table 3.

Hip MRI reads

One hundred and twenty-two hips had intact cartilage, 10 had low-grade, 6 had high-grade, and 18 had full-thickness cartilage loss. There was 1 3D MRI with an image quality of 1, 4 3D MRIs with a quality of 2, 20 3D MRIs with a quality of 3, 55 3D MRIs with a quality of 4, and 76 3D MRIs with a quality of 5. The mean quality of 3D MRIs was 4.29 with a standard deviation of 0.83. An example of a hip with multifocal labral tears is included in Figure 2, and an example of a posteroinferior tear is included in Figure 3. Detailed data regarding the hip MRI reads can be found in Table 4.

3D Hip MRI Measurements

The minimum labral tear length seen was 3.5 mm, and the maximum labral tear length was 31.17 mm. The mean labral tear length was 15.38 mm with a standard deviation of 5.57 mm. There were 9 patients that did not have any labral tears in the cohort.

Inter-Reader Analysis

There was a moderate inter-reader correlation (ICC = 0.66) on the lengths of labral tears. The Bland-Altman plots for reader 1 vs reader 2, reader 2 vs 3, and reader 1 vs 3 are included in Figure 4.

Hip Dysplasia (HD) is a developmental condition characterized by a shallow and up sloping acetabulum and sometimes accompanied with femoral head in congruency [1]. The resultant instability of the joint if left untreated, can lead to hyaline cartilage damage, labral tears, and premature hip osteoarthritis [2]. Radiographs are used for the initial imaging screening and assessment of HD and various validated measurements like Tonnis angle, lateral center edge angle and extrusion index have been described for grading the extent of HD [3]. Following radiographic assessment, multiplanar 2D (dimensional) MR imaging with or without arthrogram is routinely performed for outlining the health of labrum and hyaline cartilage [4,5]. Recently, 3D spin echo MR imaging is being adopted for hip assessment. 3D MRI can be performed in an isotropic manner on high-field magnets (3 Tesla and newer 1.5T MRI scanners) [6,7]. Such volume imaging allows high-resolution assessment of labrum and cartilage lesions. In addition, it presents opportunities to measure the extent of labral tears with labrum specific reconstructions [8].

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Inter-Reader Analysis

There was a moderate inter-reader correlation (ICC = 0.66) on the lengths of labral tears. The Bland-Altman plots for reader 1 vs reader 2, reader 2 vs 3, and reader 1 vs 3 are included in Figure 4.

PROMs

The patients surveyed had a mean score of 69.93% on EqVAS, which suggested moderate pain, and 63.99% on the SF-12, which is slightly above the depression threshold. The reported mean UCLA activity score was 6.09, which suggested moderate exercise activity. Means and standard deviations for all PROMs studied are included in Table 5.

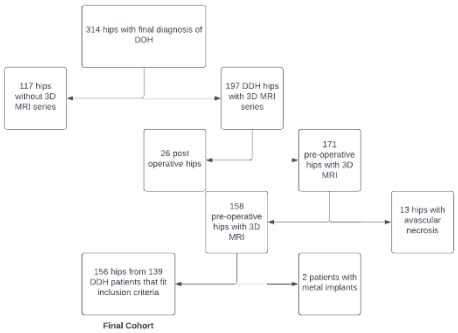

Figure 1: Breakdown of how the final cohort for the study was selected. A total of 156 hips from 139 DDH patients fit the inclusion criteria from a total pool of 314 hips with a final diagnosis of DDH.

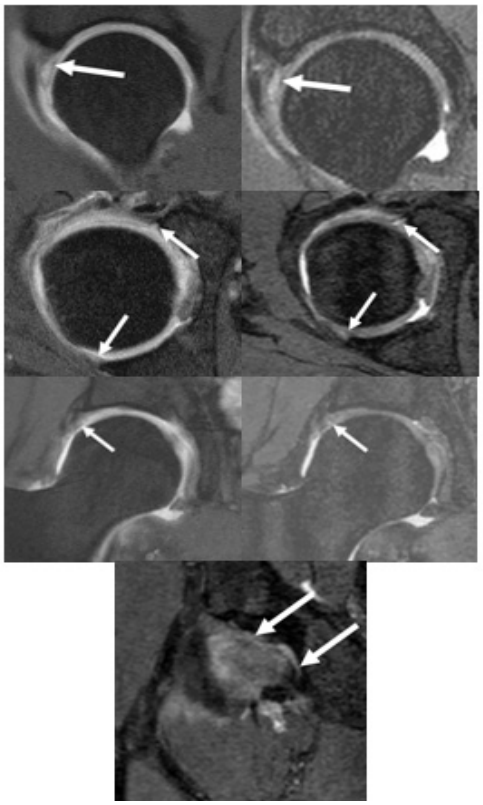

Figure 2: Multifocal labral tear seen in all quadrants in a 29-year-old male patient, with a 3D MRI image quality of 4. Images on the left-hand side panel were taken from 2D MRI sequences, with tears outlined by white arrows. Images on the right-hand side panel were taken from 3D MRI sequence and correspond with the same viewing plane as the 2D MRI images. The last image outlines the posteroinferior tear measured for the study (arrows).

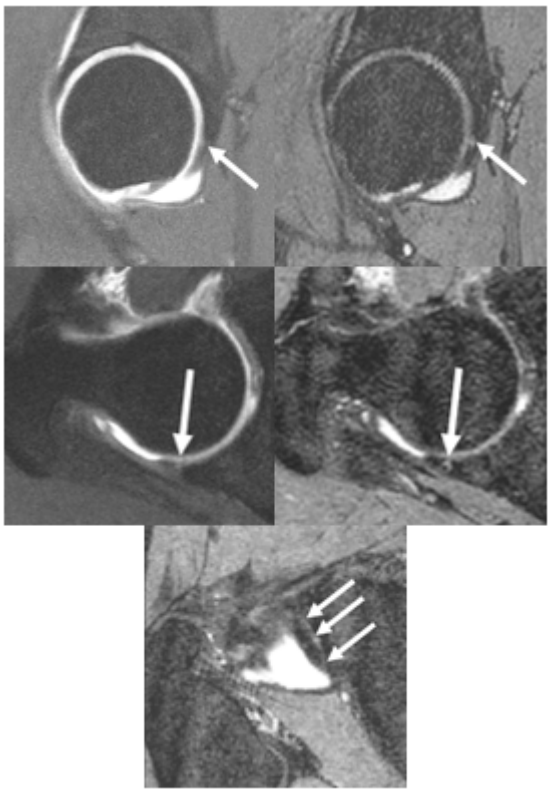

Figure 3: Posteroinferior tear seen in a 36-year-old male patient with 3D MRI image quality of 3. Images on the left-hand side panel were obtained from 2D MRI sequences, and images on the right-hand side panel were taken from 3D MRI sequence and correspond with the same viewing plane as the 2D MRI images. The last image outlines the full length of the tear measured for the study.

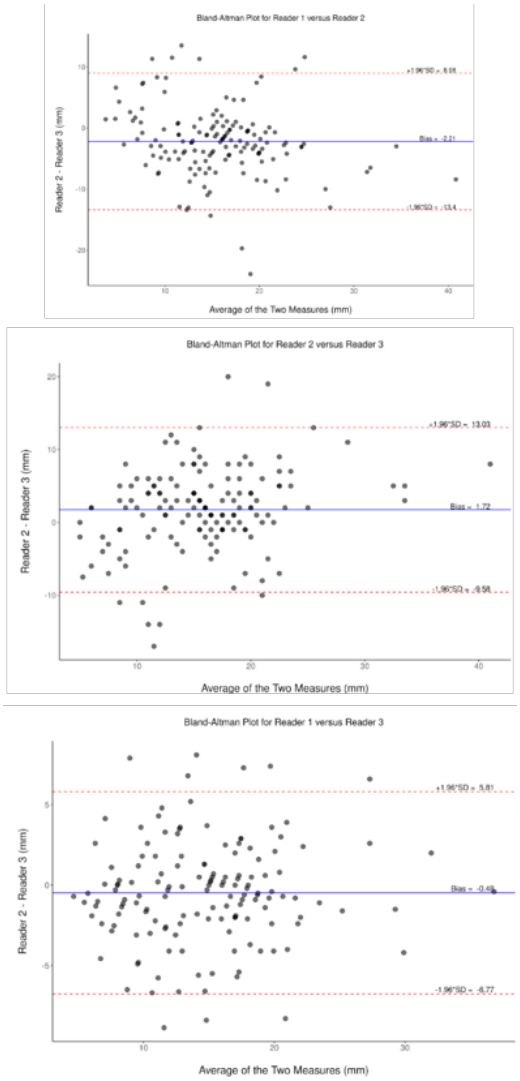

Figure 4: Bland-Altman plots for reader 1 versus reader 2, reader 1 versus reader 3, and reader 2 versus reader 3.

Table 1: Explanation of various PROMs.

PROMs	Description
HHS	Survey evaluating hip function that include parameters such as ability to use public transportation, amount of support needed when walking, and presence of limp [16].
SF-12	Measures the impact of physical and mental health on an individual's quality of life [17].
iHOT-12	Evaluates quality of life changes due to hip disease [11].
Eq-VAS	Vertical visual analogue scale that allows the patient to indicate the state of their overall health [10].
UCLA Activity Score	10-point activity scale that evaluates the patient's activity levels [13].
WOMAC	Self-assessment of the impact of hip and knee osteoarthritis on quality of life [15].
HOS	Assesses the outcome of treatment intervention for acetabular tears in patients who are functioning through a wide range of abilities [14].
VAS	The patient is asked to indicate their perceived pain intensity along a 100 mm horizontal line, which is then measured from the left edge [12].

Table 2: Recording sheet for MRI assessment.

Patient number	Quality of 3D MRI (1-5) Not diagnostic/ substantial artifacts/ moderate artifacts/mild artifacts/excellent	Hyaline Cartilage Intact/Low-grade/ high-grade/ full-thickness loss	Subchondral Bone Cyst Present/ absent	Para-Labral Cyst Present/absent	Number of Labral Tears 0-4	Location of Tears Anterosuperior, posterosuperior, anteroinferior, posteroinferior	Location of Tear Measured Largest tear	Labral Tear Size (mm)

Table 3: Patient demographics.

Age in Years (Male)		
Min	17.68	
Max	68.10	
Mean	35.67	
BMI in kg/m^2 (Male)		
Min	19.00	
Max	42.12	
Mean	27.97	
Age in Years (Female)		
Min	15.99	
Max	64.22	
Mean	34.75	
BMI in kg/m^2 (Female)		
Min	17.00	
Max	42.00	
Mean	25.11	
Gender	Individuals	Percentage
Male	46	29.49
Female	110	70.51

Table 4: MRI findings.

Locations of Tears	Number	Percentage
Anterosuperior	90	54.88
Anteroinferior	23	14.02
Posterosuperior	34	20.73
Posteroinferior	17	10.37
Locations of Measured Tears		
Anterosuperior	133	90.48
Anteroinferior	3	2.04
Posterosuperior	4	2.72
Posteroinferior	7	4.76
Side		
Left	74	47.44
Right	82	52.56
Number of Tears		
0	9	5.77
1	93	59.62
2	42	26.92
3	11	7.05
4	1	0.64
Presence of Subchondral Cysts	18	11.54
Presence of Para-labral Cysts	53	33.97
Quality of 3D MRI		
1	1	0.64
2	4	2.56
3	20	12.82
4	55	35.26
5	76	48.72

Table 5: Mean and standard deviation of all PROMs studied.

PROMs	Mean	Standard Deviation
EqVAS	69.93	18.47
SF 12	63.99	13.53
UCLA Activity	6.09	2.86
Percent Function	58.24	21.99
VAS Pain Now	4.78	2.36
VAS Pain Average	5.23	1.95
VAS Best Pain	2.88	2.18
VAS Worst Pain	8.08	1.88
HOS ADL	62.98	20.37
HOS Sport	47.93	23.09
HOS Total	57.64	20.69
HOOS Symptom	48.76	20.92
HOOS Stiff	48.93	22.14
HOOS Pain	51.29	20.09
HOOS ADL	51.53	25.54
HOOS Sport	56.69	27.21
HOOS QOL	60.60	26.44
HOOS Total	51.56	18.93
iHot12 Total	54.17	23.69
HHS	60.04	19.58

Table 6: Spearman correlation coefficient of length of labral tears versus other MRI measurements.

	Mean Labral Tear Size (mm)	P value
Cartilage Damage	0.23 (0.06, 0.39)	0.008
Subchondral Bone Cyst	0.20 (0.03, 0.36)	0.020
Para-Labral Cyst	0.31 (0.14, 0.46)	<.001
Number of Labral Tears	0.31 (0.15, 0.46)	<.001

Correlation Analysis

There were non-negligible correlations with various PROM parameters. There was a weak negative correlation between the length of the mean labral tear and the EqVas Health Rating (Spearman coefficient of -0.24 (95%CI: -0.40, -0.08)) and a weak positive correlation between the length of the mean labral tear and VAS worst pain (Spearman coefficient of 0.24 (95% CI: 0.07, 0.39)). All raw p values were reported in supplemental table 1. However, none of the p values were significant after FDR adjustment (supplemental table 2). The mean labral tear size directly positively correlated with worsening cartilage damage, the presence of subchondral bone cysts, para-labral cysts, and the number of labral tears (supplemental table 3&4) (Table 6).

Discussion

HD is a common condition presenting in adult hip preservation practice. This work has shown that isotropic 3D MRI can be reliably used to measure labral tears, detect multifocality of tears and find correlations between the labral tears and hyaline cartilage loss. Labral tear lengths directly correlated with worsening hyaline cartilage damage and presence of subchondral and para-labral cysts. This suggests a possible protective role of labrum on the hyaline cartilage. Our first hypothesis was partially validated.

However, we found no significant correlation between labral tear lengths and PROMs. This discrepancy is likely explained by confounding clinical factors, complex pathophysiology, and clinical presentation of HD along with the limitations of the study as discussed below. Existing literature suggests that features measured by 3D MRI are not correlated with PROMs in other conditions such as femoroacetabular impingement syndrome, but impaired physical functioning measured through PROMs was found to be associated with severity of HD [18,19]. The correlation trends however somewhat support our hypothesis that worsening labral tear measurements correlate with poorer PROMs and a greater degree of hyaline cartilage damage. The positive correlation between labral tear lengths and VAS average pain suggests that as labral tears become larger, the patient experiences more pain on average.

There are several limitations to the study. First, HD is a complicated disease with a wide variety of clinical presentations and sequelae, producing an irregular pattern of disease burden across individuals. Thus, the PROMs collected may be influenced by different factors in the patients' lives. Second, the cohort is overwhelmingly female, which can be attributed to the fact that HD is more common in females. This disparate gender ratio may have influenced the correlation trends seen. The patients were all symptomatic patients who presented to a hip preservation clinic for possible surgery. Thus, the results are limited to more severe patients than would be encountered in the general population of individuals with HD. We did not correlate labral tear lengths with those obtained in surgery due to retrospective assessment and the fact that tears in other hip locations are usually not repaired. Additionally asymptomatic labral tears are not uncommon and other factors which could cause changes in PROMs, such as presence of synovitis and tendon integrity (iliopsoas, gluteal) or timing of labral tear were not considered.

Despite such limitations, this still represents a novel study that delves into the clinical correlations of 3D MRI measurements of a homogeneous population of HD patients. Further studies could examine larger and more heterogenous cohorts of HD to determine the correlation trends among labral tear lengths, hyaline cartilage damage, and PROMs. Future studies may also study the correlation trends between labral tear lengths appreciated through 3D MRI and routinely used radiographic measurements for HD. Such studies can add to the existing literature regarding the usage of 3D MRI in diagnostic and treatment capacities, which can influence the practice of hip preservation.

In conclusion, this study showed that labral tear lengths can be measured on 3D MRI series. Larger labral tears were positively correlated with deteriorating hyaline cartilage and presence of subchondral and para-labral cysts, although worsening joint health was not directly correlated to hip symptomatology.

Conflict of Interest

The authors declare that they have no conflict of interest.

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