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Correlation of Hip Capsule Morphology with Patient Symptoms from Femoroacetabular Impingement

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Abstract

The relationship between morphological characteristics of the hip capsule and patient symptoms in the setting of femoroacetabular impingement (FAI) is undefined. In this study, patients with symptomatic FAI prospectively underwent 3T MRI of the affected hip and completed the Hip disability and Osteoarthritis Outcome Score (HOOS) to determine the correlation between hip capsule anatomy and patient symptoms. Anterior hip capsule volume, posterior capsule volume, anterior-posterior capsule volume ratio, and proximal-distal volume ratio in the anterior capsule were quantified and measured using axial-oblique intermediate-weighted 3D fast spin echo MR images. 35 patients (35 hips) were included for analysis (mean age, 30.6 years; mean body mass index [BMI], 24.9 kg/m2; 57% male). The mean alpha angle was 62.2° ± 4.7°, the mean anterior hip capsule volume was 1705.1 ± 450.3mm^3, the mean posterior hip capsule volume was 1284.8 ± 268.5 mm^3, the mean anterior to posterior capsule volume ratio was 1.1 ± 0.39, and the mean proximal to distal volume ratio of the anterior capsule was 0.65 ± 0.28. There was no correlation between age, gender, or BMI and any hip capsule characteristics. Worse scores on the HOOS pain scale were correlated with increased anterior to posterior volume ratio (r = −0.38; 95% CI, −0.06 to −0.63). In conclusion, hip capsule morphology correlates with patient symptoms in the setting of FAI as increased anterior capsular volume, relative to posterior capsular volume, is associated with greater patient pain.

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Keywords

femoroacetabular impingement; hip capsule; hip arthroscopy; patient symptoms; hip anatomy

Introduction

Femoroacetabular impingement (FAI) is an increasingly recognized cause of hip pain. FAI results from abnormal morphology of the proximal femur and acetabulum, which causes chondral and labral damage and accelerated joint degeneration.[1–3] Surgical management of FAI is often required for symptomatic patients who fail conservative treatment and involves restoring the anatomic relationships between bony and soft tissue structures in the joint. Hip arthroscopy for FAI has been shown to produce significant improvements in pain and function,[4] and there has been a dramatic rise in its utilization for the management of FAI, labral tears, and chondral injuries over the past decade.[5,6]

With this growth in surgical treatment of FAI has come controversy surrounding the management of the hip capsule during arthroscopy. Most surgeons use an interportal capsulotomy, where a transverse incision is made connecting two established arthroscopy portals in the anterior hip capsule.[7] Others perform a T-capsulotomy, which involves an additional longitudinal incision along the length of the femoral neck. This approach is particularly useful in the management of distal cam lesions[8] but may require capsular repair to preserve stability.[9] Another strategy, periportal capsulotomy, involves dilation of established portals without connecting them, which preserves the iliofemoral ligament.[10,11] Despite various theoretical advantages to each of these approaches, there is currently no consensus on proper capsule management for hip arthroscopy.[7]

Of the ligaments comprising the hip capsule, the iliofemoral ligament is the strongest[12] and plays a significant role in hip stability.[13] As such, there is increasing interest in the relationship between hip capsule anatomy and the development and symptomology of FAI. One study suggests the thickness and tension of the iliofemoral ligament may contribute to the development of cam deformities in FAI.[14] Another study demonstrates that increased anterior hip capsule thickness is correlated with decreased range of motion in FAI patients,[15] while a systematic review shows a thinner anterior capsule is associated with clinical hip laxity.[16] Still, relatively little is known about how hip capsule characteristics affect patient-reported outcomes (PRO) scores in FAI, including pain, symptoms, and function. A deeper understanding of this relationship holds the potential to improve surgical planning and management of patients as correlation of hip capsule morphology with patient symptoms can help direct surgical techniques for capsular management such as the type of capsulotomy used for hip arthroscopy access (periportal, interportal, or T-capsulotomy) and whether capsule closure is necessary.[10]

The purpose of this study is to correlate hip capsule morphological characteristics, including volume and thickness, with patient-reported symptoms in a population of FAI patients. We hypothesize that increased anterior hip capsule thickness will be associated with increased pain in patients with FAI.

Methods

Patient Cohort

Patients with symptomatic FAI from the hip preservation center of a single tertiary-referral institution were prospectively enrolled in this Level II cohort analysis,. The study protocol was reviewed and approved by the institutional review board, and written informed consent was obtained prior to enrollment. Age, BMI, and sex were recorded. Patients were eligible for inclusion if they were aged 18 to 50 years, had a BMI < 30 kg/m^2, no radiographic findings of joint space narrowing (Tonnis grade 0 or 1), no radiographic signs for pincer lesions (all patients had lateral center edge angle <40 and no cross-over sign), no signs of joint laxity (Beighton score <4) and were diagnosed with symptomatic cam-type FAI (alpha angle >55 degrees) that was refractory to at least 6 weeks of conservative treatment including activity modification, physical therapy, and/or corticosteroid injections. Patients with abnormal pathology of the femur such as slipped capital femoral epiphysis or Perthes disease were excluded. A cohort of cam-type FAI patients were enrolled to decrease variability in inherent capsule anatomy that may arise from patients with pincer-type FAI, coxa profunda and/or acetabular retroversion.

MR Imaging

All patients underwent preoperative magnetic resonance imaging with standard sequences of the affected hip at the study institution using a 3-Tesla MRI scanner with an 8-channel cardiac coil (GE Healthcare). The imaging protocol included (1.) an isotropic 3D intermediate-weighted fast spin echo (FSE) sequence, which was acquired in the coronal plane, with a voxel size of 0.8×0.8×0.8 mm, a field of view (FOV) of 15.3 cm, echo time (TE) of 60 ms and repetition time (TR) of 2400–3700 ms, and (2.) a coronal 2D fat-suppressed intermediate-weighted FSE sequence with a slice thickness of 4.0mm, a FOV of 18.0 cm, TE of 60 ms, TR of 2400 to 3700 ms, matrix size = 512×512 pixels with a resulting in plane spatial resolution of 0.35×0.35 mm. The isotropic 3D sequence was reconstructed in the oblique axial, axial and sagittal planes with a slice thickness of 4 mm and an in plane spatial resolution of 0.8×0.8 mm resulting in a voxel size 0.8×0.8×4 mm.

Image and Segmentation Analysis

Segmentation analysis was performed using the oblique axial reformations of the intermediate weighted 3D FSE sequence (pixel size 0.8×0.8mm in plane and 4 mm slice thickness) using the Image Processing Package software (IPP, version 6.43.01) developed by Musculoskeletal Quantitative Imaging Research in the Department of Radiology and Biomedical Imaging at the University of California, San Francisco to quantify hip capsule volume. Within IPP, a region of interest (ROI) is manually highlighted and selected. The IPP software is used for segmentation as it quantifies each voxel within the ROI, thereby allowing for volume to be calculated. Three consecutive central slices were identified for each patient centered at the widest diameter of the femoral head on the oblique axial plane for the first slice followed by an adjacent slice superior and an adjacent slice inferior. The total and mean segmentation volume for each series of slices was calculated using the IPP software. Anterior hip capsule volume (Figure 1), posterior hip capsule volume, proximal-distal volume ratio (defined at midpoint) in the anterior hip capsule (Figure 2), anterior-posterior hip capsule volume ratio (Figure 3), as well as alpha angle were measured. Intraclass correlation coefficient (ICC) estimates and 95% confidence intervals were calculated using IBM SPSS Statistics software for intra-rater reliability based on a single rater, consistency, two-way mixed effects model, and inter-rater reliability based on a multiple rater, consistency, two-way mixed effects model. Intra-rater reliability was performed 3 weeks apart on 10 out of 35 patients by a single rater trained by two musculoskeletal radiologists. and found to be 0.915 (CI 0.839–0.955). Inter-rater reliability was performed on 10 samples by two raters trained in the same fashion and found to be 0.922 (CI 0.836–0.963).

Self-Reported Outcomes

Preoperatively, patients completed the Hip disability and Osteoarthritis Outcome Score (HOOS), a valid and reliable measurement of clinical outcomes in patients with FAI.[17] The HOOS was used as it is an in-depth score that provides information on specific functional outcomes after hip surgery and includes 5 subscales: symptoms, pain, activities of daily living (ADL), sport, and quality of life (QOL).[18,19] All data were collected in REDcap (version 7.0.19; Vanderbilt University).

Statistical analysis

A power analysis was performed a priori using data from previous studies correlating patient-reported HOOS results with quantitative MRI findings that demonstrated a sample size of 32 for alpha = 0.05 and beta = 0.80.[20] Correlation analyses were performed to evaluate the association between PRO scores and alpha angle, anterior hip capsule volume, posterior hip capsule volume, anterior to posterior capsular volume ratio and proximal to distal anterior capsular volume ratio. Pearson correlation coefficients (r) were obtained for correlations between continuous variables such as anterior hip capsule volume and PRO scores. All statistical analyses were performed on IBM SPSS Statistics software with significance set to $P < 0.05$. The 95% confidence intervals on all calculated correlations were included.

Results

Patient Cohort

A total of 35 patients (35 hips) were enrolled for the study. The cohort included 20 men (57%) and 15 women (43%). Patient demographics and capsule morphologic characteristics are listed in Table 1, with values +/− standard deviation. There was no correlation between age or BMI and any hip capsule characteristics (Table 2).

Correlation with PRO scores

With respect to PRO scores, lower (worse) scores on the HOOS Pain subscale ($R = -0.38$, $P = 0.02$, CI −0.06 to −0.63) were correlated with increased anterior to posterior capsule volume ratio (Figure 4A and B), which means that a thicker anterior relative to the posterior capsule is related to worse patient pain symptoms (Figure 5). HOOS scores did not demonstrate any significant correlations with anterior hip capsule volume, proximal to distal capsule volume ratio, or alpha angle with respect to all subscales including pain, symptoms, ADL, sports or QOL (Table 2).

Discussion

In FAI, there is an increasing recognition of the hip capsule and the role it may play in disease development and progression.[14,15,21] However, there is a paucity of research investigating its connection with patient symptoms in this population. The purpose of this study was to analyze the relationship between structural hip capsule characteristics and PRO scores in patients with FAI. We found that increased anterior hip capsule volume, relative to posterior hip capsule volume, was associated with increased pain in FAI patients.

The anterior hip capsule is comprised primarily of the iliofemoral ligament, which has been characterized as one of the strongest ligaments in the body. We found that the mean anterior to posterior hip capsule volume ratio in this cohort was nearly 1. However, the range of values for this ratio varied from 0.5 to 2. We also found a weak but statistically significant negative correlation ($R = -0.38$, $P = 0.02$)[22] between pain score and anterior to posterior hip capsule volume indicating that increased thickness of the iliofemoral ligament cause increased pain levels in patients with FAI. Previous studies have shown that, at the femoral head-neck junction, capsular thickness is greatest anterosuperiorly in FAI hips,[21] whereas normal hips are thickest posterosuperiorly.[23] Further, studies have reported that increased thickness of the anterior hip capsule is associated with decreased range of motion in FAI patients[15] and may play a role in the development of cam deformities.[14]

However, since increasing anterior capsule volume in isolation did not demonstrate any correlation with symptoms, it appears that the combination of a thicker anterior capsule with a thinner posterior capsule is the most important factor in patient-reported pain. Although this correlation between pain and anterior to posterior capsule volume is classified as weak, it is a statistically and clinically significant finding that indicates a relationship exists. To our knowledge, capsule morphology has not been correlated with any clinical symptoms in previous research. Prior studies have found an association between FAI and posterior hip instability,[24–26] proposing that interaction between a cam lesion and the anterosuperior acetabulum during hip flexion causes the femoral head to lever out posteriorly, creating subluxation and laxity in the posterior hip capsule. Our findings correlating pain with a thicker anterior and thinner posterior capsule may further substantiate this phenomenon. A thicker anterior hip capsule may exacerbate physical impingement on the labrum and femoral head-neck junction during hip flexion, which may, in turn, cause greater posterior microinstability and result in increased pain, especially in patients with thinner posterior capsules.

There was no correlation between the ratio of proximal to distal volume of the anterior hip capsule and PRO scores. We investigated whether the shape of the anterior hip capsule affected symptoms, as we hypothesized a thicker proximal volume near the labrum may be more symptomatic than a thicker distal volume near the trochanter. However, there was no relationship here, and it appears the overall volume of the anterior capsule relative to the posterior capsule demonstrates the strongest association with patient pain. Moreover, alpha angle did not correlate with any PRO scores. Previous studies have reported an association between higher alpha angles and increased pain in FAI.[27,28] We did not find this correlation in our study, likely because included patients all had large cam lesions with high alpha angles (average 62°, range 55–72°), whereas previous studies included patients with a much broader range of alpha angles.

We also found no correlation between age, gender, or BMI and hip capsule characteristics. Our results are consistent with another study showing no correlation between age and hip capsular thickness.[15] Other reports have shown that in FAI patients, men have thicker capsules than women, particularly anterosuperiorly.[15,21] This observation is likely due to men being generally larger than females as well as the increased prevalence of cam deformity in men.[29–31] All patients in our study had a significant cam deformity, while previous studies included patients with cam or pincer type deformities, which may explain the difference in results.

Our study is subject to several limitations. First, the hip capsule is a dynamic 3-dimensional structure and measuring it with 2-dimensional MRI does not reflect the full morphology of the capsule. We used 3 consecutive axial slices centered on the slice with the widest diameter of the femoral head, which, on standard MRI sequences of the hip, demonstrate the anterior and posterior structures reliably. Segmentation of these slices provide multiple cross-sectional samples of the capsule for volumetric analysis but not the full volume of the capsule. However, emphasis should not be placed on the absolute volume measurements from our study but rather the ratios of volumes (between anterior and posterior and proximal and distal capsule) as these measurements are a better representation of capule morphology. This study also included only cam-type FAI, and it is a goal for future studies to investigate the hip capsule characteristics in pincer-type FAI. Finally, we used a small cohort of 35 patients for this pilot investigation, but it was powered to >80% and we aim to expand on this work in the future. Our study demonstrates the feasibility of this process and provides the groundwork for future research, such as evaluating the effects of different hip arthroscopy techniques, including capsulotomy type and decision to repair capsulotomies, on postoperative hip capsule characteristics and patient outcomes.

Conclusion

Hip capsule morphology correlates with patient symptoms in the setting of FAI. Increased anterior capsular volume, relative to posterior capsular volume, is associated with greater pain in patients with FAI.

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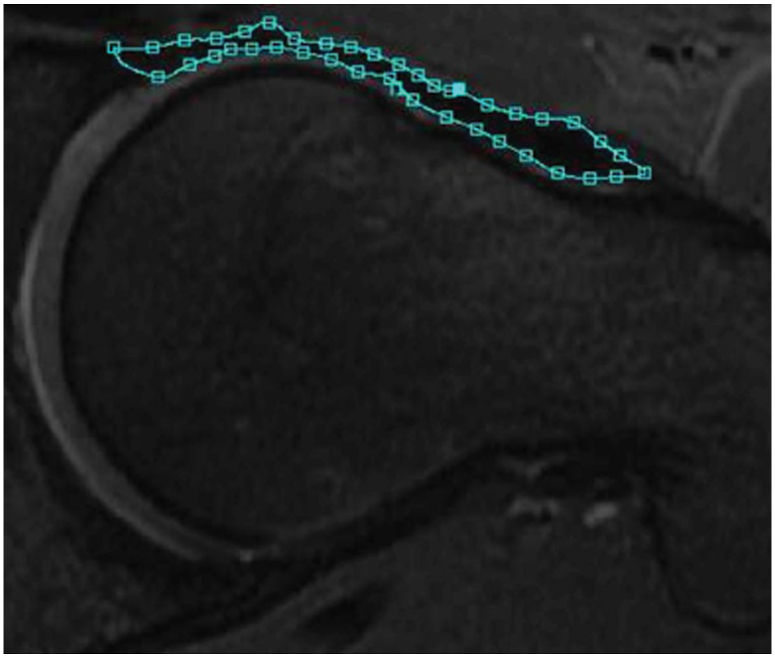

Figure 1:

Total Anterior Hip Capsule Volume Segmentation. Anterior hip capsule segmentation is highlighted with green region of interest (ROI). Volume was calculated from voxels within ROI using IPP software.

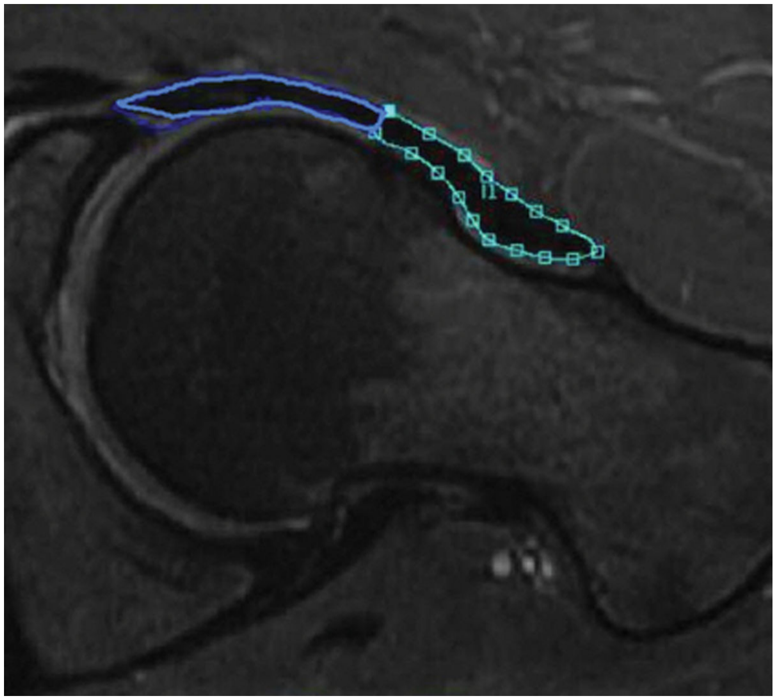

Figure 2:

Proximal-Distal Volume Ratio Segmentation. Proximal anterior hip capsule segmentation is highlighted with blue region of interest (ROI) and distal anterior hip capsule segmentation is highlighted with green region of interest (ROI). Volume was calculated from voxels within ROI using IPP software.

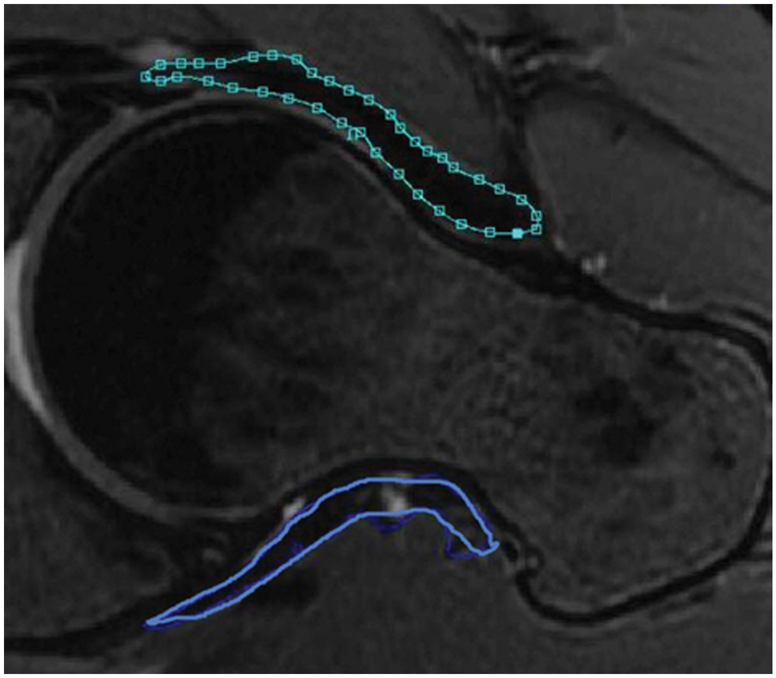

Figure 3:

Anterior-Posterior Hip Capsule Volume Ratio Segmentation. Anterior hip capsule segmentation is highlighted with green region of interest (ROI) and posterior hip capsule segmentation is highlighted with blue ROI. Volume was calculated from voxels within ROI using IPP software.

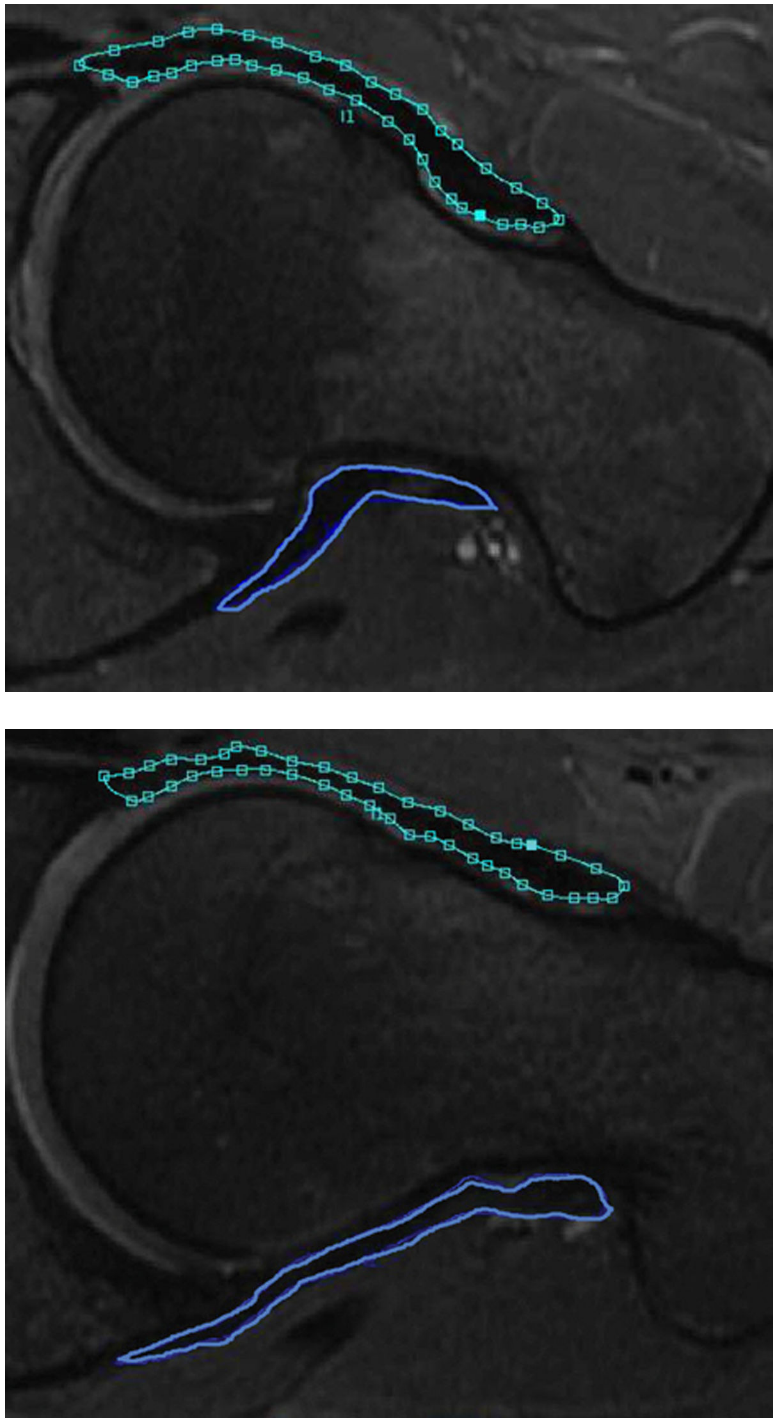

Figure 4:

A) MRI of Higher Anterior-Posterior Hip Capsule Volume Ratio. Anterior hip capsule segmentation is highlighted with green region of interest (ROI) and posterior hip capsule segmentation is highlighted with blue ROI. Ratio of anterior-posterior capsule volume is 1.96. B) MRI of Lower Anterior-Posterior Hip Capsule Volume Ratio. Anterior hip capsule segmentation is highlighted with green region of interest (ROI) and posterior hip capsule segmentation is highlighted with blue ROI. Ratio of anterior-posterior capsule volume is 0.87.

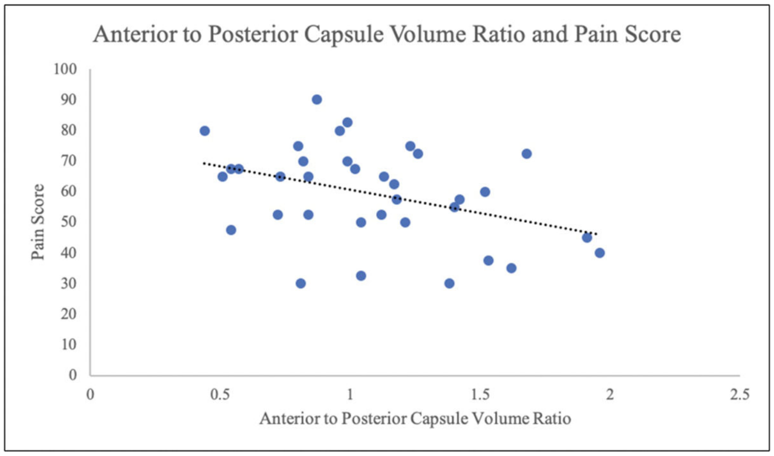

Figure 5:

Anterior-Posterior Hip Capsule Volume Ratio and HOOS Pain Score Correlation. Lower scores on the HOOS Pain subscale were correlated with increased anterior to posterior capsule volume ratio (R = −0.38, P = 0.02, CI −0.06 to −0.63).

Table 1

Demographics and Characteristics (N = 35 Patients)

Age, y	30.6 ± 6.0
BMI, kg/m^2	24.9 ± 3.2
Male, %	57%
Mean Tonnis Grade	0
Alpha Angle	62.2° ± 4.7°
Anterior Hip Capsule Volume (mm^3)	1705.1 ± 450.3
Posterior Hip Capsule Volume (mm^3)	1284.8 ± 268.5
Anterior-Posterior Volume Ratio	1.1 ± 0.39
Proximal-Distal Volume Ratio in Anterior Capsule	0.65 ± 0.28

Table 2

Correlations with Patient-Reported Outcome Scores[1,2]

	Age		BMI		HOOS Pain		HOOS Symptoms		HOOS ADL		HOOS Sports		HOOS QOL	
	r/ρ	**P**	**r/ρ**	**P**	**r/ρ**	**P**	**r/ρ**	**P**	**r/ρ**	**P**	**r/ρ**	**P**	**r/ρ**	**P**
Alpha angle	0.04 (−0.30 to 0.37)	0.82	−0.09 (−0.44 to 0.29)	0.66	0.06 (−0.28 to 0.38)	0.74	−0.06 (−0.38 to 0.28)	0.74	0.03 (−0.31 to 0.36)	0.88	−0.09 (−0.41 to 0.25)	0.59	−0.18 (−0.48 to 0.16)	0.30
Anterior Capsule Volume	0.36 (−0.07 to 0.68)	0.10	−0.24 (0.63 to 0.26)	0.34	−0.25 (−0.61 to 0.19)	0.27	0.21 (−0.23 to 0.58)	0.34	−0.24 (−0.60 to 0.21)	0.29	−0.19 (−0.56 to 0.26)	0.41	−0.06 (−0.47 to 0.37)	0.78
Posterior Capsule Volume	−0.02 (−0.55 to 0.51)	0.93	−0.12 (−0.61 to 0.44)	0.69	0.48 (−0.07 to 0.81)	0.08	0.37 (−0.20 to 0.75)	0.20	0.42 (−0.14 to 0.78)	0.13	0.17 (−0.40 to 0.64)	0.57	−0.23 (−0.68 to 0.34)	0.43
Anterior to Posterior Capsule Volume Ratio	0.23 (−0.11 to 0.52)	0.18	−0.03 (−0.39 to 0.34)	0.87	**−0.38 (−0.63 to −0.06)**	**0.02**	−0.03 (−0.36 to 0.30)	0.85	−0.20 (−0.50 to 0.14)	0.25	−0.18 (−0.48 to 0.16)	0.30	0.07 (−0.27 to 0.40)	0.67
Anterior Capsule Proximal to Distal Volume Ratio	−0.05 (−0.43 to 0.35)	0.82	0.03 (−0.40 to 0.46)	0.89	−0.14 (−0.51 to 0.27)	0.50	−0.15 (−0.52 to 0.26)	0.46	−0.31 (−0.63 to 0.09)	0.13	−0.25 (−0.59 to 0.16)	0.23	−0.005 (−0.40 to 0.39)	0.98

[1] 95% CI in parentheses. ADL, Activities of Daily Living; BMI, body mass index; HOOS, Hip disability and Osteoarthritis Outcome Score; QOL, Quality of Life.

[2] Lower scores on the HOOS indicate worse outcomes.