Frequency of Subspine Impingement in Patients With Femoroacetabular Impingement Evaluated With a 3-Dimensional Dynamic Study

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Purpose: (1) To estimate the frequency of subspine impingement (SSI) morphology in patients with a diagnosis of femoroacetabular impingement (FAI) and (2) to describe the performance of the alpha angle, range of motion, and femoral and acetabular anteversion for the identification of cases with and without SSI morphology. **Methods:** We performed a retrospective observational study of patients with symptomatic FAI evaluated by computed tomography between February 2015 and June 2017. SSI morphology was identified using a 3-dimensional dynamic study with Move Forward software. A case was considered positive if a contact area of the anterior inferior iliac spine with the femoral neck was evidenced. Measurements of acetabular anteversion, femoral anteversion, the lateral center-edge angle, the alpha angle, and the neck-shaft angle, as well as range-of-mobility data, were collected. **Results:** The study included 135 patients (194 hips), with a mean age of 39.1 ± 13.9 years; 65.2% were women. SSI morphology was found in 23.7% of hips (46 hips) (95% confidence interval, 18.3%-30.2%). Of the hips identified with SSI, 52.2% had a type I anterior inferior iliac spine, 41.3% had type II, and 6.5% had type III. In hips with SSI, median femoral anteversion was 5.6° (interquartile range, 2.1°-7.5°) and values of less than 8° would increase the suspected SSI morphology (81.8% sensitivity, 70.5% specificity). **Conclusions:** SSI morphology is a frequent finding in patients with symptomatic FAI through a 3-dimensional dynamic study. A decrease in femoral anteversion could be considered a useful criterion to suspect SSI morphology. **Level of Evidence:** Level IV, case series.

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Femoroacetabular impingement (FAI) is recognized as one of the main causes of hip pain in young adults. It is characterized by irregular contact between the acetabulum and femoral head-neck joint.[1] Recently, there has been an increase in interest in the origins of extra-articular injuries that can contribute to hip pain.[2,3]

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Among the group of extra-articular impingement conditions, subspine impingement (SSI) is identified by a morphologic alteration in the anterior inferior iliac spine (AIIS), which consequently generates an irregular contact with the femoral neck.[4] A clinical characteristic that is common in both FAI and SSI is pain induced by the impingement test of flexion—adduction—internal rotation (FADIR); however, with SSI, it is also common to find pain as well as a limit in functionality when maximum flexion is generated.[5]

As a common practice, arthroscopic treatment in FAI is known to give satisfying results; however, there is a group of patients who continue to have pain and restriction in range of mobility despite the procedure.[6] Larson et al.[7] studied 79 cases (85 hips) that underwent revision surgery for residual FAI and found a prominent or low AIIS in 39 hips. They concluded that the identification as well as treatment of a prominent or low AIIS is a predictive factor of greater improvement in the modified Harris Hip Score from the preoperative baseline value. In 100 patients who underwent arthroscopy for FAI on the affected hip, Amar et al.[8] found that 21% of them also had a low AIIS with anterior labral lesions. These findings suggest that an unknown coexistence of FAI and SSI could influence the clinical outcome of hip arthroscopy.

With the aid of advanced software in imaging studies and the incorporation of diagnostic tools, an improved identification of pathologies causing hip pain from a different source than the intra-articular source has emerged. Through implementation of axial tomography with 3-dimensional (3D) reconstruction, it is possible to visualize areas of injuries in the subspinal area and calculate measurements such as femoral and acetabular anteversion, which are essential in the pathogenesis of FAI.[5] The objectives of this study were as follows: (1) to estimate the frequency of SSI morphology in patients with a diagnosis of FAI and (2) to describe the performance of the alpha angle, range of motion, and femoral and acetabular anteversion for the identification of cases with and without SSI morphology.

Methods

We performed a retrospective observational study of patients with a diagnosis of symptomatic FAI who underwent a 3D dynamic study with a computed tomography (CT) scan between February 2015 and June 2017. The diagnosis of FAI was made based on clinical data, the flexion—adduction—internal rotation (FADIR) test, and morphologic alterations (cam or pincer) through radiographic images. The institutional hip arthroscopy registry was reviewed to identify patients with a 3D dynamic study. The cases were eligible if they had hip pain and showed abnormal contact between the acetabulum and femoral head-neck joint in a 3D dynamic study. Our institutional review board approved this study.

The radiologic cuts for the hip and knee and 3D reconstruction were achieved with CT scans (Brilliance CT 6 Slice; Philips Healthcare, Cleveland, OH) and Clinical Graphics software (Move Forward; Zimmer Biomet, Miami, FL), respectively, in the same institution and under a standardized protocol. The software creates segmentations and subsequent 3D models of the femoroacetabular morphology using an active shape modeling technique.[9] The software uses the 3D models to simulate range of motion of the femoroacetabular joint based on the recommendations of the International Society of Biomechanics[10] and the equidistant method described by Puls et al.[11] The measurements of acetabular anteversion, femoral anteversion, the lateral center-edge (LCE) angle, the alpha angle, and the neck-shaft angle were obtained by the same software. Range-of-motion data (i.e., flexion, internal rotation, and external rotation) were gathered from medical records.

The SSI morphology was assessed using 3D CT dynamic reconstruction through a consensus panel of 3 orthopaedic surgeons (M.B., R.C., and B.A-B.). Every image was revised until the panel reached a consensus. A case would be considered positive if a contact area of the AIIS with the femoral neck was evidenced (Fig 1). The AIIS was classified into 3 morphologic variants according to Hetsroni et al.[5] Type I was defined by a smooth ilium wall between the AIIS and the acetabular rim, type II was classified as the AIIS prominences extending from the AIIS to the acetabular rim, and type

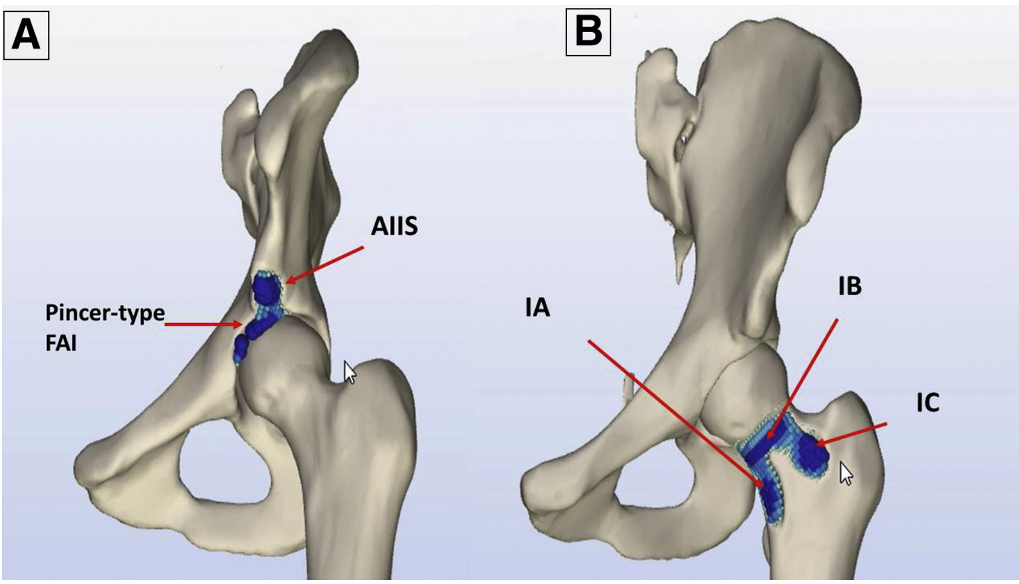

Fig 1. Three-dimensional dynamic reconstruction of left hip. (A) Hip with pincer-type femoroacetabular impingement (FAI) and subspine impingement morphology. The abnormal contact between the anterior inferior iliac spine (AIIS) and femoral neck is evidenced. (B) Area of impingement on AIIS with femoral side during hip flexion movement (IA); area of impingement on acetabular rim with femoral side during flexion-adduction and internal rotation (IB); and area of impingement on AIIS with femoral side during flexion-adduction and internal rotation (IC).

III was defined by the AIIS prominences extending distally to the anterosuperior acetabular rim.

Statistical Analysis

All of the analyses were conducted using Stata 13 (StataCorp, College Station, TX) and R.3.3.3 (R Foundation for Statistical Computing, Vienna, Austria) with the "nlme" package. The Fisher exact test and χ-square test were used to compare the groups according to the AIIS type. A mixed linear regression model was used to evaluate the differences in range of motion, the alpha angle, and femoral and acetabular anteversion according to SSI morphology, adjusted for the individual effect. To calculate the diagnostic performance of femoral and acetabular anteversion in cases with SSI morphology, we used receiver operating characteristic curves with their 95% confidence intervals (CIs). $P < .05$ was considered statistically significant.

Results

The images of 194 hips were studied, and only 147 hips had a knee cut by which to evaluate femoral anteversion. A total of 135 patients (194 hips) were included in the study, with a mean patient age of 39.1 ± 13.9 years; 65.2% were women. In 23.7% of hips (95% CI, 18.3%-30.2%), we observed abnormal contact between the AIIS and femoral neck. A greater decrease in internal rotation and flexion was found in patients identified with SSI morphology ($P < .05$). The physical examination findings and demographic characteristics of the patients are described in Table 1.

The AIIS classification of the hips was as follows: 52.2% were classified as type I; 41.3%, as type II; and 6.5%, as type III. There were no variations in the neck-shaft angle and alpha angle between the groups; nonetheless, there was a tendency toward a greater LCE angle in hips with SSI morphology. Decreases in femoral and acetabular anteversion were observed in the SSI group ($P < .05$) (Table 2).

Table 1. Demographic Data and Physical Examination Findings

	FAI (n = 148)	FAI and SSI (n = 46)	*P* Value
Sex,[†] n (%)			.068
Female	69 (69.7)	19 (52.8)	
Male	30 (30.3)	17 (47.2)	
Age,[†] yr			.492
Mean ± SD	39.6 ± 13.8	37.7 ± 14.5	
Range	13-69	14-67	
Flexion, median (IQR), °	120 (120-130)	110 (100-120)	<.001*
External rotation, median (IQR), °	45 (40-50)	45 (40-60)	.797
Internal rotation, median (IQR), °	40 (20-40)	20 (10-32.5)	.001*

FAI, femoroacetabular impingement; IQR, interquartile range; SD, standard deviation; SSI, subspine impingement.
*$P < .05$.
[†]Overall, 135 patients.

Table 2. Findings of 3D Dynamic Study

	FAI (n = 148)	FAI and SSI (n = 46)	*P* Value
Laterality, n (%)			.797
Left	74 (50.0)	24 (52.2)	
Right	74 (50.0)	22 (47.8)	
Type of spine, n (%)			<.001*
I	127 (85.8)	24 (52.2)	
II	21 (14.2)	19 (41.3)	
III	0 (0.0)	3 (6.5)	
Neck-shaft angle, °			.535
Mean ± SD	131.6 ± 6.0	132.8 ± 6.0	
Range	118.4-153	119.8-143.6	
Femoral anteversion,[†] median (IQR), °	10.9 (7.2-19.4)	5.6 (2.1-7.5)	<.001*
Acetabular anteversion, °			.019*
Mean ± SD	20.3 ± 6.4	15.7 ± 6.3	
Range	−0.7 to 35.5	1.5-27.8	
Alpha angle, median (IQR), °	43.1 (40.3-48.1)	44.5 (42.4-51.9)	.770
LCE angle, °			.060
Mean ± SD	35.5 ± 7.8	39.3 ± 8.2	
Range	18.4-61.4	19.4-60.1	
Tönnis angle, median (IQR), °	2.9 (−1.67 to 8.5)	−0.1 (−4.0 to 4.2)	.063

FAI, femoroacetabular impingement; IQR, interquartile range; LCE, lateral center edge; SD, standard deviation; SSI, subspine impingement; 3D, 3-dimensional.
*$P < .05$.
[†]Overall, 147 cases, 35 of which had SSI.

Femoral anteversion was calculated with the information gathered for 147 hips; of these, 112 were identified as having FAI whereas 35 had FAI and SSI morphology. Statistically significant differences were observed in femoral and acetabular anteversion, the LCE angle, internal rotation, and flexion in hips with and without SSI in which the AIIS was classified as type I. In those in which the AIIS was classified as type II or III, there were only differences in the flexion angle. Among the cases of SSI morphology, no significant differences were found between AIIS types in range of motion and acetabular anteversion; however, hips with a type I AIIS presented a decrease in femoral anteversion (Table 3).

The area under the curve was 0.754 (95% CI, 0.657-0.850) for femoral anteversion and 0.764 (95% CI, 0.679-0.850) for acetabular anteversion; therefore, these findings indicated adequate criteria to distinguish cases without SSI morphology (Fig 2). An angle of less than 8° for femoral anteversion was determined as the optimal cutoff value to suspect SSI morphology, with 81.8% sensitivity and 70.5% specificity. We more frequently found cases with SSI morphology using femoral anteversion with an odds ratio of 10.8. The optimal cutoff value identified for acetabular

Table 3. Imaging Findings and Results From 3D Dynamic Study for Type of Spine in Patients With SSI

	Type I Spine (n = 151)			Type II or III Spine (n = 43)			*P* Value for Type of Spine: FAI and SSI
	FAI (n = 127)	FAI and SSI (n = 24)	*P* Value	FAI (n = 21)	FAI and SSI (n = 22)	*P* Value	
Neck-shaft angle, °			.748			.816	.235
Mean ± SD	131.3 ± 6.2	131.7 ± 6.4		133.5 ± 4.4	133.9 ± 5.5		
Range	118.4-153	119.8-140.3		120.8-139	121.1-143.6		
Femoral anteversion,[†] median (IQR), °	12 (7.3-19.8)	5.4 (1.4-7.3)	<.001*	9.9 (6.6-11.7)	7.5 (2.8-11.1)	.221	.055
Acetabular anteversion, °			<.001*			.798	.747
Median ± SD	20.9 ± 6.2	15.4 ± 7.1		16.5 ± 6.6	16.1 ± 5.4		
Range	−0.7 to 35.5	1.5-27.8		6-30	4.6-26.8		
LCE angle, °			.016*			.798	.858
Median ± SD	34.8 ± 7.8	39.1 ± 9.1		40.1 ± 5.8	39.5 ± 7.3		
Range	18.4-61.4	19.4-57.3		28.3-55.6	29.7-60.1		
Flexion, °			<.001*			.017*	.073
Median ± SD	122.5 ± 10.48	112.9 ± 11.2		116.7 ± 14.6	106.8 ± 11.3		
Range	90-150	90-130		90-140	80-120		
External rotation, median (IQR), °	45 (40-50)	45 (40-60)	.499	45 (40-52.5)	45 (30-50)	.849	.389
Internal rotation, median (IQR), °	40 (30-40)	20 (6.2-30)	<.001*	30 (10-35)	20 (10-40)	.701	.696

FAI, femoroacetabular impingement; IQR, interquartile range; LCE, lateral center edge; SD, standard deviation; SSI, subspine impingement; 3D, 3-dimensional.

*$P < .05$.

[†]Overall, 112 cases with FAI (95 with type I spines and 17 with type II or III spines) and 35 cases with FAI and SSI (17 with type I spines and 18 with type II or III spines).

anteversion was not clinically significant because the value was within the normal range (Table 4).

Discussion

The principal outcome of this study suggests that SSI morphology is frequent, with a prevalence of approximately 2 in every 10 cases of symptomatic FAI (22.7%). The number of cases surgically revised after arthroscopic or open treatment of FAI has increased in recent years, allowing us to infer the possibility of an extra-articular pathology causing hip pain, which can be present simultaneously with an intra-articular pathology or can be an isolated injury.[7,12]

In our study, we found cases predominantly with type I AIIS, a finding similar to that reported by Zaltz et al.,[13] who identified a greater prevalence of type I AIIS in a group of 53 patients with symptomatic FAI. Hetsroni et al.[5] found a major proportion of type II AIIS in men (75%) and women (76%) and discarded the possibility of impingement in normal spines (type I). Hapa et al.[14] described cases of SSI with type I AIIS that were characterized by an elevated range of flexion. A predominant outcome in our study was that half of our cases with SSI were identified with type I AIIS, a finding that can be explained by a decrease in femoral anteversion (5.4° for SSI vs 12° for FAI), which can be a determinant parameter in identifying SSI independent of AIIS type. Hetsroni et al. described that type II and III spines are associated with an irregular contact, with the type III AIIS in greater proportion. Balazs et al.[15] showed that type II or III AIIS had a high sensitivity (80%) and low specificity (23%) to discriminate patients with symptomatic hip impingement. In addition, they found positive and negative predictive values of 10% and 91%, respectively.

In cases of SSI morphology, a tendency toward an increase in the LCE angle compared with the FAI group was observed. These data hold a close relation to what Schindler et al.[16] reported, which indicates that an increase in the LCE angle might suggest morphologic lateral changes in the AIIS.

A femoral anteversion angle of less than 8° could be considered an optimal cutoff to distinguish patients

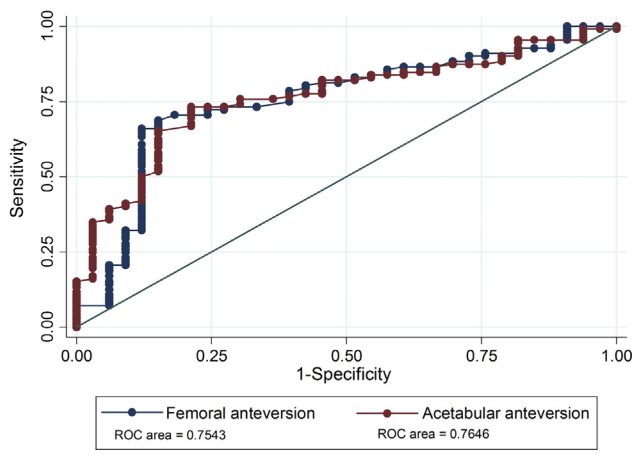

Fig 2. Receiver operating characteristic (ROC) curves of femoral and acetabular anteversion to identify femoroacetabular impingement morphology and femoroacetabular impingement plus subspine impingement morphology. The ROC area has a maximum value of 1.0. The curves closer to the upper left-hand corner have a higher discriminant capacity; the curves closer to the diagonal have a less accurate discriminant capacity.

Table 4. Optimal Cutoff Values for Identification of SSI With Femoral and Acetabular Anteversion

	Cut Point, °	Sensitivity (95% CI), %	Specificity (95% CI), %	PPV (95% CI), %	NPV (95% CI), %	OR (95% CI)
Femoral anteversion	<8	81.8 (63.9-92.4)	70.5 (61.0-78.6)	45.0 (32.3-58.3)	92.9 (84.7-97.1)	10.7 (4.1-28.5)
Acetabular anteversion	<18	69.6 (54.1-81.8)	67.6 (59.3-74.9)	40.0 (29.4-51.6)	87.7 (79.9-92.9)	4.8 (2.3-9.7)

CI, confidence interval; NPV, negative predictive value; OR, odds ratio; PPV, positive predictive value; SSI, subspine impingement.

with extra-articular pathologies as having SSI, with a sensitivity of 81.8% and specificity of 70.5%. Therefore, a decrease in femoral anteversion could be useful to suspect SSI morphology, even in patients with a type I AIIS. Throughout the physical examination, it is possible to presume the existence of SSI if there is induced pain by maximum flexion of the hip, independent of the intra-articular pathology.

Acetabular anteversion and a decrease in femoral offset are considered a bony dysmorphism that produces mechanical alterations and consequently provokes areas of irregular contact in the nondysplastic hips of young patients.[17] In populations without musculoskeletal conditions, an estimate of acetabular anteversion of $23.2° \pm 6.6°$ was measured; thus, a value of less than 10° would be considered a significant clinical finding (−2 standard deviations).[18] In an attempt to distinguish cases with SSI, we used acetabular anteversion lower than 18° as a cutoff value, which can suggest the presence of impingement with a sensitivity of 69.6% and specificity of 67.6%. However, this cutoff point would not describe the biomechanical alterations to identify SSI cases given that the value was within the normal range.[19]

A decrease in flexion and internal rotation was identified in the cases with SSI morphology compared with the groups of patients with FAI only, and these results were similar to those reported by Hetsroni et al.[5] In type I AIIS, this mechanical decrease could be associated with femoral retroversion, which has the effect of restricting range of movement.

According to the literature, SSI is defined as a condition based on the bony prominence morphology (type II-III) that, when surgically resected, undergoes improvements in pain, function, and range of motion.[2,3,14,20] It is important to single out other causes of extra-articular impingement, such as central iliopsoas impingement, ischiofemoral impingement, and major trochanter impingement with the pelvis. Patients can be referred for direct therapy, and surgical reinterventions for extra-articular causes can be decreased, even when there is an optimal treatment for intra-articular pathologies.[7]

Hetsroni et al.[5] proposed a systematic method to characterize AIIS variants based on the relation between the distal extension of the AIIS and the anterosuperior acetabular rim through 3D CT reconstructions. Although the original study reported 100% interobserver agreement,[5] a recent work published by Balazs et al.[15] showed moderate interobserver reliability with a κ coefficient of 0.50 (95% CI, 0.47-0.5). According to their conclusions, the discrepancies between examiners could be explained by the fact that the original classification system does not describe how much ilium must separate the acetabular rim from the inferior extent of the AIIS to discriminate between type I and type II. In other cases, the disagreement was attributed to the presence of small prominences inferior to the AIIS with a smooth ilium wall.

Limitations

The limitations encountered in this study were as follows: (1) The study was based on a set of 64 axial cuts from a CT scan followed by a 3D dynamic reconstruction, a tool that is not available in all institutions. (2) The cases were enrolled from a single institution, which does not allow generalization and estimation of the frequency of SSI morphology with accuracy. (3) All cases included in this study had hip pain; however, we did not establish whether the pain could be attributed to FAI or SSI. In this regard, the findings of this work should not be generalized to the symptomatic SSI, and it is necessary to perform a complete physical examination in conjunction with radiologic images as part of the decision to operate. (4) The reading of images was not conducted independently by the 3 orthopaedic surgeons. For this reason, the interobserver reliability and intraobserver reliability were not reported. Nonetheless, we believe that the identification of abnormal contact between the AIIS and femoral neck (SSI morphology) would not be affected because the software performs it automatically.

Conclusions

SSI morphology is a frequent finding in patients with symptomatic FAI through a 3D dynamic study. A decrease in femoral anteversion could be considered a useful criterion to suspect SSI morphology.

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