Patients With Unilateral Femoroacetabular Impingement Syndrome Have Asymmetrical Hip Muscle Cross-Sectional Area and Compensatory Muscle Changes Associated With Preoperative Pain Level

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Purpose: To compare the symptomatic hip muscle cross-sectional area (CSA) in patients with unilateral femoroacetabular impingement syndrome (FAIS) with the asymptomatic-side hip muscle CSA and to determine whether correlations exist between the hip muscle CSA and preoperative pain level, preoperative symptom duration, and postoperative function. **Methods:** We performed a retrospective review of magnetic resonance imaging data of patients who underwent hip arthroscopy from January 2012 through June 2015 for the treatment of unilateral FAIS and who had a minimum of 2 years' follow-up after hip arthroscopy for FAIS. A picture archiving and communication system workstation with an embedded region-of-interest tool was used to measure the muscle CSA of both the symptomatic and asymptomatic sides in FAIS patients. One-way repeated-measures analyses of variance were used to determine differences between symptomatic and asymptomatic hip muscle CSAs. Spearman rank correlations were used to determine relations between the symptomatic-side hip muscle CSA and preoperative pain level, preoperative symptom duration, and multiple validated patient-reported outcomes to quantify the level of function. **Results:** A total of 50 patients met the inclusion criteria and were analyzed. The mean age of the patients was 34.22 ± 14.12 years, and 64% were women. Specific muscles of the symptomatic hip displaying significantly decreased CSAs compared with the asymptomatic hip included the gluteus maximus ($P = .007$), gluteus minimus ($P = .022$), and rectus femoris ($P = .028$). The tensor fascia lata ($\rho = 0.358$; $P = .011$), pectineus ($\rho = 0.369$, $P = .008$), adductor longus ($\rho = 0.286$, $P = .044$), and obturator externus ($\rho = 0.339$, $P = .016$) showed a moderate positive correlation with preoperative pain level on a visual analog scale in unilateral FAIS patients. No associations were found between the symptomatic-side hip muscle CSA in patients with unilateral FAIS and symptom duration or patient-reported function. **Conclusions:** Patients with unilateral FAIS have a significantly decreased muscle CSA in the symptomatic hip compared with the asymptomatic hip. The symptomatic-side hip muscle CSA was correlated with the preoperative pain level on a visual analog scale. The association between the muscle CSA and preoperative pain level may represent a compensatory change in muscle function around the hip joint in patients with unilateral FAIS. **Level of Evidence:** Level IV, therapeutic case series.

See commentary on page 1454

"Femoroacetabular impingement syndrome" (FAIS) is defined as a clinical disorder of the hip that includes symptoms, clinical signs, and radiographic evidence of femoroacetabular impingement morphology.[1] FAIS represents the symptomatic premature contact between the proximal femur and the

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acetabulum, which can result in chondrolabral injury and early osteoarthritis (OA) in young individuals and active adults.[2-5] A primary clinical sign of chronic hip conditions, including FAIS, is hip muscle weakness.[5-8] However, it is unknown whether this muscle weakness is associated with hip pain, duration of symptoms, or possible changes in muscle size.

Alterations in muscle size have been well documented in patients with hip and knee OA.[9-13] Hip muscle size can be assessed by quantifying the cross-sectional area (CSA) using axial cuts of pelvis magnetic resonance imaging (MRI). Although muscle CSA has been assessed previously in patients with hip OA, little evidence exists on muscle size in patients with FAIS.[9,14-16] Recently, greater hip abductor muscle volume was found in female patients with chronic hip joint pain, although these patients' diagnoses were not limited to FAIS.[16] In addition, a reduced gluteus medius muscle CSA has been reported in patients with developmental hip dysplasia when the symptomatic hip was compared with the asymptomatic side.[17] It is interesting to note that the evidence on the association between muscle CSA and muscle function (i.e., strength and activation) in patients with hip pathology is inconsistent and limited. Perhaps the reason for the lack of an association between muscle structure and function is related to the difference in the position of the hip joint during imaging versus muscle testing.[6,16] Because MRI scans are routinely used in the clinical evaluation of FAIS patients, the investigation of hip muscle CSA may help to identify a meaningful radiographic biomarker for disease progression and chronicity, both of which have been associated with postoperative outcomes of FAIS patients.[4,5,8]

As such, the purposes of this study were to compare the symptomatic hip muscle CSA in patients with unilateral FAIS with the asymptomatic-side hip muscle CSA and to determine whether correlations exist between the hip muscle CSA and preoperative symptom duration, preoperative pain level, and postoperative function. We hypothesized that the CSA of the gluteus minimus, gluteus medius, and gluteus maximus muscles would be reduced and that the iliopsoas, tensor fascia lata, rectus femoris, vastus lateralis, vastus medialis, adductor longus, adductor brevis, adductor magnus, pectineus, and obturator muscles would show greater CSAs in the symptomatic hips of FAIS patients compared with the asymptomatic hips. We also hypothesized that muscle CSA alterations would be negatively correlated with a patient's preoperative pain level and symptom duration, such that greater pain and a greater symptom duration would be associated with a lower hip muscle CSA. Conversely, we hypothesized that a greater hip muscle CSA on the symptomatic side would be positively correlated with patient-reported function, such that a higher symptomatic-side hip CSA would be associated with higher patient-reported outcome scores.

Methods

Patient Selection

All MRI scans were prospectively collected as part of the standard of care for all patients undergoing primary hip arthroscopy for the treatment of FAIS between January 1, 2012, and June 1, 2015, and were available for review. Only MRI scans from patients who met the inclusion and exclusion criteria for the study were retrospectively reviewed and analyzed. The inclusion criteria were (1) a history, physical examination findings, and radiographic imaging findings consistent with FAIS; (2) symptoms that were not alleviated by nonsurgical treatment and that had a duration of greater than 3 months; (3) unilateral symptoms; (4) minimum 2-year follow-up; and (5) preoperative T1-weighted fast spin echo pulse sequence MRI of the entire pelvis from the level of the iliac crest superiorly to the level of the knee joint inferiorly, performed at our institution. The exclusion criteria included (1) patients with previous hip surgery including open or arthroscopic surgery; (2) bilateral FAIS; (3) patients who underwent an isolated iliopsoas release, iliotibial band lengthening, or hip abductor, hamstring, or any musculotendinous repair; (4) absence of MRI scans available for assessment; and (5) MRI of inadequate quality such as images containing a motion artifact as determined by the attending orthopaedic surgeon (A.V.S.) or radiologist. The patient flowchart is outlined in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) diagram (Fig 1).

Surgical Technique

All hip arthroscopic procedures were performed by a single, fellowship-trained surgeon (S.J.N.) with the patient under general anesthesia in the supine position on a standard traction table at a tertiary referral center for hip arthroscopy according to the previously described technique.[1-4] Standard portals were established under traction, and central-compartment pathology was addressed under traction. Traction was then released. The vertical limb of the T-capsulotomy was created through the distal anterolateral accessory portal and was used for visualization of the peripheral compartment. The procedures performed included acetabuloplasty for pincer deformities and femoral osteochondroplasty for cam deformities. The labrum was repaired when it was detached from the acetabular rim, and selective debridement was performed in patients with sufficient labral tissue and little or no labral detachment. Microfracture of the femoral head was performed with an awl for discrete chondral lesions. Other procedures included limited synovectomy, subspine decompression, trochanteric bursectomy, and heterotopic ossification excision. A dynamic examination under direct visualization and fluoroscopy confirmed the impingement was

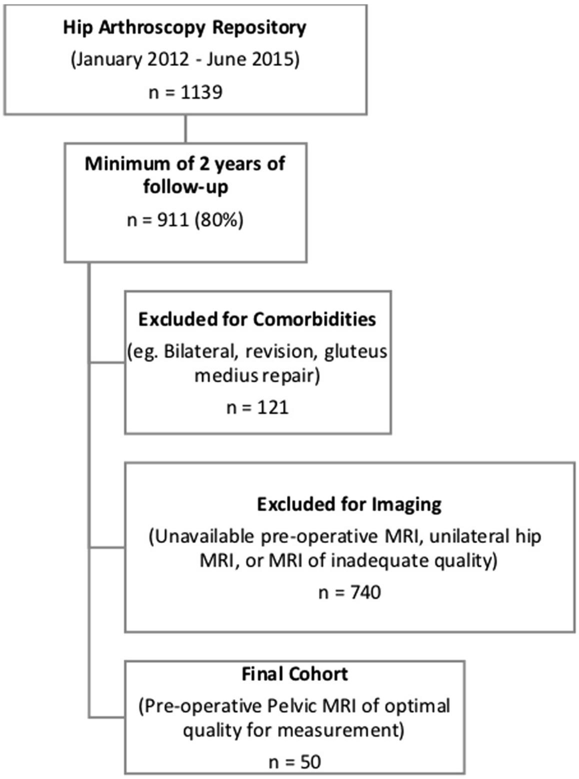

Fig 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) flowchart for patient selection. (MRI, magnetic resonance imaging.)

decompressed. The capsule was then selectively closed or plicated. Multiple high-strength sutures were passed through the vertical limb of the T-capsulotomy to plicate the iliofemoral ligament.

Postoperative Rehabilitation

Postoperative rehabilitation was initiated during the first postoperative week according to a standardized 16- to 18-week, 4-phase rehabilitation program.[18,19] Phase 1 of rehabilitation focused on joint protection through limited weight bearing, range-of-motion restrictions, and patient education. Phase 2 was directed at the restoration of normal gait, symmetrical active range of motion, and restoration of 80% of hip strength compared with the nonsurgical limb. Phase 3 emphasized continued muscle strengthening, neuromuscular training exercises, and core stabilization for a full return to recreational exercise and daily function without pain. Phase 4, if required, addressed the return to high-level functional activities such as sports or high-demand occupational training. Phase 4 exercises addressed power, agility, and skill.

Patient-Reported Outcomes of Preoperative and Postoperative Function

Patients completed hip-specific outcome measures to quantify the level of function both preoperatively and at a minimum of 2 years postoperatively. The patient-reported outcome measures included the Hip Outcome Score—Activities of Daily Living (HOS-ADL), Hip Outcome Score—Sport-Specific Subscale, modified Harris Hip Score (mHHS), and International Hip Outcome Tool 12-component score. Demographic data and intraoperative and surgical findings were also recorded for each patient.

Pain Level and Symptom Duration Measures

The preoperative pain level was quantified using a visual analog scale (VAS). Symptom duration was organized into 4 continuous levels consisting of the following time frames: 4 months or less, 4 to 12 months, 1 to 2 years, and more than 2 years. Symptom duration was treated as an ordinal-scale level of measurement.

Radiographic Analysis Using MRI

Pelvis MRI was performed on a 1.5-T system (Siemens, Erlangen, Germany) to measure muscle CSA on axial images. Patients were supine on the imaging table. In the supine position, the legs were fully extended and the feet were positioned in neutral rotation (i.e., 0° of hip rotation). Tape was used to ensure that the hip remained in a neutral position and to minimize lower-extremity movement during imaging. The FAIS MRI protocol at our institution involves a full pelvic MRI scan, which includes both hip joints. The scan is performed from the level of the iliac crest to the level of the knee joint to also evaluate femoral version in all patients with nonarthritic hip pain. All MRI cuts used in our analysis were specifically from axial images, and no axial oblique images were used for analysis. All images were obtained using a T1-weighted axial fast spin echo pulse sequence of the pelvis. The slice thickness was 4 mm, and the interslice gap was 5 mm. A picture archiving and communication system workstation (Mingtian, Ningbo, China) with an embedded region-of-interest (ROI) tool was used to acquire all measurements. To determine the CSA of each muscle, the ROI freehand tool was used to draw around the muscles of interest bilaterally, with care taken to avoid nearby bony structures and soft tissues, as performed in previous studies[9,20] (Figs 2-4). The ROIs around the muscles were manually drawn by 2 trained medical students (W.H.N.) under the supervision of an attending orthopaedic surgeon (A.V.S.) and radiologist (K.N.K.). Two trained raters were used to measure the muscle CSA to assess inter-rater reliability for these measurements. Three separate regions were determined to measure the pelvic and thigh muscles because these allowed standardization of measurements across patients[9,21] (Fig 5): slice A, in which the inferior border of the ilium was used to measure the CSA of the gluteus maximus, gluteus medius, gluteus minimus, iliopsoas, and piriformis muscles; slice B, in which the inferior border of the acetabulum (4- to 7-o'clock position on a

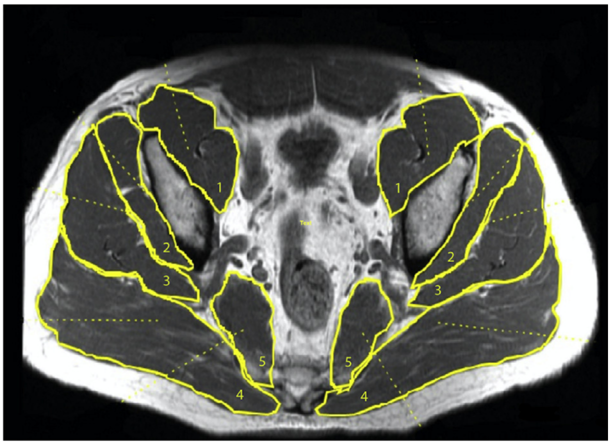

Fig 2. Cross-sectional area in slice A. 1, iliopsoas; 2, gluteus minimus; 3, gluteus medius; 4, gluteus maximus; 5, piriformis.

clock-face model) was used to measure the CSA of the tensor fascia lata, rectus femoris, sartorius, pectineus, obturator externus, and obturator internus muscles; and slice C, in which the most proximal aspect of the femoral diaphysis was used to measure the CSA of the vastus lateralis, vastus intermedius, vastus medialis, adductor magnus, adductor longus, and adductor brevis muscles.

Statistical Analysis

All data were inspected to determine whether all parametric statistical assumptions were met. In cases of violation of parametric statistical assumptions, nonparametric testing was used for analysis. One-way repeated-measures analyses of variance were used to determine differences between the symptomatic and asymptomatic limbs in patients with unilateral FAIS. Spearman rank correlations were used to determine associations between muscle group CSA and (1) symptom duration level, (2) preoperative pain level, and (3) postoperative patient-reported outcome scores. Inter-rater reliability was determined using a 2-way mixed-effect intraclass coefficient model and was determined to be excellent for a sample of 20 MRI measurements reviewed by 2 raters, with ICC(3,2) of 0.989 (95% confidence interval, 0.985-0.992; $P < .001$).[22] An a priori α level was set at $\alpha = .05$ to indicate statistical significance. All statistical analyses were performed using SPSS statistical software (IBM SPSS Statistics for Windows, version 23.0; IBM, Armonk, NY).

Results

Patient Demographic Data

A total of 50 patients met the inclusion criteria and were included in the study. The mean age of the patients was 34.2 years (95% CI 30.7-39.3 years), with a mean body mass index of 24.1 (95% CI 22.9-25.7), and 64% of the patients were women. For 24 patients (48%), the left hip was the operative limb. All intraoperative findings and hip arthroscopic procedures performed are presented in Table 1. All patients had significant improvements in postoperative patient-reported outcomes at a mean follow-up of 2.2 years (95% CI 2.1-3.9 years) (Table 2). The VAS pain score decreased from 6.5 (95% CI 6.0-7.1) preoperatively to 2.2 (95% CI 1.4-2.8) postoperatively ($P = .001$).

Symptomatic Limb CSA Versus Asymptomatic Limb CSA

Patients with unilateral FAIS showed reduced hip muscle CSAs of the gluteus maximus ($P = .007$), gluteus minimus ($P = .022$), and rectus femoris ($P = .028$) on the symptomatic side compared with the asymptomatic side (Table 3).

Association Between Hip Muscle CSA and Symptom Duration

Symptom duration was not significantly correlated with muscle CSA (Table 4).

Association Between Hip Muscle CSA and Preoperative Pain Level

The muscle CSAs of the pectineus ($\rho = 0.369$, $P = .008$), tensor fascia lata ($\rho = 0.358$, $P = .011$), obturator externus ($\rho = 0.339$, $P = .016$), and adductor longus ($\rho = 0.286$, $P = .044$) were significantly positively correlated with preoperative VAS pain scores. These correlations represented moderate correlations between muscle CSA and preoperative pain. No other muscles were correlated with preoperative pain in FAIS patients (Table 4).

Association Between Hip Muscle CSA and Postoperative Patient-Reported Outcomes

The CSA of the pectineus was negatively correlated with the HOS-ADL ($\rho = -0.349$, $P = .015$) and

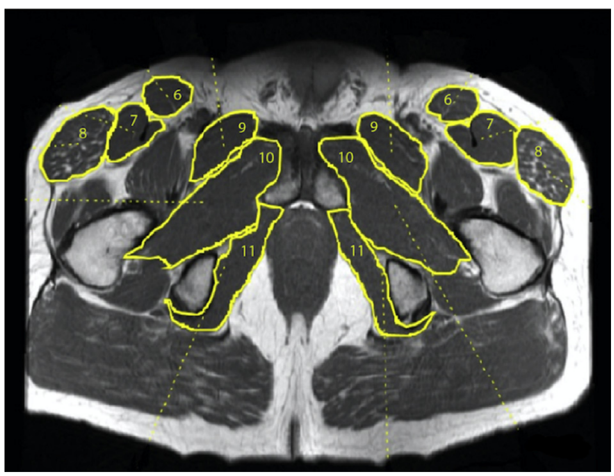

Fig 3. Cross-sectional area in slice B. 6, sartorius; 7, rectus femoris; 8, tensor fascia lata; 9, pectineus; 10, obturator externus; 11, obturator internus.

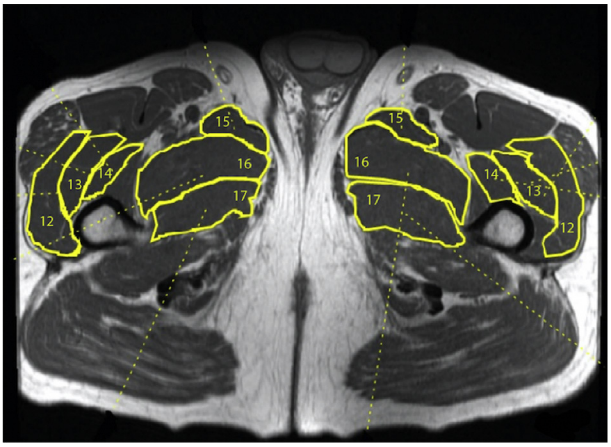

Fig 4. Cross-sectional area in slice C. 12, vastus lateralis; 13, vastus intermedius; 14, vastus medialis; 15, adductor magnus; 16, adductor longus; 17, adductor brevis.

positively correlated with the postoperative VAS pain score (ρ = 0.361, P = .010). The rectus femoris CSA was positively correlated with the VAS pain score (ρ = 0.310, P = .028). The CSA of the tensor fascia lata was negatively correlated with the HOS-ADL (ρ = −0.450, P = .001), Hip Outcome Score—Sport-Specific Subscale (ρ = −0.357, P = .015), mHHS (ρ = −0.341, P = .018), International Hip Outcome Tool 12-component score (ρ = −0.346, P = .033), and patient satisfaction measured using a VAS score (ρ = −0.364, P = .011). The CSA of the tensor fascia lata was positively correlated with the VAS pain score (ρ = 0.389, P = .005).

Discussion

This study compared hip muscle CSA between the symptomatic and asymptomatic hips in patients with unilateral FAIS. The results showed significant reductions in the hip muscle CSAs of the gluteus maximus, gluteus minimus, and rectus femoris muscles of the symptomatic hips compared with the asymptomatic hips in patients with unilateral FAIS. No other differences in hip muscle CSA were observed between the sides in patients with unilateral FAIS. The findings provide partial support for our hypothesis that muscle CSA would be reduced in the gluteus minimus and gluteus maximus muscles of the symptomatic hips in FAIS patients. Surprisingly, muscle CSA was not correlated with a symptom duration of greater than 2 years for any muscle. However, the pectineus, tensor fascia lata, obturator externus, and adductor longus muscles of the symptomatic hip showed significant correlations with preoperative pain level in patients with unilateral FAIS, although these associations were not consistent with our hypothesis of a negative correlation between hip muscle CSA and preoperative pain level. Although more research is needed to determine the functional implications of changes in muscle structure in FAIS patients, our findings provide information that may be used to establish radiographic biomarkers for patients with FAIS.

There is a considerable paucity of evidence on the hip muscle structure in patients with hip pathology.[9,15-17] To our knowledge, this is the first study to investigate hip muscle CSA in patients with a diagnosis of unilateral FAIS. Our results are consistent with those of other authors who compared hip muscle size on the affected side with that on the unaffected side in patients with mild and severe hip OA.[15] Grimaldi et al.[15] found that patients with severe hip OA showed significantly less muscle volume of the lower gluteus maximus muscles on the affected side compared with the unaffected side. However, these side-to-side differences were not found in patients with mild hip OA.[15] Of interest between the FAIS patients in our study and the patients with severe hip OA in the previous study is the similarity between the groups' self-reported pain and function quantified using the mHHS. The mean preoperative mHHS (± standard deviation) of FAIS patients in our study was 59.6 ± 14.6, whereas the patients with severe OA in the study by Grimaldi et al. had an mHHS of 58.1 ± 58.7. Given that both studies compared side-to-side differences in muscle size and both studies' samples reported similar levels of pain and functional limitation on the mHHS, it is not surprising that our results and their results are similar. Our results are also similar to those of previous authors who measured hip muscle CSA in men with and without hip OA.[9] Although these authors did not find differences in hip and pelvis muscle CSAs between men with and without hip OA, they did report side-to-side differences in gluteus maximus muscle size between the more severely affected hip and the contralateral better hip in men with hip OA.[9] As such, the finding of a reduced gluteus maximus muscle CSA between the hip with FAIS and the contralateral asymptomatic hip in our study adds important evidence to the overall general picture of side-

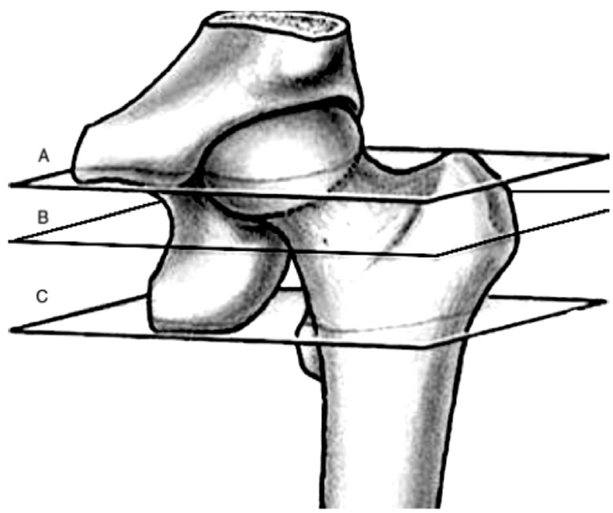

Fig 5. Standardized MRI slices used for measurements.

Table 1. Intraoperative Findings and Surgical Procedures

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Intraoperative finding	
Cam impingement	45 (90%)
Pincer impingement	43 (86%)
Mixed-type FAIS	40 (80%)
Labral tear	42 (84%)
Cartilage delamination	14 (28%)
Surgical procedure	
Labral repair	45 (90%)
Labral debridement	4 (8%)
Acetabuloplasty	43 (86%)
Femoral osteochondroplasty	49 (98%)
Capsular closure	50 (100%)
Trochanteric bursectomy	4 (8%)
Microfracture	3 (6%)

FAIS, femoroacetabular impingement syndrome.

to-side differences in hip muscle CSA in patients with intra-articular hip pathology.

Another finding in our study was a difference in the muscle CSA of the gluteus minimus muscle between the symptomatic and asymptomatic sides in patients with unilateral FAIS. This result is inconsistent with the findings of a previous study measuring gluteus minimus muscle volume in patients with mild and severe hip OA.[15] However, the authors did state that a significant 21.5% difference in gluteus minimus muscle volume existed between the sides in severe hip OA patients once the single outlier subject was removed from analysis.[15] Despite this lack of consistency in statistical differences between our study and the previous study regarding gluteus minimus size, when both studies' results are considered in context, it does seem that the findings are consistent. Further support again comes from the fact that the FAIS patients in our study and the patients with severe OA in the 2 studies by Grimaldi et al.[14,15] showed similar degrees of functional limitation and pain when measured with the mHHS.

Although it was surprising that no difference in the iliopsoas CSA was found between the symptomatic side and asymptomatic side, the difference in the rectus femoris muscle CSA between the sides in patients with unilateral FAIS provides evidence that changes in muscle structure may not occur uniformly throughout the functional muscle group, which refers to all of the primary and secondary hip flexor muscles. Although multiple investigations have reported reduced isometric hip flexion strength in patients with FAIS and acetabular labral tears, no evidence of changes in hip flexor muscle CSA has been found in previous investigations.[5,6] Despite finding differences in hip flexor muscle strength, Mendis et al.[6] did not find differences in hip flexor muscle CSA, including that of the rectus femoris muscle, when comparing the muscle CSA of acetabular labral tear patients with that of controls or when comparing the muscle CSA between sides in the acetabular labral tear group. These authors reported that acetabular labral tear patients showed similar activity levels to those of healthy controls, and they did not include measures of functional limitations or pain for this group in their study. Therefore, the lack of change in muscle CSA in the previous study by Mendis et al. may simply be because these patients showed minimal functional limitations and this prevented muscle atrophy of the hip flexor functional muscle group. Given that multiple studies have reported reductions in isometric hip flexor strength in patients with hip pathology, including FAIS, it could be argued that reduced CSA of the rectus femoris could contribute to observed reductions in the maximal hip flexion isometric force generated. However, it remains unknown whether reduced hip muscle CSA is related to disuse owing to pain and activity avoidance behaviors or is related to neurogenic origins, such as arthrogenous inhibition, which has been shown to occur at the hip joint.[23]

Our study investigated potential explanations for reduced muscle CSA in patients with unilateral FAIS by examining correlations between hip muscle CSA and pain, as well as duration of symptoms. Given that the patients in this study showed considerable functional limitations, it is reasonable that some of these changes in hip muscle CSA may be related to symptom duration and preoperative pain level. Surprisingly, the hip muscles found to exhibit reduced CSA between the symptomatic and asymptomatic sides were not associated with symptom duration or pain; however, other muscle groups did show significant positive associations with pain only. At first glance, the findings may seem counterintuitive in that greater muscle CSAs of the pectineus, tensor fascia lata, obturator externus, and adductor longus were positively correlated with preoperative pain. However, modeling studies of hip muscles have shown compensatory upregulation of hip muscle force output and muscle activation during gait in response to isolated muscle weakness.[24] Van der Krogt et al.[24] showed upregulation in muscle activation of the tensor fascia lata and pectineus muscles with

Table 2. Patient-Reported Outcomes

Patient-Reported Outcome	Preoperative	Postoperative	*P* Value
HOS-ADL	65.8 (60.5-71.8)	85.8 (78.4-93.1)	.001
HOS-SSS	45.4 (38.8-52.7)	72.8 (65.7-85.2)	.001
mHHS	59.6 (54.1-64.9)	78.6 (72.2-86.6)	.001
VAS pain level	6.54 (5.63-6.93)	2.18 (1.42-3.24)	.001
VAS satisfaction level	—	79.2 (69.5-86.7)	—
iHOT-12 score	36.9 (30.2-43.9)	68.1 (57.7-78.4)	.001

NOTE. Data are reported as mean (95% confidence interval).

HOS-ADL, Hip Outcome Score—Activities of Daily Living; HOS-SSS, Hip Outcome Score—Sport-Specific Subscale; iHOT-12, International Hip Outcome Tool 12-component form; mHHS, modified Harris Hip Score; VAS, visual analog scale.

Table 3. CSA of Hip and Thigh Muscles Measured on Both Symptomatic and Asymptomatic Sides

Muscle	CSA, mm^2 Symptomatic Side	CSA, mm^2 Asymptomatic Side	*P* Value
Gluteus maximus	3,671 (3,401.1-3,940.9)	3,824 (3,557.6-4,090.9)	.007*
Gluteus medius	2,701 (2,551.5-2,851.1)	2,784 (2,583.1-2,985.1)	.234
Gluteus minimus	1,219 (1,116.8-1,320.8)	1,297 (1,197.2-1,397.2)	.022†
Iliopsoas	1,510 (1,431.1-1,670.0)	1,568 (1,450.9-1,686.0)	.468
Piriformis	920 (837.8-1,001.2)	966 (879.3-1,052.2)	.169
Pectineus	720 (660.9-779.3)	739 (675.1-802.1)	.384
Sartorius	350 (314.5-385.3)	355 (321.0-388.5)	.595
Rectus femoris	586 (535.6-635.7)	625 (575.7-673.5)	.028†
Tensor fascia lata	583 (522.3-643.0)	596 (537.2-655.7)	.461
Obturator externus	2,035 (1,872.8-2,197.2)	2,065 (1,902.2-2,227.4)	.533
Obturator internus	740 (670.4-809.1)	719 (644.6-792.7)	.403
Vastus lateralis	1,026 (911.8-1,140.6)	1,085 (953.0-1,217.3)	.171
Vastus intermedius	497 (427.2-567.7)	504 (446.3-561.6)	.822
Vastus medialis	313 (266.5-358.5)	322 (281.5-363.2)	.514
Adductor magnus	555 (491.9-617.6)	552 (485.7-617.6)	.856
Adductor longus	1,072 (942.0-1,202.6)	1,029 (906.5-1,151.3)	.200
Adductor brevis	1,101 (983.5-1,219.5)	1,101 (981.8-1,220.6)	.993

NOTE. Data are reported as mean (95% confidence interval).
CSA, cross-sectional area.
*Significant at .01 level.
†Significant at .05 level.

isolated iliopsoas weakness and greater activity of the tensor fascia lata with isolated rectus femoris weakness. In addition, iliopsoas weakness resulted in increased muscle force output of the adductor longus muscle, and gluteus maximus weakness resulted in upregulation in muscle activation of the adductors.[24] Therefore, when the reductions in muscle CSA results and correlations in our study are considered in combination and in the context of previous literature, it seems that in patients with unilateral FAIS, compensations may have developed that resulted in reductions in muscle CSAs of some muscle groups with compensatory changes in adjacent muscle groups at the hip, which may explain the positive association between muscle CSA and preoperative pain.

The findings of this study have important implications for rehabilitation protocols for patients with FAIS. A recent systematic review reported that patients with FAIS show significantly less strength than healthy controls and that this is an important clinical sign to be addressed in rehabilitation.[25] Previous studies have also identified that CSA positively correlates with strength and that decreased CSA may be responsible for up to 90% of the decreased strength about the hip.[26,27] Masuda et al.[28] examined a CSA relation about the hip between the dominant and nondominant legs in healthy soccer players. They found minimal differences in healthy participants except for a small difference in the proximal adductor CSA. These findings suggest that a decrease in the CSA in the dominant leg and associated decrease in strength due to early hip pathology may place the athlete at increased risk of injury because of poor biomechanics. Therefore, on the basis of our study's findings of reduced muscle CSA and its potential association with muscle strength and hip biomechanics, these results provide considerable support for the inclusion of muscle strengthening and movement retraining for patients with FAIS.

Limitations

Although this study does add important information to the current literature on FAIS, several limitations must be considered. Our study is limited to the

Table 4. Correlations Between Muscle CSA, Preoperative Pain, and Symptom Duration

	Symptom Duration		Pain	
	ρ	*P* Value	ρ	*P* Value
Gluteus maximus	0.196	.173	0.190	.186
Gluteus medius	−0.056	.697	0.074	.611
Gluteus minimus	−0.015	.920	0.116	.424
Iliopsoas	−0.057	.592	0.086	.554
Piriformis	−0.165	.253	0.178	.215
Pectineus	−0.007	.964	0.369	.008*
Rectus femoris	0.012	.935	0.252	.078
Sartorius	−0.015	.917	0.087	.546
Tensor fascia lata	0.169	.240	0.358	.011†
Obturator externus	−0.031	.831	0.339	.016†
Obturator internus	0.042	.774	−0.055	.706
Vastus medialis	0.050	.732	0.125	.306
Vastus intermedius	−0.097	.502	0.107	.461
Vastus lateralis	0.028	.845	0.208	.148
Adductor magnus	0.072	.620	0.083	.569
Adductor longus	0.131	.364	0.286	.044†
Adductor brevis	−0.043	.766	0.227	.113

CSA, cross-sectional area; ρ, Spearman rank coefficient.
*Significant at .01 level.
†Significant at .05 level.

radiographic findings, with no muscle strength testing having been prospectively collected in the patient study group. Although this did limit our ability to determine a potential relation between muscle CSA and strength in patients with FAIS, previous studies have reported significant correlations between muscle strength and corresponding MRI measurement of the CSAs of these muscle groups.[28-33] Another limitation of this study was that muscle CSA was not measured postoperatively. Therefore, although we reported correlations between preoperative muscle CSA and postoperative outcomes, the conclusions that can be drawn from these data are limited. Our current results provide initial information on muscle CSA in patients with FAIS and will guide our future investigations to explore this potential relation in this patient population. The significant differences in our study suggest that a decrease in CSA would be associated with a decrease in force generation because CSA comparisons were made within the same patient on the contralateral side.

Conclusions

Patients with unilateral FAIS have a significantly decreased muscle CSA in the symptomatic hip compared with the asymptomatic hip. The symptomatic-side hip muscle CSA was correlated with the preoperative VAS pain level. The association between the muscle CSA and preoperative pain level may represent a compensatory change in muscle function around the hip joint in patients with unilateral FAIS.

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