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

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**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, 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. The BTS is a commonly used assessment of mobility, with a maximum score of 9 points. GJH has been described as a risk factor for injury and musculoskeletal pain, particularly in athletes. 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.
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%; $P < .0001$). 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. 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 capsule thickness on MRI. Thinner capsules also have been seen in patients with FAIS pathology than those without FAIS, based on anterior capsule has been shown to be thicker in those with GJH, 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. Thinner capsules also have been seen in patients with greater BTS and clinical hip joint laxity on examination.

Given greater ROM in patients with GJH, 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.

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. Other studies have demonstrated that female patients have a greater relative risk compared with male patients of having a BTS ≥4. 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 Brighton 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.
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 45° 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.).

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 ≥4 and BTS<4 groups were examined via mean (standard deviation) and N (%). Differences in these variables were assessed by a t-test or \( \chi^2 \) 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
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   | 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 | BCS | <BTS/C21 | P Value When Controlling for BTS | P Value Controlling for Sex | P Value Controlling for Sex and Age |
|-----|-----|---------|-------------------------------|-----------------------------|----------------------------------|
|     | BTS |         |                          |                             |                                  |
|     | Male | 110.4 (12.5) | 107.2 (12.0) | .303 | 110.9 (13.6) | 107.3 (12.0) | .181 |
|     | Female | 109.6 (12.4) | 106.0 (11.9) | .150 | 109.3 (12.3) | 106.0 (11.9) | .105 |

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 (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 \( \geq 4 \) (55.6° vs 65.2°, \( P = .016 \)). The presence of a posterior wall sign was significantly associated with a BTS \( \geq 4 \) (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 \( \geq 4 \) 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 \( \geq 4 \), and alpha angle was unvariably 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 \( \geq 4 \) (\( P = .124 \)). 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 (\( P = .247 \)).
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 3. Radiographic Variables by BTS

| Radiographic measures | 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 | 35 (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

| Radiographic measures | 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.
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%)      | .040    | .999                                          | 61 (98.4%)         | 37 (100.0%)     | 1       | .998                                          |
| Acetabular cyst, yes | 3 (5.1%)     | 4 (10.0%)       | .356    | .035                                          | 3 (4.8%)           | 4 (10.8%)       | .419    | .106                                          |
| Femoral cyst, yes | 4 (8.6%)        | 2 (5.0%)        | .018    | .247                                          | 3 (4.8%)           | 3 (8.1%)        | .668    | .583                                          |
| Axial           | 6.5 (1.5)       | 6.6 (1.5)       | .174    | .522                                          | 6.6 (1.5)          | 6.5 (1.6)       | .842    | .993                                          |
| Oblique axial thick | 5.2 (1.0)   | 5.9 (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 FAIS, 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 $\geq 4$ 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 $\geq 4$ 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 $\geq 4$ 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.

References
1. Weidner J, Buchler L, Beck M. Hip capsule dimensions in patients with femoroacetabular impingement: A pilot study. Clin Orthop Relat Res 2012;470:3306-3312.
2. Saadat AA, Lall AC, Battaglia MR, Mohr MR, Maldonado DR, Domb BG. Prevalence of generalized ligamentous laxity in patients undergoing hip arthroscopy: A prospective study of patients’ clinical presentation, physical examination, intraoperative findings, and surgical procedures. Am J Sports Med 2019;47:885-893.
3. Naal FD, Muller A, Varghese VD, Wellauer V, Impellizzeri FM, Leunig M. Outcome of hip impingement surgery: Does generalized joint hypermobility matter? Am J Sports Med 2017;45:1309-1314.
4. Bin Abd Razak HR, Bin Ali N, Sen Howe T. Generalized ligamentous laxity may be a predisposing factor for musculoskeletal injuries. J Sci Med Sport 2014;17:474-478.
5. Beighton P, Solomon L, Soskolne CL. Articular mobility in an African population. Ann Rheum Dis 1973;32:413-418.
6. Konopinski MD, Jones GJ, Johnson MI. The effect of hypermobility on the incidence of injuries in elite-level professional soccer players: A cohort study. Am J Sports Med 2012;40:763-769.
7. Pacey V, Nicholson LL, Adams RD, Munn J, Munns CF. Generalized joint hypermobility and risk of lower limb joint injury during sport: A systematic review with meta-analysis. Am J Sports Med 2010;38:1487-1497.
8. Santore RF, Gosey GM, Muldoon MP, Long AA, Healey RM. Hypermobility assessment in 1,004 adult patients presenting with hip pain: correlation with diagnoses and demographics. J Bone Joint Surg Am 2020;102:27-33 (21S suppl 1).
9. Naal FD, Hatzung G, Müller A, Impellizzeri F, Leunig M. Validation of a self-reported Beighton score to assess hypermobility in patients with femoroacetabular impingement. Int Orthop 2014;38:2245-2250.
10. Devitt BM, Smith BN, Stapl R, Tacey M, O’Donnell JM. Generalized joint hypermobility is predictive of hip capsular thickness. Orthop J Sport Med 2017;5.
11. Kay J, Memon M, Rubin S, et al. The dimensions of the hip capsule can be measured using magnetic resonance imaging and may have a role in arthroscopic planning. Knee Surg Sports Traumatol Arthrosc 2020;28:1246-1261.
12. Rakhra KS, Bonura AA, Nairn R, Schweitzer ME, Kolanko NM, Beaulé PE. Is the hip capsule thicker in diseased hips? Bone Joint Res 2016;5:586-593.
13. Magerkurth O, Jacobson JA, Morag Y, Caoli E, Fessell D, Sekiya JK. Capsular laxity of the hip: Findings at magnetic resonance arthrography. Arthroscopy 2013;29:1615-1622.
14. Naal FD, Hatzung G, Muller A, Impellizzeri F, Leunig M. Validation of a self-reported Beighton score to assess hypermobility in patients with femoroacetabular impingement. Int Orthop 2014;38:2245-2250.
15. Spiker AM, Fabricant PD, Wong AC, Suryavanshi JR, Sink EL. Radiographic and clinical characteristics associated with a positive PART (Prone Apprehension Relocation Test): A new provocative exam to elicid hip instability. J Hip Preserv Surg 2020;7:288-297.
16. 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.
17. Strickland CD, Kraeutler MJ, Brick MJ, et al. MRI evaluation of repaired versus unrepaired interportal capsulotomy in simultaneous bilateral hip arthroscopy: A double-blind, randomized controlled trial. J Bone Joint Surg Am 2018;100:91-98.
18. Weber AE, Kuhns BD, Cvetanovich GL, et al. Does the hip capsule remain closed after hip arthroscopy with routine capsular closure for femoroacetabular impingement? A magnetic resonance imaging analysis in symptomatic postoperative patients. Arthroscopy 2017;33:108-115.
19. Zhang K, de SA D, Yu H, Choudur HN, Simunovic N, Ayeni OR. Hip capsular thickness correlates with range of motion limitations in femoroacetabular impingement. Knee Surg Sport Traumatol Arthrosc 2018;26:3178-3187.
20. Air ME, Harrison JR, Nguyen JT, Kelly BT, Bogner EA, Moley PJ. Correlation of measurements of the prearthritic hip between plain radiography and computed tomography. PM R 2019;11:158-166.
21. Smith KM, Gerrie BJ, McCulloch PC, Lintner DM, Harris JD. Comparison of MRI, CT, Dunn 45° and Dunn 90° alpha angle measurements in femoroacetabular impingement. HIP Int 2018;28:450-455.
22. Kapron AL, Anderson AE, Peters CL, et al. Hip internal rotation is correlated to radiographic findings of cam femoroacetabular impingement in collegiate football players. Arthroscopy 2012;28:1661-1670.
23. Kraeutler MJ, Chadayammuri V, Garabekyan T, Meidan O. Femoral version abnormalities significantly outweigh effect of cam impingement on hip internal rotation. J Bone Joint Surg Am 2018;100:205-210.
24. Domb BG, Philippon MJ, Giordano BD. Arthroscopic capsulotomy, capsular repair, and capsular plication of the hip: Relation to atraumatic instability. Arthroscopy 2013;29:162-173.
25. Yeung M, Memon M, Simunovic N, Belzile E, Philippon MJ, Ayeni OR. Gross instability after hip arthroscopy: An analysis of case reports evaluating surgical and patient factors. Arthroscopy 2016;32:1196-1204.e1.
26. Nho SJ, Beck EC, Kunze KN, Okoroha K, Suppauksorn S. Contemporary management of the hip capsule during arthroscopic hip preservation surgery. Curr Rev Musculoskelet Med 2019;12:260-270.
27. Domb BG, Chaharbakshii EO, Perets I, Walsh JP, Yuen LC, Ashberg LJ. Patient-reported outcomes of capsular repair versus capsulotomy in patients undergoing hip arthroscopy: Minimum 5-year follow-up—a matched comparison study. Arthroscopy 2018;34:853-863.e1.
28. Hassebrook JD, Makovichka JL, Chhabra A, et al. Hip arthroscopy in the high-level athlete: Does capsular closure make a difference? Am J Sports Med 2020;48:2465-2470.
29. Frank RM, Lee S, Bush-Joseph CA, Kelly BT, Salata MJ, Nho SJ. Improved outcomes after hip arthroscopic surgery...
in patients undergoing t-capsulotomy with complete repair versus partial repair for femoroacetabular impingement: A comparative matched-pair analysis. Am J Sports Med 2014;42:2634-2642.

30. Chahla J, Mikula JD, Schon JM, et al. Hip capsular closure. Am J Sports Med 2017;45:434-439.

31. Morris SL, O’Sullivan PB, Murray KJ, Bear N, Hands B, Smith AJ. Hypermobility and musculoskeletal pain in adolescents. J Pediatr 2017;181:213-221.e1.

32. Singh H, McKay M, Baldwin J, et al. Beighton scores and cut-offs across the lifespan: Cross-sectional study of an Australian population. Rheumatology 2017;56:1857-1864.
**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.