Original Article

Patients With Generalized Joint Hypermobility Have Thinner Superior Hip Capsules and Greater Hip Internal Rotation on Physical Examination

Elizabeth H. G. Turner, M.D., B. Keegan Markhardt, M.D., Eric J. Cotter, M.D.,
Scott J. Hetzel, M.S., Andrew Kanarek, M.D., McDaniel H. Lang, M.D.,
Douglas N. Mintz, M.D., and Andrea M. Spiker, M.D.

Purpose: To compare preoperative hip range of motion (ROM), hip capsular thickness on magnetic resonance imaging (MRI), and bony morphology on radiographs and computed tomography (CT) between patients with and without joint hypermobility as measured by the Beighton Test score (BTS), with subanalysis based on sex and age. **Methods:** Consecutive patients who underwent hip arthroscopy for a diagnosis of femoroacetabular impingement syndrome with or without dysplasia were retrospectively reviewed. Patient BTS, hip ROM, demographics, surgical data, morphologic measures on radiographs and CT, and MRI findings including hip capsule thickness at various locations were compiled. Multiple statistical tests were performed, including multivariable linear or logistic regression models, while controlling for BTS, age, and sex. **Results:** In total, 99 patients were included with a mean age of 29 ± 9.9 years; 62 (62.6%), were female. Forty patients (40.4%) had a BTS ≥4. Female patients ($P < .001$) and younger patients (26.7 vs 30.9 years, $P = .030$) were more likely to have a BTS ≥4. Male patients had significantly thicker superior capsules (3.4 mm vs. 2.8 mm, $P = .034$). BTS was not associated with capsular thickness when controlling for sex. On CT, femoral version (18.9° vs 11.4°, $P < .001$), and McKibben index (37.8° vs. 28.2°, $P < .001$) were significantly greater in those with a BTS ≥4. Patients with a BTS ≥4 had more hip internal rotation at 90° of flexion (15.0° vs 10.0°, $P < .001$), when prone (30.0° vs 20.0°, $P = .004$), and in extension (10.0° vs. 5.0°, $P < .001$). **Conclusions:** All female patients, regardless of Beighton score, and all patients with a BTS ≥4 indicated for primary hip arthroscopy for femoroacetabular impingement syndrome with or without dysplasia were more likely to have thinner superior hip capsules on MRI and greater hip internal rotation on exam. Bony morphologic differences exist between sexes and between patients with and without hypermobility, likely contributing to differences in ROM. **Level of Evidence:** III, retrospective cohort study.

While multiple studies have included analysis on hip capsule thickness,[1-3] the true relationship of hip capsule thickness and whether hip capsule thickness is an independently important characteristic of the femoroacetabular impingement syndrome (FAIS) hip is still under investigation. Therefore, we sought to understand the relationship between hip capsule thickness and other parameters of FAIS patient presentation, especially generalized joint hypermobility (GJH). GJH, defined as a greater-than-normal range of motion (ROM) determined by a Beighton test score (BTS) ≥4, has been shown to be common especially in young, healthy persons.[2,4] The BTS is a commonly used assessment of mobility, with a maximum score of 9 points.[5] GJH has been described as a risk factor for injury and musculoskeletal pain, particularly in athletes.[3,6,7] A subset of patients with FAIS, with or without hip dysplasia, has been shown to have GJH, with reports as high as 32.7% in a recent case series.[3]

From the Department of Orthopaedic Surgery, Henry Ford Hospital, Detroit, Michigan (E.H.G.T.); Departments of Radiology, (B.K.M., A.K.), Orthopedic Surgery, (E.J.C., M.H.L., A.M.S.), and Biostatistics and Medical Informatics (S.J.H.), University of Wisconsin — Madison, Madison, Wisconsin; and Department of Orthopaedic Surgery, Hospital for Special Surgery, New York City, New York (D.N.M.), U.S.A.

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Address correspondence to Andrea M. Spiker, M.D., Department of Orthopedic Surgery, Sports Medicine and Hip Preservation, University of Wisconsin — Madison, UW Health at The American Center, 4602 Eastpark Blvd., Madison, WI 53718. E-mail: spiker@ortho.wisc.edu

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A cohort study of 1,004 patients found that patients who had hip dysplasia without osteoarthritis had a much greater prevalence of GJH (77.9%) compared with those with nondysplastic hips (32.8%; $P < .0001$).[8] Further, patients who have undergone hip arthroscopy for management of FAIS with GJH as determined by a BTS ≥4 have been reported to be more commonly female, have a younger mean age at onset of symptoms, lower mean body mass index (BMI), and greater hip ROM with flexion, internal rotation (IR), external rotation (ER), and abduction.[5,9] Patients with FAIS, including borderline dysplastic patients, as defined by a lateral center edge angle (LCEA) of 18 to 25°, with GJH have been reported as having thinner hip capsules measured arthroscopically.[10] Further, a recent systematic review of patients with FAIS reported that clinical laxity as defined by a BTS ≥4 was correlated with thinner anterior joint capsules on magnetic resonance imaging (MRI).[11]

Hip capsule management is a topic of increasing focus in the evaluation and management of both FAIS and hip dysplasia, especially in the setting of GJH. The anterior capsule has been shown to be thicker in those with FAIS pathology than those without FAIS, based on MRI and magnetic resonance arthrogram measurements.[1,12] Thinner capsules also have been seen in patients with greater BTS and clinical hip joint laxity on examination.[10,11,13] Given greater ROM in patients with GJH,[4,14] it is important to understand the characteristics of bony and soft-tissue anatomy that may be present, including variations in hip capsule morphology, when planning arthroscopic management of labral pathology in FAIS or hip dysplasia. Preoperative hip ROM is multifactorial, with contributions from femoral version, femoral cam morphology, as well as ligamentous laxity. Understanding how capsule thickness contributes to the equation can add to our understanding of factors contributing to ROM. In the immediate clinical application, expected ROM is important in setting patient expectations for ROM after hip arthroscopy surgery. To date, limited data exist examining the associations between BTS and preoperative clinical hip ROM, BTS and capsular thickness on MRI, and preoperative clinical hip ROM and capsular thickness on MRI.[5,12]

Sex differences have been identified in patients with FAIS and/or developmental dysplasia of the hip related to differences in BTS, bony, and soft-tissue hip morphology. Hip capsule thickness has been reported in several investigations to be thinner in women than men.[10,11] Other studies have demonstrated that female patients have a greater relative risk compared with male patients of having a BTS ≥4.[5] However, there has been limited study to date to discern the complex relationship between sex, GJH defined by BTS ≥4, bony and soft-tissue morphology, and capsule thickness in patients with FAIS with or without hip dysplasia. Our goal was to further clarify this complex relationship of multiple characteristics of the FAIS hip and hip capsule thickness.

The purpose of this study was to compare preoperative hip ROM, hip capsular thickness on MRI, and bony morphology on radiographs and computed tomography (CT) between patients with and without joint hypermobility as measured by the BTS, with subanalysis based on sex and age. The authors hypothesized that thinner capsules on MRI would be associated with GJH, as defined by greater Beighton scores, as well as demonstrate correlation with joint ROM, with certain exceptions based on bony morphology. It also was hypothesized that female sex would be associated with a greater BTS, and therefore, thinner capsular tissue, increased clinical hip ROM, and less bony constraint on imaging. By understanding what baseline capsular thickness is, based on MRI, and how it relates to currently better understood parameters of patient presentation, we can place other studies looking at the hip capsule into perspective and understand what impact capsular thickness may have on surgical planning and postoperative outcomes.

Methods

Study Criteria

Consecutive patients who underwent hip arthroscopy for a diagnosis of FAIS with or without dysplasia were retrospectively identified. Patients who had hip arthroscopy performed by a single hip preservation fellowship-trained orthopaedic surgeon (A.M.S.), were indicated for hip arthroscopy for a diagnosis of FAIS with or without hip dysplasia, and were <50 years of age were included. Eleven patients were excluded, as their arthroscopy was performed after hip fracture or dislocation; 46 patients were excluded due to previous hip surgery, and 4 patients were excluded due to previous diagnosis with a connective tissue disorder such as Ehlers—Danlos or Marfan syndrome by a separate physician. As concomitant FAIS is very common in hip dysplasia, we subanalyzed these patients to look for a difference between patients with FAIS and hip dysplasia as opposed to FAIS alone. Of note, patients with concomitant FAIS and hip dysplasia were treated with both hip arthroscopy and simultaneous periacetabular osteotomy.

Patient Demographics

Patient demographic information was recorded from the medical record, including age, BMI, sex, laterality, sports actively participating in (if applicable), duration of symptoms, inciting trauma, previous nonoperative treatment measures, tobacco use, medical comorbidities, family history of hyperlaxity conditions such as Ehlers—Danlos or Marfan syndrome, and BTS. BTS was measured at the first clinical visit by the senior author (A.M.S.), who also performed all hip surgeries.

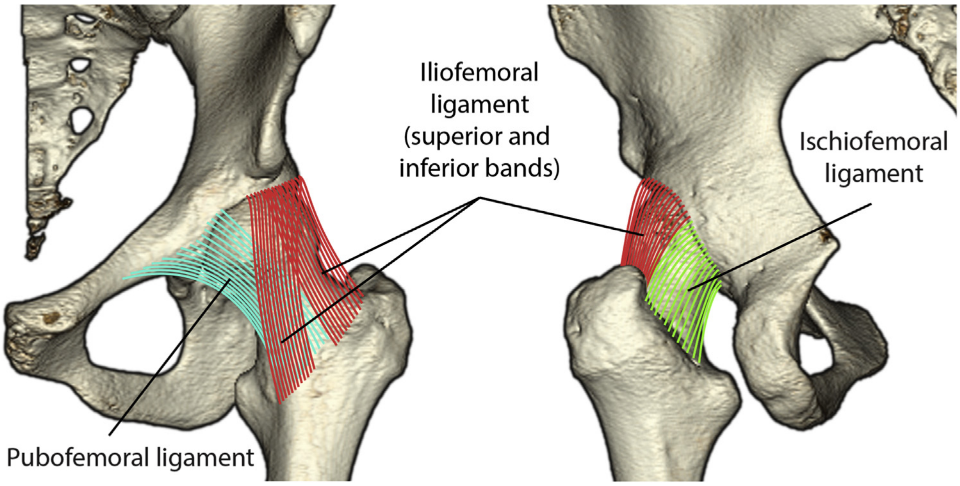

Fig 1. Anatomy of the hip joint capsule. The ligaments of the (left) hip joint capsule, which are differentiated both by color and lines indicating their names, are superimposed over the pelvis and femur.

Clinical Examination

The following physical examination findings were recorded from the clinic visit: ROM, including IR and ER when prone, supine, IR and ER at 90° of flexion, as well as hip abduction, flexion adduction internal rotation, flexion abduction external rotation, subspine impingement sign, prone apprehension relocation test, and the Stinchfield test.[15] These examination parameters were all measured and determined positive or negative by the senior author (A.M.S.).

Radiographic and CT Measurements of Bone Morphology

Preoperative radiographs included standing anteroposterior pelvis and 45o Dunn lateral hip views. The following radiographic measurements were made: LCEA, alpha angle, Tönnis grade, acetabular depth, minimum joint space, acetabular inclination, acetabular index, joint congruity, the presence or absence of ischial spine sign, crossover sign, and posterior wall sign. Hip CT was obtained on all patients as part of routine preoperative evaluation, and measurements recorded included alpha angle, femoral version, acetabular version at the 1-, 2-, and 3-o'clock positions, neck—shaft angle, coronal center edge angle (CCEA), sagittal center edge angle, and McKibben's index. Routine preoperative, 3T noncontrast MRI of the hip was obtained on all patients. The coronal and axial fat suppressed T2-weighted sequences, and oblique axial proton-density fat-suppressed sequences were reviewed for the presence or absence of a labral tear, acetabular subchondral cyst, or femoral neck cyst. Measurements of capsular thickness were made on these sequences, as defined to follow, and were obtained and averaged by 2 musculoskeletal fellowship-trained radiologists (B.K.M. and A.K.).

MRI Measurements of Joint Capsule

Figure 1 illustrates the hip joint capsular anatomy and Figure 2 depicts the 4 locations where the hip joint capsule was measured on MRI. The superior portion of the iliofemoral ligament was measured at the thinnest portion of the superior joint capsule on the coronal plane at 12 o'clock.[16-18] The inferior portion of the iliofemoral ligament was measured at the thickest portion of the anterolateral joint capsule on the axial plane at 3 o'clock.[18,19] The anterior joint capsule, consisting of contributions from the inferior iliofemoral and pubofemoral ligaments, was measured on the oblique axial plane at 3 o'clock, both at the thinnest portion and the thickest portion along the neck, which was the zona orbicularis when present.[13,16,19]

Operative Data

Intraoperative findings were recorded and included descriptions of labral tears, chondral wear, size, and location of impinging bone. Operative management was noted, including labral repair, capsulotomy, and capsule closure.

Statistical Analysis

Patient demographic and characteristics between BTS $\geq$4 and BTS$<$4 groups were examined via mean (standard deviation) and N (%). Differences in these variables were assessed by a t-test or χ^2 test. BTS groups were balanced among measured clinically relevant covariates except for age and sex. Because of this further analysis of radiographic and MRI, data between BTS groups were modeled via multivariable linear or logistic regression models, based on numeric or binary outcome, while controlling for age and sex as covariates. Similarly, comparison between sexes were made with multivariable

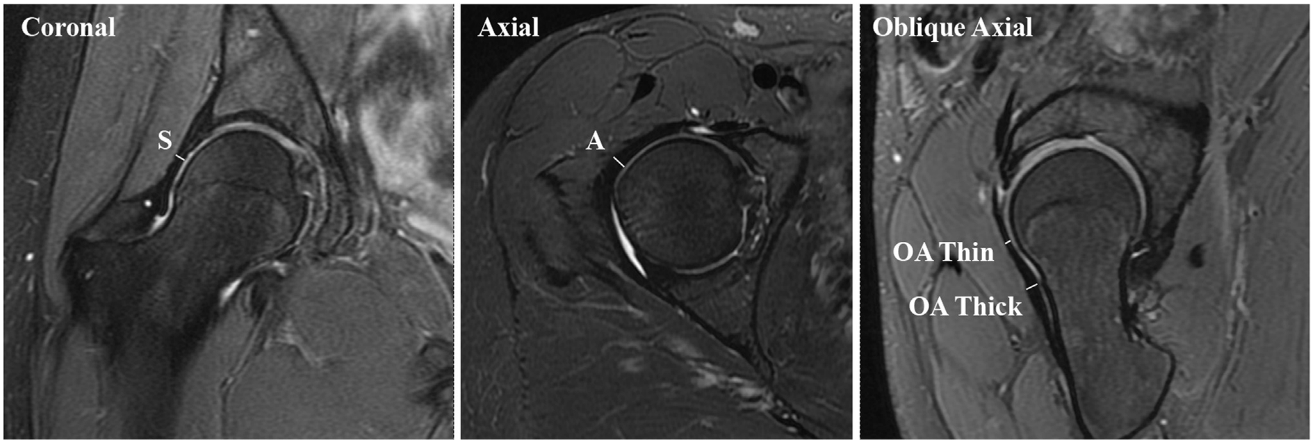

Fig 2. Hip joint capsule measurement technique. Coronal and axial fat-suppressed T2-weighted sequences, and oblique axial proton-density fat-suppressed sequences of a routine (right) hip magnetic resonance imaging with the following measurements: thinnest portion of the superior joint capsule on the coronal plane at 12 o'clock (S), thickest portion of the anterolateral joint capsule on the axial plane at 3 o'clock (A), and thinnest (OA Thin) and thickest (OA Thick) portion of the anterior joint capsule on the oblique axial plane at 3 o'clock.

linear or logistic regression models while controlling for BTS group. The relationship between measures of capsular thickness and hip ROM, including flexion, abduction, IR and ER while prone, supine, and at 90° of flexion, was examined using Pearson correlation coefficients. Statistical significance was set at alpha = 0.05. All analyses were done in R, version 3.5 (R Project for Statistical Computing, Vienna Austria).

Results

Demographics

Following approval by the University of Wisconsin — Madison institutional review board, 128 consecutive hip arthroscopy patients at a single institution from September 2017 through March 2020 were identified and retrospectively reviewed. After review of the MRIs obtained, 29 patients were excluded, as they had obtained magnetic resonance arthrogram instead of MRI. Eleven patients were excluded as their arthroscopy was performed after hip fracture or dislocation; 46 patients were excluded due to previous concomitant hip surgery, and 4 patients were excluded due to previous diagnosis of a connective tissue disorder such as Ehlers—Danlos or Marfan syndrome by a separate physician. Of the 99 patients included in this study, 62 were female and 37 were male. The overall mean ± standard deviation age of was 29 ± 9.9 years. Right hip arthroscopy occurred in 66 cases. Forty (40.4%) patients had a BTS ≥4, indicative of GJH. Female patients were more likely to have a BTS ≥4 ($P < .001$). Patients with a BTS ≥4 were also more likely to be younger, on average (26.7 vs 30.9 years, $P = .030$; Table 1). Male patients were significantly more likely to have a greater BMI in our study group (25.9 vs 23.4, $P = .005$). Female patients were significantly more likely to have had an injection before surgery (25.8% vs 2.7% $P = .008$; Table 1).

Range of Motion

Patients with a BTS ≥4 had statistically greater degrees of IR when prone (30.0° vs 20.0°, univariable $P = .004$), at 90° of flexion (15.0° vs 10.0°, $P = .010$), and in extension (10.0° vs. 5.0°, univariable $P < .001$). When controlling for age and sex, hip IR when prone and in extension were no longer significant between BTS groups ($P = .300$ and .057, respectively; Table 2).

Table 1. Demographics by BTS and Sex

	BTS <4 (n = 59)	BTS ≥4 (n = 40)	*P* Value		Female Sex (n = 62)	Male Sex (n = 37)	*P* Value
Sex, male	31 (52.5%)	6 (15.0%)	<.001	Beighton Score N (% ≥)	34 (54.8%)	6 (16.2%)	<.001
Age	30.9 (10.4)	26.7 (8.7)	.03	Age	28.4 (10.7)	30.6 (8.4)	.246
Laterality, right	36 (61.0%)	30 (75.0%)	.218	Laterality, right	43 (69.4%)	23 (62.2%)	.607
BMI	24.8 (4.3)	23.7 (4.1)	.189	BMI	23.4 (4.1)	25.9 (4.2)	.005
Previous physical therapy	43 (72.9%)	28 (70.0%)	.932	Previous physical therapy	47 (75.8%)	24 (64.9%)	.348
Previous injection	6 (10.2%)	11 (27.5%)	.049	Previous injection	16 (25.8%)	1 (2.7%)	.008
Endocrine disorder	1 (1.7%)	1 (2.5%)	1	Endocrine disorder	1 (1.6%)	1 (2.7%)	1
Autoimmune disorder	5 (8.5%)	2 (5.0%)	.698	Autoimmune disorder	4 (6.5%)	3 (8.1%)	1

BMI, body mass index; BTS, Beighton test score.

Table 2. Range of Motion Variables by BTS and Sex

	BTS < 4 (n = 59)	BTS ≥4 (n = 40)	*P* Value	*P* Value When Controlling for Sex	Female (n = 62)	Male (n = 37)	*P* Value	*P* Value When Controlling for BTS
Hip flexion	107.2 (12.0)	109.5 (13.3)	.373	.680	109.4 (12.5)	105.9 (12.4)	.171	.271
Hip internal rotation	10.0 (5.0-17.5)	15.0 (10.0-31.2)	<.001	.010	15.0 (10.0-30.0)	5.0 (5.0-15.0)	<.001	.001
Hip external rotation	30.3 (9.5)	32.8 (8.8)	.197	.882	32.8 (9.0)	28.8 (9.1)	.035	.078
Internal rotation extension	5.0 (5.0-10.0)	10.0 (10.0-15.0)	<.001	.057	10.0 (5.0-15.0)	5.0 (5.0-10.0)	.001	.304
External rotation extension	20.7 (9.6)	19.6 (9.8)	.594	.958	18.9 (8.7)	22.4 (10.6)	.094	.096
Hip abduction	41.4 (6.9)	43.9 (6.8)	.082	.121	42.6 (7.6)	42.0 (5.8)	.687	.775
Prone internal rotation	20.0 (15.0-25.0)	30.0 (20.0-42.5)	.004	.300	30.0 (20.0-40.0)	15.0 (15.0-25.0)	<.001	<.001
Prone external rotation	32.0 (10.9)	30.9 (12.5)	.67	.648	31.2 (11.7)	32.2 (11.3)	.686	.8
FADIR, yes	55 (93.2%)	35 (87.5%)	.479	.544	54 (87.1%)	36 (97.3%)	.147	.159
FABER, yes	17 (28.8%)	15 (38.5%)	.437	.657	24 (39.3%)	8 (21.6%)	.111	.119
Instability/anterior apprehension test, yes	11 (19.0%)	9 (23.7%)	.764	.371	11 (18.3%)	9 (25.0%)	.604	.29
Stinchfield, yes	19 (32.2%)	16 (47.1%)	.229	.128	22 (37.9%)	13 (37.1%)	1	.575
PART, yes	13 (22.0%)	13 (34.2%)	.277	.793	22 (36.7%)	4 (10.8%)	.011	.015

BTS, Beighton test score; FABER, flexion, abduction, external rotation test; FADIR, flexion, adduction, internal rotation test; PART, prone apprehension relocation test.

Female patients had significantly greater degrees of hip IR at 90° of flexion (15.0° vs. 5.0°, *P* = .001), when prone (30.0° vs. 15.0°, *P* < .001) and in extension (10.0° vs. 5.0°, univariable *P* = .001). When we controlled for BTS, hip IR in extension was no longer significant (*P* = .304). Female patients were also more likely to have a positive prone apprehension relocation test[15] (36.7% vs 10.8%, *P* = .015; Table 2).

Bony Morphology

The radiographic alpha angle (measured on the modified 45° Dunn view) was significantly smaller in patients with a BTS ≥4 (55.6° vs 65.2°, *P* = .016). The presence of a posterior wall sign was significantly associated with a BTS ≥4 (15.0% vs 42.4%, *P* = .042), even when controlling for sex and age. No other radiographic measurements reached significance between patients with a BTS ≥4 and those with a BTS <4. On CT, femoral version (18.9° vs 11.4°, *P* = .013), and the McKibben index (28.2° vs 37.8°, *P* = .004) were both significantly greater in those with a BTS ≥4, and alpha angle was univariably significantly smaller (54.3° vs 60.5°, *P* = .001). However, the CT alpha angle differences did not remain statistically significant when controlling for sex and age (*P* = .146). There was no significant difference in acetabular version measured at the 1-, 2-, or 3-o'clock position, neck—shaft angle, CCEA, or the sagittal center edge angle between BTS groups (Table 3).

Based on radiographic imaging, male patients were more likely to have a Tönnis grade of 1 than female patients (51.4% vs 17.7% respectively; *P* = .002). No patients had a Tönnis grade greater than 1. Male patients were more likely to have a positive posterior wall sign (51.4% vs 19.4%, *P* = .018) and a greater alpha angle on modified Dunn radiographs (68.8° vs 56.7°, *P* < .001). On CT, male patients had less femoral anteversion (9.8° vs 17.1° *P* = .017) and a decreased McKibben index (26.9° vs 35.2°, *P* = .036) (Table 4).

Capsular Thickness

The superior joint capsule thickness had a statistically significant negative correlation with hip IR at 90° of flexion (−0.352, 95% CI −0.514 to −0.167), IR in extension (−0.254, 95% CI −0.434 to −0.056), and IR while prone (−0.366, 95% CI −0.528 to −0.178), as well as ER in 90°of flexion (−0.203 to −0.385 to −0.006), meaning that patients with thinner hip capsules had greater hip ROM. Male patients had a significantly thicker capsule when compared with female patients, measured at the superior joint capsule (3.4 mm vs 2.8 mm, *P* = .034). This difference did not remain significant when controlling for BTS ≥4 (*P* = .124). Those with a BTS <4 also had a significantly thicker capsule (3.2 mm vs 2.7 mm, *P* = .018); however, that finding was insignificant when controlling for age and sex (*P* = .247).

Table 3. Radiographic Variables by BTS

	BTS <4 (n = 59)	BTS ≥4 (n = 40)	*P* Value	*P* Value When Controlling for Sex
Radiographic measures				
Tönnis grade 1	21 (35.6%)	9 (22.5%)	.243	.512
Minimum joint space	3.9 (2.8)	3.5 (0.8)	.395	.537
Lateral center edge angle	27.4 (5.7)	26.5 (6.9)	.468	.533
Acetabular depth	9.9 (2.2)	9.6 (2.1)	.603	.646
Acetabular inclination	8.4 (5.8-10.4)	9.1 (4.2-11.3)	.966	.559
Acetabular index	8.4 (4.2)	8.5 (5.4)	.949	.559
Crossover sign, Yes	28 (47.5%)	17 (42.5%)	.779	.308
Posterior wall sign, yes	25 (42.4%)	6 (15.0%)	.008	.042*
Ischial spine sign, yes	15 (25.4%)	8 (20.0%)	.701	.47
False-profile/ACE	31.1 (8.8)	30.3 (8.0)	.67	.526
Modified Dunn Alpha angle	65.2 (10.6)	55.6 (10.2)	<.001	.016*
CT measures				
Alpha angle	60.5 (9.5)	54.3 (8.7)	.001	.146
Femoral version	11.4 (9.6)	18.9 (10.0)	<.001	.013*
Acetabular version 1 o'clock	3.7 (7.8)	6.5 (8.4)	.095	.037*
Acetabular version 2 o'clock	10.2 (8.5)	13.5 (8.4)	.061	.075
Acetabular version 3 o'clock	16.8 (5.8)	18.9 (7.2)	.138	.155
Neck—shaft angle	132.1 (4.3)	132.8 (4.0)	.424	.237
Coronal center edge angle	24.9 (5.8)	26.0 (5.8)	.374	.386
Sagittal center edge angle	48.9 (6.6)	51.1 (6.7)	.117	.213
McKibben index	28.2 (10.9)	37.8 (12.1)	<.001	.004*

ACE, anterior center edge angle; BTS, Beighton test score; CT, computed tomography.

*Indicates the *P* value maintained statistical significance when controlling for other confounders.

Table 4. Radiographic Variables by Sex

	Female (n = 62)	Male (n = 37)	*P* Value	*P* Value When Controlling for BTS
Radiographic measures				
Tönnis grade 1	11 (17.7%)	19 (51.4%)	.001	.002*
Minimum joint space	3.8 (2.7)	3.5 (0.9)	.437	.326
Lateral center edge angle	26.9 (6.4)	27.2 (5.8)	.816	.949
Acetabular depth	9.8 (2.2)	9.7 (2.1)	.845	.675
Acetabular inclination	7.9 (4.6-10.4)	9.9 (6.8-12.0)	.064	.156
Acetabular index	7.9 (4.7)	9.3 (4.6)	.154	.12
Crossover sign, yes	28 (45.2%)	17 (45.9%)	1	.906
Posterior wall sign, yes	12 (19.4%)	19 (51.4%)	.002	.018*
Ischial spine sign, yes	13 (21.0%)	10 (27.0%)	.657	
False profile/ACE	31.2 (8.6)	29.8 (7.9)	.513	.423
Modified Dunn Alpha angle	56.7 (8.9)	68.8 (11.3)	<.001	<.001*
CT measures				
Alpha angle	54.6 (8.2)	63.7 (9.2)	<.001	<.001*
Femoral version	17.1 (10.0)	9.8 (9.4)	<.001	.017*
Acetabular version 1 o'clock	5.2 (8.4)	4.2 (7.8)	.563	.936
Acetabular version 2 o'clock	12.4 (8.1)	10.2 (9.2)	.236	.572
Acetabular version 3 o'clock	18.0 (6.7)	17.1 (6.0)	.471	.902
Neck—shaft angle	132.1 (4.4)	132.9 (3.7)	.351	.197
Coronal center edge angle	25.9 (5.7)	24.5 (5.8)	.247	.373
Sagittal center edge angle	50.2 (6.4)	49.1 (7.1)	.433	.82
McKibben index	35.2 (12.0)	26.9 (10.9)	.001	.036*

ACE, anterior center edge angle; CT, computed tomography.

*Indicates the *P* value maintained statistical significance when controlling for other confounders.

In the superior joint capsule, there was a statistically significant positive correlation with IR at 90° of flexion (0.243, 95% confidence interval 0.031-0.433) and IR when prone (0.265, 95% confidence interval 0.052-0.455). Notably, our data indicated a few statistically significant correlations; however, all estimated correlation coefficients were <0.4 and are considered to be weak correlations. No other comparison reached statistical significance. Appendix Table 1, available at www.arthroscopyjournal.org, contains the complete analysis comparing MRI measures of hip capsule thickness and hip ROM.

Table 5. MRI Variables by BTS and Sex

	BTS <4 (n = 59)	BTS ≥4 (n = 40)	*P* Value	*P* Value When Controlling for Female Sex and Age	Female Sex (n = 62)	Male Sex (n = 37)	*P* Value	*P* Value When Controlling for BTS
Labral tear, yes	59 (100.0%)	39 (97.5%)	.404	.999	61 (98.4%)	37 (100.0%)	1	.998
Acetabular cyst, yes	3 (5.1%)	4 (10.0%)	.436	.035	3 (4.8%)	4 (10.8%)	.419	.106
Femoral cyst, yes	4 (6.8%)	2 (5.0%)	1	.91	3 (4.8%)	3 (8.1%)	.668	.583
Axial	6.5 (1.5)	6.6 (1.5)	.58	.522	6.6 (1.5)	6.5 (1.6)	.842	.993
Superior	3.2 (1.2)	2.7 (0.8)	.018	.247	2.8 (1.0)	3.4 (1.2)	.034	.124
Oblique axial thick	5.2 (1.0)	5.5 (1.3)	.174	.143	5.3 (1.2)	5.2 (1.0)	.692	.811
Oblique axial thin	1.9 (0.5)	2.1 (0.6)	.238	.327	2.0 (0.6)	1.9 (0.4)	.408	.786

NOTE. Please see Figure 2 for descriptions of how the axial, superior, oblique axial thick, and oblique axial thin measurements were obtained. BTS, Beighton test score; MRI, magnetic resonance imaging.

As shown in Table 5, no associations were identified between BTS or sex and the presence of a labral tear, acetabular subchondral cysts, or femoral cysts.

Discussion

The main findings of this study are that a significant percentage (40.4%) of our patient population undergoing hip arthroscopy for FAIS with or without dysplasia was hypermobile, as defined by a BTS ≥4. Both female patients and patients with GJH had significantly thinner superior hip capsules than patients who were not hypermobile or female; however, this difference disappeared when controlling for one another. This may be because female patients are more likely to have greater Beighton scores in general, and the small sample size of this study may have underpowered our final conclusions. In addition, several radiographic and CT bony architectural measurements were significantly different in patients with GJH and those who are not hypermobile. Patients with GJH tended to have greater IR in 90° of flexion and in full extension than nonhypermobile patients, regardless of sex. Superior hip capsule thickness, independent of BTS, had a negative correlation with several ROM measurements, demonstrating that thinner hip capsules were associated with increased hip ROM. These data support that although female sex may account for variations in soft-tissue morphology such as thinner hip capsules, there are likely bony structural differences that exist within the pelvis between patients with a BTS ≥4 and those with a BTS <4, regardless of sex, that may have a meaningful impact on clinical presentation for FAIS.

Previous studies have evaluated differences in bony morphology between patients with GJH and those without, as well as the differences in ROM with varying bony morphology. Devitt et al.[10] found that patients with an LCEA indicative of borderline dysplasia (between 21° and 25°) had significantly greater BTS (6 vs 2) when compared with patients with nondysplastic hips (>25°).[11] We did not see an association comparing the BTS ≥4 and BTS <4 groups with LCEA or CCEA, although we did not compare BTS between dysplastic and nondysplastic groups but instead correlated the actual center edge angle measurements between BTS groups. The present study found that patients with a BTS ≥4 significantly correlated with smaller alpha angles radiograph (55.6° vs 65.2°). As an aside, alpha angles measurements obtained on CT differed slightly from the alpha angle measurements obtained on radiographs, which has been previously described.[20,21] BTS ≥4 was also found to correlate with greater femoral anteversion (18.9° vs 11.4°, $P < .001$) and greater McKibben Index (28.2° and 37.8°, $P < .001$) on CT. When we controlled for female sex and age, these differences remained significant, suggesting that both BTS and female sex have some correlation with bony morphology (including acetabular and femoral version as well as alpha angle). Our findings are in line with previous studies, which have identified that smaller alpha angles and greater femoral anteversion are correlated with more IR at the hip.[22,23]

When examining hip ROM, we found significant differences between patients who have GJH and those who do not have GJH in addition to differences between sexes. Those with GJH were found to have greater hip IR when prone, supine, and at 90° of flexion. Similarly, when controlling for BTS, female patients were found to have greater hip IR when prone and at 90° of flexion. Our analysis also indicated a few statistically significant correlations between capsular thickness and hip ROM. The superior capsule thickness had a negative correlation with hip IR at 90°, IR in extension, and IR while prone, indicating that those with thicker capsules have less hip IR; however, all estimated correlation coefficients were <0.4 and are considered to be weak correlations. Similarly, Zhang et al.[19] found that increased anterior hip capsule thickness at the femoral head—neck junction correlated with decreased hip flexion and internal rotation. It is important to note that in patients with FAIS or hip dysplasia, those patients with thinner capsules require careful preservation of the capsule as a stabilizing structure postoperatively to prevent iatrogenic instability. While initially there was debate over the necessity of hip capsule closure in arthroscopy, more recent research supports the regular practice of capsule closure. Domb et al.[24] studied capsular management in a stepwise fashion and found that capsulotomy did increase ROM of the surgical hip and that capsular closure helped to restore the native ROM of the surgical hip joint. Although marked instability and dislocation is rare after hip arthroscopy, it is a potentially devastating complication. A systematic review of 9 case reports of gross instability after hip arthroscopy found that hip dysplasia, ligamentous laxity, and female sex may be risk factors for post-hip arthroscopy hip dislocation.[25] The authors also noted that certain surgical techniques such as unrepaired capsules and iliopsoas release may increase the risk for gross hip instability.[26] As there is a risk of instability postoperatively, and a growing body of evidence supports that hip capsule closure results in significantly improved patient-reported outcomes and decreased conversion to total hip arthroplasty,[27-30] it is our recommendation that the capsule be surgically closed after hip arthroscopy to restore native joint ROM and stability, especially in those with greater BTS, greater hip internal rotation, and in in female patients.

Sex differences in hip capsule thickness on MRI have been reported previously.[10,11] The present study measured capsular thickness in 4 different MRI planes and found that, when measuring at the superior capsule, there was a significant mean difference between male and female patients of 0.6 mm (3.4 mm vs 2.8 mm; Fig 2). These findings are concordant with Kay et al.,[11] who reported that male patients had a thicker hip capsule with a mean difference of 1.92 mm (0.35-3.49). Notably, Kay et al.[11] measured their capsules during surgery with direct arthroscopic visualization whereas ours were measured on a radiology workstation with calibrated measurement tools on a static image, which may account for the difference in averages between our 2 studies. The median BTS was 4 in female patients and 0 in male patients in the present study, which is consistent with a recent study by Devitt et al,[10] which found a difference of median BTS of 4 in females and 1 in men. When comparing BTS groups, our study identified an initial significant difference in superior capsular thickness ($P = .014$); however, this significance degraded when controlling for female sex ($P = .122$), suggesting that both female sex and BTS affect capsular thickness. Although a BTS of 4 is commonly used as the cut-off for GJH, others have suggested using 3, 5, or 6.[6,31,32] It has also been consistently noted that women have greater scores of hypermobility than their age-matched male counterparts.[6] A study from a cohort of the general population in Australia found that a BTS cutoff of 4 was only appropriate for men aged 8-39 years and women aged 40-59 years for GJH.[32] Thus, it has been suggested that the cut-off point for GJH in women should be >4 when using the BTS. Our data support those findings, as women with FAIS in our patient population had a median BTS of 4, whereas men had a median BTS of 0. Notably, while a better cut-off for the Beighton score may exist, we were unable to define one in our data as a continuous variable analysis. While other studies have had similar results when comparing hip joint hypermobility, BTS, and sex, ours is the first to note that female sex is also a predictive factor for a thinner hip capsule. This is clinically significant, as it suggests that, while for male patients a BTS ≥4 may be a predictor of a thinner capsule, any female may have a thinner hip capsule. These findings are important for understanding anatomical differences that may be encountered in female patients or in male patients with a BTS ≥4 and can aid the surgeon with intraoperative capsular management.

Limitations

We acknowledge this study has a number of limitations. This was a retrospective study with a small sample size from a single surgeon's patient cohort; however, the patient population included the entire spectrum of hip-preservation patients, as the surgeon's practice includes both open and arthroscopic hip surgery. Capsule measurements were measured at 4 locations using techniques that have been previously described; however, the MRI field-of-view and imaging sequence parameters differed from some previous investigations, limiting comparison. We used small field-of-view clinical sequences and averaged the independent measurements of 2 radiologists to obtain the greatest measurement accuracy. While we found differences in hip capsule thickness in our patient population, we were unable to evaluate the clinical relevance of these findings and were not set up to study whether capsule thickness affects joint stability or outcomes after surgery. In addition, given that all capsules were closed in this study, we are unable to discern whether differences in capsular management may affect outcomes in our patient groups. While both female patients and patients with GJH had significantly thinner superior hip capsules than patients who were not hypermobile or female, this difference disappeared when controlling for sex or BTS. This may be because female patients are more likely to have greater Beighton scores in general, and the small sample size of this study may have underpowered our final conclusions. Further study may help to delineate the true relationships between female sex, Beighton score, and capsular thickness. Finally, there are inherent limitations of the BTS, as we have discussed.

Conclusions

All female patients, regardless of BTS, and patients with a BTS ≥4 indicated for primary hip arthroscopy for FAIS with or without dysplasia were more likely to have thinner superior hip capsules on MRI and greater hip IR on examination. Bony morphologic differences exist between sexes and between patients with and without hypermobility, likely contributing to differences in ROM.

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Appendix Table 1. Correlations Between MRI Measures of Hip Capsule Thickness* and Hip Range of Motion

	Axial Average	Superior Average	Oblique Axial Thick	Oblique Axial Thin
Hip flexion	−0.087 (−0.280 to 0.112)	−0.107 (−0.298 to 0.092)	−0.064 (-0.274 to 0.151)	0.035 (−0.179 to 0.247)
Hip IR	−0.156 (−0.343 to 0.043)	−0.352 (−0.514 to −0.167)	−0.054 (−0.264 to 0.161)	0.243 (0.031 to 0.433)
Hip ER	0.042 (−0.156 to 0.238)	−0.203 (−0.385 to −0.006)	−0.006 (−0.219 to 0.207)	0.175 (−0.039 to 0.374)
IR extension	−0.102 (−0.297 to 0.102)	−0.254 (−0.434 to −0.056)	−0.112 (−0.322 to 0.107)	0.153 (−0.066 to 0.358)
ER extension	0.178 (−0.024 to 0.367)	0.184 (−0.019 to 0.371)	0.018 (−0.200 to 0.234)	0.073 (−0.146 to 0.285)
Hip abduction	0.069 (−0.134 to 0.267)	−0.043 (−0.243 to 0.160)	0.141 (−0.078 to 0.347)	0.106 (−0.114 to 0.316)
Prone IR	−0.169 (−0.357 to 0.033)	−0.366 (−0.528 to −0.178)	−0.117 (−0.325 to 0.101)	0.265 (0.052 to 0.455)
Prone ER	0.028 (−0.173 to 0.228)	0.145 (−0.057 to 0.336)	0.167 (−0.050 to 0.369)	0.040 (−0.177 to 0.253)

NOTE. Pearson correlation coefficient (95% CI).

CI, confidence interval; ER, external rotation; IR, internal rotation; MRI, magnetic resonance imaging.

*Measured by the techniques described in Figure 2.