Original Article

Magnetic Resonance Imaging and Magnetic Resonance Arthrography Are Both Reliable and Similar When Measuring Hip Capsule Thickness in Patients With Femoroacetabular Impingement Syndrome

Devin L. Froerer, B.S., Ameen Z. Khalil, M.S., Allan K. Metz, M.D., Reece M. Rosenthal, B.S., Joseph Featherall, M.D., Travis G. Maak, M.D., and Stephen K. Aoki, M.D.

Purpose: To propose an accurate method of measuring hip capsular thickness in patients with femoroacetabular impingement syndrome and to compare the reliability of these measurements between magnetic resonance imaging (MRI) and magnetic resonance arthrography (MRA). **Methods:** A previously established database of patients with femoroacetabular impingement syndrome (FAIS) was used to identify candidates with preoperative MRI or MRA from November 2018 to June 2021. Two reviewers independently examined preoperative imaging for 85 patients. Capsular thickness was measured in 12 standardized locations. Intraclass correlation coefficients (ICCs) were calculated using an absolute-agreement, 2-way random-effects model. Using the same method, 30 patients were randomly selected for repeat measurements by 1 reviewer following a washout period. Ten additional patients with preoperative MRI and MRA of the same hip were identified to compare measurements between modalities using paired samples *t* test. **Results:** ICCs for measurements on MRIs and MRAs using these proposed measurements to compare inter-rater reliability were 0.981 and 0.985. ICCs calculated using measurements by a single reviewer following a washout period for intrarater reliability were 0.998 and 0.991. When comparing MRI and MRA measurements in the same patient, *t* test for all pooled measurements found no difference between modality ($P = .283$), and breakdown of measurements by quadrant found no difference in measurements ($P > .05$), with the exception of the inferior aspect of the capsule on coronal sequences ($P = .023$). **Conclusions:** In patients with FAIS, both MRI and MRA have excellent reliability for quantifying hip capsular thickness. A difference in capsular thickness was found only when comparing MRI and MRA on inferior coronal aspects of the hip capsule, indicating interchangeability of these imaging modalities when measuring the clinically important aspects of the hip capsule. **Level of Evidence:** Level IV, diagnostic case series.

There has been an increased emphasis on understanding the role that the hip capsule makes to the overall biomechanical stability of the hip joint.[1] This is driven in part by an increased recognition that certain pathologies, such as joint instability, hyperlaxity, and residual hip pain following arthroscopy, may be attributable to hip capsular insufficiency.[2-4] Although the hip joint is thought to derive inherent stability from the articulation of the acetabulum and the femoral head, the capsule and surrounding soft tissues are essential to stability.[5-7]

Evidence suggests that even small changes or defects in the fibrous hip capsule have large implications on hip stability.[8,9] Studies have helped to support the idea that the hip capsule not only helps to contribute to overall joint stability but that defects, iatrogenic or anatomic,

From the School of Medicine, University of Utah, Salt Lake City, Utah, U.S.A. (D.L.F.) and Department of Orthopaedics, University of Utah, Salt Lake City, Utah, U.S.A. (A.Z.K., A.K.M., R.M.R., J.F., T.G.M., S.K.A.).

Received July 27, 2023; accepted December 19, 2023.

Address correspondence to Stephen K. Aoki, M.D., Department of Orthopaedics, 590 Wakara Way, Salt Lake City, UT 84108, U.S.A. E-mail: stephen.aoki@hsc.utah.edu

2666-061X/231056
https://doi.org/10.1016/j.asmr.2023.100874

may contribute to poor outcomes in patients.[4,10,11] In a study by Magerkurth et al.,[12] thinner joint capsules were shown to have increased joint laxity, demonstrating that the capsule contributes to hip stability.[6] A study by Shaw et al.[13] found increased pain following surgery for femoroacetabular impingement syndrome (FAIS) in patients with thicker hip capsules. A study by Packer et al.[3] demonstrated female patients and thinner hip capsules were associated with increased joint laxity. Other recent studies have demonstrated that thinner hip capsules tend toward greater laxity and may be at an increased risk for instability.[14] Despite advancements in our understanding of the hip capsule anatomy and biomechanics, there lacks consensus regarding the optimal method for measurement of hip capsule parameters on magnetic resonance imaging (MRI). In each of the aforementioned studies, a different method was used to measure and quantify hip capsular thickness on MRI. Few of these metrics have been validated for internal consistency, and few of these metrics use more advanced studies such as magnetic resonance arthrography (MRA). Without consistent, internally validated measurement systems, it is difficult to review and draw conclusions from the literature as it is unclear whether the methodology of these studies is comparable.

The purposes of this study were to propose an accurate method of measuring hip capsular thickness in patients with FAIS and to compare the reliability of these measurements between MRI and MRA. The authors hypothesized there will be no significant difference in capsular thickness measurements using the proposed methodology between MRI and MRA.

Methods

Measurement Development Cohort

A previously generated database of patients diagnosed with FAIS was retrospectively reviewed following institutional review board (#00055341) approval. This cohort was initially identified by querying all surgical cases performed by the senior author (S.K.A.). A chart review was conducted, and patients with FAIS, diagnosed as an alpha angle greater than 55°, were identified for databased inclusion. This database solely comprised patients who underwent surgical intervention by the senior author, a fellowship-trained hip arthroscopist, for the treatment of FAIS from November 2018 to June 2021. Using a random-number generator, 85 patients were selected at random for inclusion. Inclusion criteria were (1) diagnosis of FAIS and subsequent treatment with arthroscopy and (2) preoperative MRI or MRA. Exclusion criteria were (1) any history of surgery in the measured hip and (2) contrast extravasation on MRA.

MRI and MRA Direct Comparison Cohort

A separate database of all patients who had hip arthroscopic procedures by the senior author from November 2018 to September 2022 was queried to identify patients who had both MRI and MRA performed on the same hip. This cohort of 10 patients was used for the portion of the study directly comparing measurements between imaging modalities. Exclusion criteria for this subset of patients included (1) surgical intervention between the dates of the MRI and MRA and (2) contrast extravasation on MRA.

Hip Capsule Measurements

All measurements were conducted in a blinded fashion by 2 trained medical students (A.K.M., D.L.F.). Measurements were performed through the institution's Picture Archive and Communication System (PACS) (Intellispace; Philips). In all cases, 3.0 Tesla, T2-weighted images from MRI or MRA studies were used for measurement to allow for standardization between patients. Additionally, all measurements on both the coronal and axial slices were made on the cross-sectional image slice with the largest femoral head diameter to ensure accurate cross-sectioning of the capsule, using a previously established methodology.[11] Measurement locations for the hip capsular thickness were selected to approximate the 3 ligaments that comprise the hip capsule: the iliofemoral, ischiofemoral, and pubofemoral ligaments. Six measurements were taken on coronal sequences, with 3 taken on the superior (S) and 3 on the inferior (I) aspect of the capsule. Both superiorly and inferiorly, the thickness of the capsule was measured immediately proximal to the zona orbicularis (S-ZO, I-ZO), at the level of the acetabular labrum (S-AL, I-AL), and at the midpoint between these 2 points (S-M, I-M). Measurements were taken in a similar fashion in the axial plane with 3 measurements made on both the anterior (A) and posterior (P) aspects of the capsule. In this case, the capsular thickness was measured immediately medial to the zona orbicularis (A-ZO, P-ZO), at the acetabular labrum (A-AL, P-AL), and a point between the previous two (A-M, P-M; Figs 1 and 2). All 12 measurements were on each of the 85 patients. Additionally, to assess intrarater reliability of this measurement protocol, 30 patients were randomly selected from the initial 85 selected patients for repeat measurement by a single reviewer (D.L.F.) following a 2-week washout period.

MRI and MRA Direct Comparison Measurements

A single reviewer (D.L.F.) was used for the measurements on patients whose chart contained both MRI and MRA with no surgical intervention between collection, using the same 12 measurement methods described above.

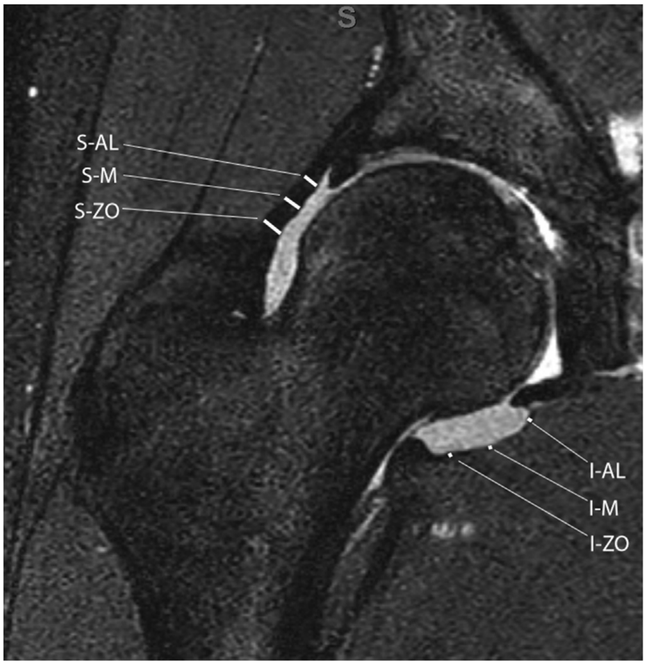

Fig 1. Measurements on T2-weighted axial images of a left hip on magnetic resonance imaging. Measurements were made on the cross-sectional image with the largest femoral head diameter to ensure accurate cross-sectioning of the capsule. (A-AL, anterior acetabular labrum; A-M, anterior midpoint; A-ZO, anterior zona orbicularis; P-AL, posterior acetabular labrum; P-M, posterior midpoint; P-ZO, posterior zona orbicularis.)

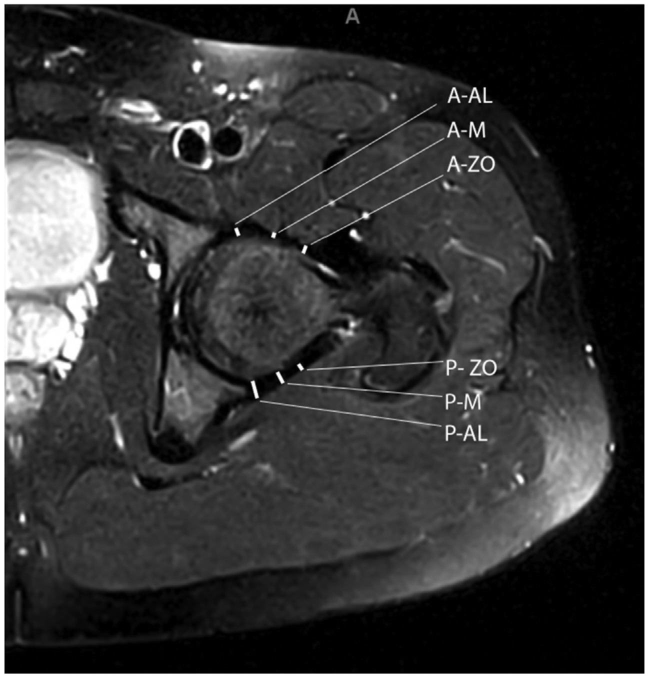

Fig 2. Measurements on T2-weighted coronal images of a right hip on a magnetic resonance arthrogram. Measurements were made on the cross-sectional image with the largest femoral head diameter to ensure accurate cross-sectioning of the capsule. (I-AL, inferior acetabular labrum; I-M, inferior midpoint; I-ZO, inferior zona orbicularis; S-AL, superior acetabular labrum; S-M, superior midpoint; S-ZO, superior zona orbicularis.)

Reliability Analysis

A reliability analysis was conducted for the 12 capsular measurements described above using an absolute-agreement, 2-way random-effects model to generate intraclass correlation coefficients (ICCs). In the first reliability analysis, comparisons between values measured by each reviewer were made to assess inter-rater reliability. A second reliability analysis was then used for the 30 patients selected for remeasurement. The measurements taken after the washout period were then compared to initial measurements by the same reviewer to assess intrarater reliability. Based on previously established guidelines, ICC values of 0.91 to 1.00 were considered "excellent" agreement, while values of 0.76 to 0.90, 0.51 to 0.75, and 0.00 to 0.50 were considered "good," "moderate," and "poor" agreement, respectively.[15] Given the small sample size available of patients who had both MRI and MRA without surgical intervention between these 2 imaging modalities, a post hoc power analysis was also conducted to determine the cohort size that would be necessary to show a difference between these modalities. All analysis was carried out using Microsoft Excel version 16.54 and SPSS version 29 (IBM).

Paired Samples *t* Test

Comparison of measurements made between MRI and MRA within the same patient was accomplished via a paired samples, 2-sided *t* test to compare the differences between the measurements. This test was used for a pooled comparison of the measurements. Additional paired *t* tests were then used for analysis of the measurements split up by quadrant (superior coronal, inferior coronal, anterior axial, posterior axial) for a total of 4 additional paired *t* tests.

Results

The electronic medical records of 85 patients and their advanced imaging were assessed. Of these 85 patients, 43 had preoperative MRIs, and 42 had preoperative MRAs. Of the patients with an MRA, 5 patients were excluded because of contrast extravasation (Fig 3). Mean patient age was 30.6 ± 11.9 years, and mean body mass index was 25.6 ± 4.9. Fifty-six of the 85 selected patients were female (70%).

The mean values for all measurements by both reviewers was calculated and is within Table 1. Between the 2 blinded reviewers, the mean inter-rater ICC value for all 12 measurements made was 0.981 (95% CI,

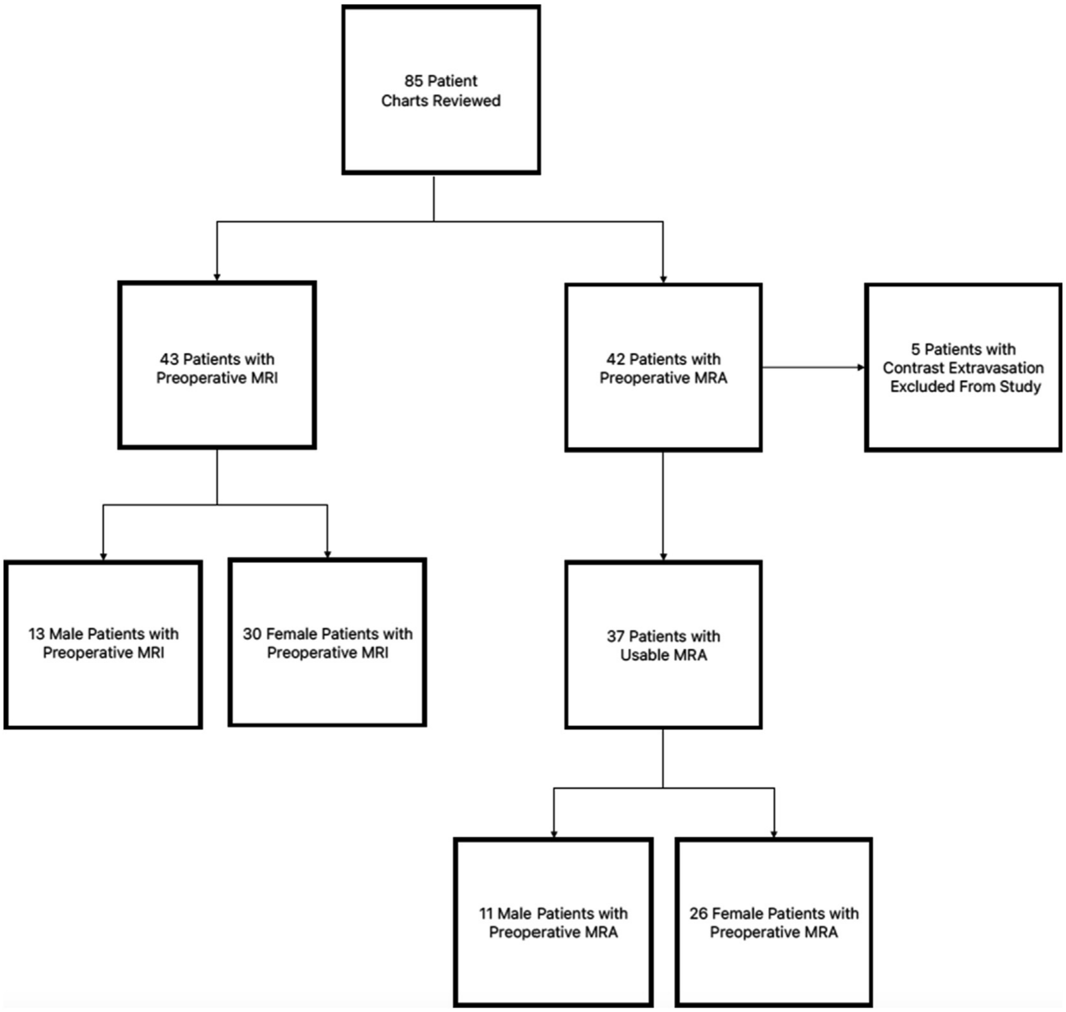

Fig 3. Flow diagram showing application of inclusion and exclusion criteria for the selection of patients for inter-rater reliability calculations.

0.978-0.984) for MRI and 0.985 (95% CI, 0.982-0.987) for MRA. The averaged intrarater ICC was 0.988 (95% CI, 0.984-0.991) for MRI and 0.991 (95% CI, 0.988-0.994) for MRA. On inter-rater reliability analysis, 11 of 12 (92%) measurements were assessed as having excellent agreement using both MRI and MRA. One measurement, measured at the midpoint of the inferior capsule in the coronal plane (I-M), was found to have good agreement using both imaging modalities. For the ICC values calculated to represent intrarater reliability, all MRI measurements and 11 of 12 (92%) of MRA measurements were assessed as having excellent agreement. The inferior capsule measured at the acetabular labrum in the coronal plane (I-AL) using MRA was determined to have good agreement. Specific ICC values for each measurement made are reported in Table 2 and Table 3.

During database query to identify patients who had both MRI and MRA to compare these modalities, no patients with native hips were identified. The query was expanded to included revision hip arthroscopy patients within this database, which identified 127 patients with both MRI and MRA within our home institution's PACS system. Of these, 10 patients in total were identified who had no surgical instrumentation of the hip of interest during the interval between MRI and MRA. Capsular measurements were made on these 10 patients, for a total of 240 measurements. For all measurements pooled, a P value was calculated at .283. Pooled measurements for the measurements on the axial sequences on the anterior side were found to have a P value of .267, and posterior side had a P value of .723. For coronal sequences, superior measurements pooled had a P value of .536, and inferior side had a P value of .023 (Table 4). A power analysis was conducted in SPSS to determine the cohort size that would be necessary to determine a difference. Due to the lack of literature comparing capsular thickness measurements between MRI and MRA, a mean difference of 1 mm was selected as a value that would be

Table 1. Mean Values of All Measurements Made by Both Reviewers Using Both Imaging Modalities

Measurement Location	Reviewer 1 MRI (mm)	Reviewer 2 MRI (mm)	Reviewer 1 MRA (mm)	Reviewer 2 MRA (mm)
Superior coronal: zona orbicularis	3.61	3.62	3.43	3.51
Superior coronal: midpoint	2.90	2.99	2.97	3.07
Superior coronal: acetabular labrum	3.60	3.60	2.73	2.73
Inferior coronal: zona orbicularis	2.04	2.06	1.55	1.54
Inferior coronal: midpoint	1.71	1.90	1.26	1.29
Inferior coronal: acetabular labrum	1.95	1.96	1.39	1.34
Anterior axial: zona orbicularis	3.59	3.57	3.28	3.21
Anterior axial: midpoint	2.34	2.42	2.35	2.42
Anterior axial: acetabular labrum	2.80	2.76	2.51	2.51
Posterior axial: zona orbicularis	1.90	1.90	1.58	1.55
Posterior axial: midpoint	1.66	1.70	1.49	1.51
Posterior axial: acetabular labrum	1.79	1.87	1.53	1.54

NOTE. These average values were calculated from the group of measurements used to calculate the intraclass correlation coefficients in this study. The measurements of the 43 patients were averaged for each measurement in the magnetic resonance imaging columns, and those of the 37 magnetic resonance arthrograms were averaged in the other columns.

significant between these 2 modalities. Using a standard power of 0.8, a required sample size of 18 was found as the total sample size needed for sufficient power.

Discussion

The proposed 12-measurement protocol for capsular thickness was found to be reliable, with no statistically significant differences between measurements taken on MRI and MRA across 2 blinded reviewers. Additionally, this study demonstrates interchangeability of these measurements between MRI and MRA on the clinically important aspects of the hip capsule, namely, the iliofemoral ligament.

This measurement strategy allows for a more consistent quantification of the hip capsule than has been shown in previous work.[16,17] Repeatable measurement protocols of hip capsule thickness are increasingly important as the focus on the hip capsule continues to rise. Our findings demonstrate an opportunity for future standardization of hip capsule measurements on advanced imaging studies. Clinically, the findings of this study allows for reassurance to providers that either MRI or MRA may be used to measure capsular thickness. This study's methodology may provide a standard for future work in this area and would allow for an increased ease of comparison across studies.

In this study, it has been demonstrated that measurements taken on the portion of the hip capsule on inferior coronal sequences were found to have a lower level of agreement both between reviewers and with the same reviewer. The inferior capsule is the thinnest region of the hip capsule and was the most difficult area to identify the exact capsular tissue borders. Additionally, these measurements may be affected by the known volume average effects that are often seen on thin structures on MRI.[18] However, even with the small size of the measured portion of the capsule and possible interference, all measurements within this study have correlation coefficients that are considered good or better in both intrarater and inter-rater reliability. Notably, this portion of the hip capsule was found to be the only area when comparing the interchangeability of MRI and MRA within the same patient to have statistically significant differences in their measurements, adding evidence to the difficulty of measuring the inferior capsule.

In a study by Metz et al.[14] in 2022, hip capsular thickness was measured on MRI in a similar manner as in this study and established a correlation between reduced capsular thickness and increased joint distratibilty. Our methodology expanded on their original study, collecting more hip capsule data through the 12-point, anatomic method on both MRI and MRA. These additional points data can provide greater insight on the integrity and thickness of these hip-stabilizing ligamentous structures. Our results demonstrate that the proposed 12 measurements are not only usable in both imaging modalities but also repeatable, reliable, and interchangeable for hip capsular thickness quantification. This is highly clinically relevant from a resource allocation and cost-benefit perspective when deciding what imaging study to order for an individual patient. MRA is an invasive procedure with greater complication potential vs MRI, with greater resource allocation and associated costs.[19] That said, if a surgeon wishes to examine the thickness of a patient's hip capsule, either MRI or MRA may be used.

In a study by Packer et al.[3] in 2020, they used MRA to quantify hip capsular thickness. Their method for measuring the capsule was done at the level of the capsular attachment at the greater trochanter, and in addition to hip capsular thickness, they also measured

Table 2. Calculations for Interrater Reliability Using an Absolute-Agreement, 2-Way Random Effects Model to Generate Interclass Correlation Coefficients

Two Reviewers/ Measurement Location	ICC Values	
	MRI (95% CI)	MRA (95% CI)
Coronal: superior zona orbicularis (S-ZO)	0.990 (0.982-0.995)	0.992 (0.982-0.996)
Coronal: superior acetabular labrum (S-AL)	0.989 (0.980-0.994)	0.991 (0.983-0.996)
Coronal: superior mid (S-M)	0.957 (0.922-0.977)	0.979 (0.957-0.989)
Coronal: inferior zona orbicularis (I-ZO)	0.985 (0.973-0.992)	0.927 (0.862-0.962)
Coronal: inferior acetabular labrum (I-AL)	0.980 (0.964-0.989)	0.951 (.905-0.975)
Coronal: inferior mid (I-M)	0.889* (0.803-0.939)	0.869* (0.761-0.930)
Axial: anterior zona orbicularis (A-ZO)	0.990 (0.982-0.995)	0.968 (0.940-0.984)
Axial: anterior acetabular labrum (A-AL)	0.988 (0.977-0.993)	0.989 (0.978-0.994)
Axial: anterior mid (A-M)	0.913 (0.846-0.952)	0.977 (0.954-0.989)
Axial: posterior zona orbicularis (P-ZO)	0.978 (0.960-0.988)	0.984 (0.970-0.992)
Axial: posterior acetabular labrum (P-AL)	0.944 (0.896-0.970)	0.983 (0.967-0.991)
Axial: posterior mid (P-M)	0.948 (0.907-0.972)	0.901 (0.816-0.948)
Total: all measurements	0.981 (0.978-0.984)	0.985 (0.982-0.987)

ICC, intraclass correlation coefficient; MRA, magnetic resonance arthrography; MRI, magnetic resonance imaging.
*Values <0.9.

Table 3. Calculated Values for Intra-Rater Reliability Using an Absolute-Agreement, 2-Way Random Effects Model to Generate Intraclass Correlation Values

Single Reviewer/ Measurement Location	ICC Values	
	MRI (95% CI)	MRA (95% CI)
Coronal: superior zona orbicularis (S-ZO)	0.995 (0.987-0.998)	0.991 (0.974-0.997)
Coronal: superior acetabular labrum (S-AL)	0.995 (0.986-0.998)	0.994 (0.977-0.998)
Coronal: superior mid (S-M)	0.976 (0.930-0.992)	0.979 (0.939-0.993)
Coronal: inferior zona orbicularis (I-ZO)	0.948 (0.856-0.982)	0.926 (0.799-0.974)
Coronal: inferior acetabular labrum (I-AL)	0.957 (0.878-0.985)	0.897* (0.727-0.964)
Coronal: inferior mid (I-M)	0.954 (0.870-0.984)	0.925 (0.662-0.978)
Axial: anterior zona orbicularis (A-ZO)	0.997 (0.992-0.999)	0.994 (0.982-0.998)
Axial: anterior acetabular labrum (A-AL)	0.992 (0.969-0.998)	0.986 (0.960-0.995)
Axial: anterior mid (A-M)	0.980 (0.942-0.993)	0.971 (0.918-0.990)
Axial: posterior zona orbicularis (P-ZO)	0.971 (0.908-0.990)	0.992 (0.976-0.997)
Axial: posterior acetabular labrum (P-AL)	0.971 (0.917-0.990)	0.977 (0.933-0.992)
Axial: posterior mid (P-M)	0.963 (0.895-0.987)	0.975 (0.929-0.992)
Total: all measurements	0.988 (0.984-0.991)	0.991 (0.988-0.994)

NOTE. The measurements used were generated by a single reviewer following a 2-week washout period.
ICC, intraclass correlation coefficient; MRA, magnetic resonance arthrography; MRI, magnetic resonance imaging.
*Values <0.9.

the anterior joint recess. Using this method for measurement, they demonstrated that in female patients, there was an increase in intraoperative laxity in women with thinner hip capsules compared to those with thicker hip capsules. The point of measurement in their study is most similar to our measurement taken at the level of the zona orbicularis on axial sections in the current study (A-ZO).

In 2022, Bai et al.[16] performed a study comparing hip capsular thickness between MRI and intraoperative hip capsule measurements. In their study, oblique-sagittal planes were used to approximate the thickness of the anterior hip capsule. Intraoperative measurements of the iliofemoral ligament were taken using a standardized hook probe at the midpoint of this ligament. Correlation coefficients using their method for both intrarater and inter-rater reliability were also calculated and were found to be similar to the ones calculated in this current study, with intrarater reliability being considered in excellent agreement and inter-rater being considered good for their measurements. Although their study does show a repeatable way of measuring the hip capsule, this study was limited to measuring the capsule in 1 location. The measurement that Bai et al.[16] calculated on MRIs was most similar in location to the measurement taken on coronal sequences at the midpoint between the acetabular labrum and zona orbicularis (C-M).

While this current study has provided evidence to the interchangeability of MRI and MRA in quantifying hip capsular thickness, there are pros and cons to each of these imaging modalities that warrant discussion.

Table 4. Results of Paired Samples *t* test Comparing Measurements Made on Patients With Both MRI and MRA With No Surgical Instrumentation of the Hip Between the Acquisition of These Images

Pooled Measurements	Paired Samples 2-Sided *t* Test *P* Value
Superior coronal	.536
Inferior coronal	.023*
Anterior axial	.267
Posterior axial	.723
All measurements	.283

NOTE. Ten patients in total were identified, totaling 240 measurements. Measurements were pooled within each quadrant (30 per quadrant per modality) and magnetic resonance imaging and magnetic resonance arthrography measurements were directly compared.

*Indicates statistical significance.

Studies performed in the past have demonstrated that MRA is more sensitive in diagnosing capsular defects than MRI when looking at preoperative imaging compared to intraoperative findings.[20] Other studies have also shown that MRA is the modality of choice for the identification of labral tears, cartilaginous lesions, and intra-articular foreign bodies.[21,22] Additionally, MRA has also been shown to be effective in assessing intracapsular volume, which is not possible in MRI alone.[23] These differences demonstrate a significant advantage of MRA when compared to MRI if the surgeon is interested in these specific findings. However, other studies have demonstrated that MRA is not only more expensive than MRI, but also that side effects such as joint pain, swelling, fatigue, and headaches are also common complications of this invasive procedure.[19,20,24]

There are few situations within clinical medicine that would warrant obtaining both MRI and MRA within the same patient for surgical planning. In this current study, following a careful query of the past 5 years of all revision hip arthroscopic patients seen by the senior author, 127 patients were identified whose medical records contained both MRI and MRA. However, several studies, such as in 2022 by Nguyen et al.,[25] have demonstrated that there are postoperative changes to the hip capsule, including decreases in hip capsular thickness, making a direct comparison between these modalities separated by surgical instrumentation of the hip unfeasible. That said, considering the clinical importance of capsular thickness and integrity in the revision setting, using the proposed 12-point measurement protocol on either modality in the future may provide additional clinical insight and decision-making.

Limitations

Several limitations exist within this current study. First, the PACS system used for this study had several technological limitations when it came to creating small, precise measurements. When measuring capsular thickness on the studies, the software does not measure at 0.1-mm increments. For instance, when measuring a portion of the capsule with a thickness less than 1 mm, the software would only allow 4 discrete numbers below 1 mm in thickness. While many aspects of the hip capsule are in fact frequently larger than 1 mm, it is worth mentioning that many of these measurements made were at the nearest 0.1-mm measurement allowed by the PACS software, which may have artificially inflated our correlation coefficient values. However, this is a similar PACS system that is used throughout clinical orthopaedics, so we believe our results to still be pertinent to clinical practice. Second, our study cohort was restricted to patients who underwent surgical intervention and did not include patients who were treated conservatively. Given this, we attempted to identify patients who had both MRI and MRA prior to any surgical violation of the capsular tissue to compare whether capsular measurements were similar between the 2 modalities. Unfortunately, we were only able to identify MRI and MRA studies in revision hip arthroscopy patients. In these patients, the MRI and MRA were obtained between the original surgical intervention and the revision surgery. While not ideal, we were still able to demonstrate similar capsular measurements on the 2 modalities. Additionally, our cohort was primarily composed of female patients. Although this accurately represents the demographic breakdown of patients treated by the senior author, having an even distribution of male and female patients may reveal additional differences. Next, due to the lack of indications for patients to obtain both MRI and MRA of the same hip without surgical intervention in between, the measurements for direct comparison of these imaging modalities were underpowered. While the cohort used had a sample size of 10, our power analysis indicated a sample size of 18 was necessary to truly demonstrate a difference between MRI and MRA. Given the lack of statistical significance among our measured results and the difficulty in finding patients with multiple imaging studies that are not clinically indicated, we believe the results of the present study are still meaningful. Finally, our 12-point capsular thickness measurement protocol only demonstrates that measuring the capsule in these areas is reliable, reproducible, and comparable on MRI and MRA. We do not make any clinical inferences in this study and do not know if all of the regions are clinically important to measure. Future studies can focus on identifying the capsular regions that are the most clinically important.

Conclusions

In patients with FAIS, both MRI and MRA have excellent reliability for quantifying hip capsular thickness. A difference in capsular thickness was found only when comparing MRI and MRA on inferior coronal aspects of the hip capsule, indicating interchangeability of these imaging modalities when measuring the clinically important aspects of the hip capsule.

Disclosure

The authors report the following potential conflicts of interest or sources of funding: T.G.M. reports a relationship with Arthrex that includes consulting or advisory and speaking and lecture fees and is on the CORR Editorial Board. S.K.A. reports a relationship with Stryker Corporation that includes consulting or advisory. All other authors (D.L.F., A.Z.K., A.K.M., R.M.R., J.F.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

References

1. Ng KCG, Jeffers JRT, Beaulé PE. Hip joint capsular anatomy, mechanics, and surgical management. *J Bone Joint Surg Am* 2019;101:2141-2151. doi:10.2106/JBJS.19.00346.
2. Safran MR. Microinstability of the hip—Gaining acceptance. *J Am Acad Orthop Surg* 2019;27:12-22. doi:10.5435/JAAOS-D-17-00664.
3. Packer JD, Foster MJ, Riley GM, et al. Capsular thinning on magnetic resonance arthrography is associated with intra-operative hip joint laxity in women. *J Hip Preserv Surg* 2020;7:298-304. doi:10.1093/jhps/hnaa018.
4. Mortensen AJ, Metz AK, Froerer DL, Aoki SK. Hip capsular deficiency—A cause of post-surgical instability in the revision setting following hip arthroscopy for femoroacetabular impingement. *Curr Rev Musculoskelet Med* 2021;14:351-360. doi:10.1007/s12178-021-09732-5.
5. Elkins JM, Stroud NJ, Rudert MJ, et al. The capsule's contribution to total hip construct stability—A finite element analysis. *J Orthop Res* 2011;29:1642-1648. doi:10.1002/jor.21435.
6. Wagner FVM, Negrao JRM, Campos JM, et al. Capsular ligaments of the hip: Anatomic, histologic, and positional study in cadaveric specimens with MR arthrography. *Radiology* 2012;263:189-198. doi:10.1148/radiol.
7. Ranawat AS, Sekiya JK. Arthroscopic capsular plication and thermal capsulorrhaphy. In: Sekiya JK, Ranawat AS, Safran MR, Leunig M, eds. *Techniques in Hip Arthroscopy and Joint Preservation Surgery*. Vol. 26. 3rd ed. Philadelphia, PA: Elsevier, 2011;131-138.
8. O'Neill DC, Tomasevich KM, Mortensen AJ, Featherall J, Ohlsen SM, Aoki SK. Capsular repair during hip arthroscopy demonstrates restoration of axial distraction resistance in an in vivo intraoperative testing model. *J Bone Joint Surg Am* 2021;103:1977-1985. doi:10.2106/JBJS.20.01932.
9. Kemp JL, Collins NJ, Roos EM, Crossley KM. Psychometric properties of patient-reported outcome measures for hip arthroscopic surgery. *Am J Sports Med* 2013;41:2065-2073. doi:10.1177/0363546513494173.
10. Day M, Westermann R, Duchman K, et al. Comparison of short-term complications after rotator cuff repair: Open versus arthroscopic. *Arthroscopy* 2018;34:1130-1136. doi:10.1016/j.arthro.2017.10.027.
11. Hoppe DJ, Truntzer JN, Shapiro LM, Abrams GD, Safran MR. Diagnostic accuracy of 3 physical examination tests in the assessment of hip microinstability. *Orthop J Sports Med* 2017;5:1-6. doi:10.1177/2325967117740121.
12. Magerkurth O, Jacobson JA, Morag Y, Caoili E, Fessell D, Sekiya JK. Capsular laxity of the hip: Findings at magnetic resonance arthrography. *Arthroscopy* 2013;29:1615-1622. doi:10.1016/j.arthro.2013.07.261.
13. Shaw C, Warwick H, Nguyen KH, et al. Correlation of hip capsule morphology with patient symptoms from femoroacetabular impingement. *J Orthop Res* 2021;39:590-596. doi:10.1002/jor.24788.
14. Metz AK, Featherall J, Froerer DL, Mortensen AJ, Tomasevich KM, Aoki SK. Female patients and decreased hip capsular thickness on magnetic resonance imaging associated with increased axial distraction distance on examination under anesthesia: An in vivo study. *Arthroscopy* 2022;38:3133-3140. doi:10.1016/j.arthro.2022.04.011.
15. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med* 2016;15:155-163. doi:10.1016/j.jcm.2016.02.012.
16. Bai H, Fu YQ, Ayeni OR, Yin QF. The anterior hip capsule is thinner in dysplastic hips: A study comparing different young adult hip patients. *Knee Surg Sports Traumatol Arthrosc* 2022;31:70-78. doi:10.1007/s00167-022-07022-2.
17. Le Bouthillier A, Rakhra KS, Belzile EL, Foster RCB, Beaulé PE. Soft tissue structures differ in patients with prearthritic hip disease. *J Orthop Trauma* 2018;32:S30-S34. doi:10.1097/BOT.0000000000001093.
18. Gonzalez Ballester MA, Zisserman AP, Brady M. Estimation of the partial volume effect in MRI. *Med Image Anal* 2002;6:389-405.
19. Kahlenberg CA, Han B, Patel RM, Deshmane PP, Terry MA. Time and cost of diagnosis for symptomatic femoroacetabular impingement. *Orthop J Sports Med* 2014;2:1-7. doi:10.1177/2325967114523916.
20. Tomasevich KM, Mills MK, Allen H, et al. Magnetic resonance arthrogram improves visualization of hip capsular defects in patients undergoing previous hip arthroscopy. *Arthrosc Sports Med Rehabil* 2022;4:e471-e478. doi:10.1016/j.asmr.2021.11.005.
21. Czerny C, Hofmann S, Neuhold A, et al. Lesions of the acetabular labrum: Accuracy of MR imaging and MR arthrography in detection and staging. *Radiology* 1996;200:225-230. doi:10.1148/radiology.200.1.8657916.
22. Aubry S, Bélanger D, Giguère C, Lavigne M. Magnetic resonance arthrography of the hip: Technique and

spectrum of findings in younger patients. *Insights Imaging* 2010;1(2):72-82. doi:10.1007/s13244-010-0023-x.

23. Featherall J, O'Neill DC, Mortensen AJ, Tomasevich KM, Metz AK, Aoki SK. Three-dimensional magnetic resonance arthrography of post-arthroscopy hip instability demonstrates increased effective intracapsular volume and anterosuperior capsular changes. *Arthrosc Sports Med Rehabil* 2021;3:e1999-e2006. doi:10.1016/j.asmr.2021.09.022.
24. Saupe N, Zanetti M, Pfirrmann CWA, Wels T, Schwenke C, Hodler J. Pain and other side effects after MR arthrography: Prospective evaluation in 1085 patients. *Radiology* 2009;250:830-838. doi:10.1148/radiol.2503080276.
25. Nguyen KH, Shaw C, Link TM, et al. Changes in hip capsule morphology after arthroscopic treatment for femoroacetabular impingement syndrome with periportal capsulotomy are correlated with improvements in patient-reported outcomes. *Arthroscopy* 2022;38:394-403. doi:10.1016/j.arthro.2021.05.012.