Anterior Inferior Iliac Spine Morphology Correlates With Hip Range of Motion: A Classification System and Dynamic Model

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Abstract

Background The anterior inferior iliac spine (AIIS) contributes to hip dysfunction in patients with symptomatic impingement and resection of a prominent AIIS can reportedly improve function. However, the variability of the AIIS morphology and whether that variability correlates with risk of associated symptomatic impingement are unclear.

Questions/purposes We characterized AIIS morphology in patients with hip impingement and tested the association between specific AIIS variants and hip range of motion.

Each author certifies that he or she, or a member of his or her immediate family, has no funding or commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.

All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research* editors and board members are on file with the publication and can be viewed on request. Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained. This work was performed at the Hospital for Special Surgery, New York, NY, USA.

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Methods We evaluated three-dimensional CT reconstructions of 53 hips (53 patients) with impingement and defined three morphological AIIS variants: Type I when there was a smooth ilium wall between the AIIS and the acetabular rim, Type II when the AIIS extended to the level of the rim, and Type III when the AIIS extended distally to the acetabular rim. A separate cohort of 78 hips (78 patients) with impingement was used to compare hip range of motion among the three AIIS types.

Results Mean hip flexion was limited to 120°, 107°, and 93° in hips with Type I, Type II, and Type III AIIS, respectively. Mean internal rotation was limited to 21°, 11°, and 8° in hips with Type I, Type II, and Type III AIIS, respectively.

Conclusions When the AIIS is classified into three variants based on the relationship between the AIIS and the acetabular rim in patients with impingement, Type II and III variants are associated with a decrease in hip flexion and internal rotation, supporting the rationale for considering AIIS decompression for variants that extend to and below the rim.

Level of Evidence Level III, diagnostic study. See Guidelines for Authors for a complete description of levels of evidence.

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Introduction

Femoroacetabular impingement is recognized in recent years as a predominant cause of hip pain and labral tears in a young population [1, 3, 5, 6, 9, 11]. Morphological characteristics most commonly associated with this diagnosis include decreased head-neck offset [1, 5, 6, 9] and retroversion of the acetabulum [11]. Corrective bony procedures in this population are therefore aimed to improve hip kinematics [2] by increasing the head-neck offset and sphericity of the proximal femur and recreating normal version and coverage of the acetabular rim.

Recently, several studies [4, 8, 10] have demonstrated that prominence of the anterior inferior iliac spine (AIIS) could also contribute to hip impingement. In these cases, terminal hip flexion results in impingement of the caudad prominence (ie, most distal extension) of the AIIS against the femoral neck. Improvement in hip flexion, decreased pain, and overall improvement in hip function have been reported after resection of the AIIS prominence [4, 8, 10]. Although this information supports the rationale that prominence of the AIIS could contribute to hip dysfunction and may therefore benefit from surgical decompression, the variable AIIS morphology has not been characterized nor has any correlation of any particular AIIS dysmorphism associated with the risk of symptomatic hip impingement. Consequently, a potential mechanical contributor (ie, prominent AIIS) to hip impingement in young patients with hip dysfunction may be underappreciated.

We therefore developed a classification system of AIIS morphologies in patients with hip impingement and tested the association between specific AIIS types and hip ROM.

Patients and Methods

To examine and classify AIIS morphologies in patients with symptomatic impingement, we reviewed our hip arthroscopy registry between June 2008 and June 2010 and identified 53 patients (28 hips of 28 males, 25 hips of 25 females) between the ages of 15 and 30 years who underwent arthroscopic cam decompression, rim decompression, and labral repair or débridement by the senior author (BTK). In three patients (all males), the AIIS was also decompressed in addition to the intraarticular procedures (ie, cam decompression, rim decompression, labral repair or débridement) using a technique recently described [4]. All patients had insidious onset of hip pain or pain that followed low-energy sports trauma, positive hip impingement sign [7], Tönnis Grade 0 to 1 [12], and preoperative evaluation that included CT scans performed in a single imaging institution according to a standard protocol and setup with the patient in the supine position. We excluded

patients with a history of high-energy hip trauma (ie, fracture or dislocation), history of surgery involving the femur or pelvis, Tönnis Grade 2 or above, proliferative disease of the hip (ie, synovial chondromatosis, pigmented villonodular synovitis), neuromuscular disease (ie, cerebral palsy), Legg–Calvé–Perthes deformity, and developmental dysplasia of the hip. No patients were recalled specifically for this study. All data were obtained from medical records and images. Institutional review board approval for this study was obtained through our institutional review panel and was part of a subset of ongoing data collection from our hip preservation registry.

The CT scanner (GE Lightspeed VCT 64 channel scanner; GE Medical Systems, Milwaukee, WI, USA) provided on our workstation (GE Centricity PACS-IW work station; GE Medical Systems) images acquired every 2.5 mm through the hips and knees. We used a modified radiation exposure protocol. Traditional CT hip exposure dose ranges between 6.8 and 8.2 Rad compared with three-view radiographs of the hip/pelvis, which are 3.4 Rad (skin exposure). Our modified exposure protocol decreases mAs to a dose of 1.6 Rad and allows for postimaging computer reformatting for optimal data acquisition.

To examine and classify AIIS morphologies, three-dimensional (3-D) CT reconstructions of the hips were used. The 3-D rendering was performed on the GE advantage workstation (running version 4.3 software) that created 11 3-D views of the hip, each view rotated in the axial plane 32.7° relative to the previous view, thus forming a 360° view of each hip (ie, $11 \times 32.7^\circ = 360^\circ$). Among the 11 3-D views of each hip, we identified three views that, in addition to the AP view (Fig. 1A), consistently provided excellent delineation of the shape of the AIIS and the level to which the AIIS extended distally in relation to the anterosuperior acetabular rim. These three views are: (1) a view internally rotated once 32.7° relative to the AP view (Fig. 1B); this view was termed the “head-on AIIS view” because the AIIS is seen straight head-on in this view; (2) a view internally rotated two 32.7° intervals relative to the AP view (Fig. 1C); this view was termed the “internal rotation AIIS view” because the AIIS is seen from an internally rotated position in this view; (3) a view internally rotated four 32.7° intervals relative to the AP view (Fig. 1D); this view was termed the “ischium AIIS view” because the ischium is seen straight from the back in this view. By examining the 53 hips on these four 3-D views, we were able to define three AIIS types that addressed all AIIS shapes: Type I: there is smooth ilium wall without bony prominences between the caudad level of the AIIS and the acetabular rim (Fig. 2A–D); Type II: there are bony prominences on the ilium wall extending from the caudad area of the AIIS to the acetabular rim (Fig. 3A–D), or alternatively the AIIS sits just at the level of the

Fig. 1A–D Views used for determining AIIS morphological variant in a right hip. (A) AP view; (B) “head-on AIIS view”; (C) “internal rotation AIIS view”; (D) “ischium AIIS view.” AIIS is marked with a star. Ischium is marked with a white circle on the “ischium AIIS view.”

Fig. 2A–D Type I AIIS variant in a left hip. There is a smooth ilium wall (arrowheads) between the caudal level of the AIIS and the acetabular rim. (A) AP view; (B) “head-on AIIS view”; (C) “internal rotation AIIS view”; (D) “ischium AIIS view.” AIIS is marked with a star.

Fig. 3A–D Type II AIIS variant in a left hip. Bony prominences (arrowheads) are seen on the ilium wall extending from the caudal area of the AIIS to the acetabular rim. (A) AP view; (B) “head-on

AIIS view”; (C) “internal rotation AIIS view”; (D) “ischium AIIS view.” AIIS is marked with a star.

acetabular rim and appears as a “roof-like” prominence over the hip (Fig. 4A–D); and Type III: the AIIS extends distally to the anterosuperior acetabular rim. In this case, the AIIS interferes with the continuity of the acetabular rim on the AP view or “head-on AIIS view” or both and it has a downward “spur appearance” (Fig. 5A–D).

After development of the classification system, we tested the interobserver variability of classifying the AIIS types among three independent investigators (an orthopaedic surgeon [IH], a musculoskeletal radiologist [GD], and a BA research assistant [RMZ]) by calculating weighted Kappa (wKappa) coefficients.

To test the association between each of the three AIIS types and terminal hip motion, our hip registry was reviewed for patients with signs of impingement who had primary hip arthroscopic procedures performed by the senior author between March 2010 and May 2012 for labral repair or débridement, rim trimming, and cam decompression. Hips with Type II and III AIIS also had bone decompression at the distal extension of the AIIS according to a technique recently described [4]. Inclusion criteria for this stage of the study were: age between 15 and 30 years, femoral version range 10° to 20°, acetabular version range 0° to 20°, alpha angle range 60° to 80°, and lateral center-edge angle > 25°.

Fig. 4A–D Type II AIIS variant in a right hip. The AIIS sits just at the level of the acetabular rim (arrowheads) and appears as a “roof-like” prominence over the hip. (A) AP view; (B) “head-on AIIS

view”; (C) “internal rotation AIIS view”; (D) “ischium AIIS view.” AIIS is marked with a star.

Fig. 5A–D Type III AIIS variant in a right hip. The AIIS extends distally to the anterosuperior acetabular rim (dots) and it has a downward “spur appearance.” (A) AP view; (B) “head-on AIIS

view”; (C) “internal rotation AIIS view”; (D) “ischium AIIS view.” AIIS is marked with a star.

Because no preliminary data existed regarding differences in ROM among the three AIIS types, power analysis was first calculated based on a sample of 70 consecutive patients who met the inclusion criteria. Of these, six were Type I (mean flexion $114^\circ \pm 10^\circ$), 57 were Type II (mean flexion $107^\circ \pm 10^\circ$), and seven were Type III (mean flexion $93^\circ \pm 20^\circ$). This revealed adequate power to detect differences in ROM between Type I versus Type III ($p < 0.01$) and between Type II versus Type III ($p < 0.01$), but to detect differences between Type I versus Type II with $p < 0.05$ and $\beta = 0.8$, an additional seven Type I cases were required. Our registry was consecutively reviewed and another seven Type I AIIS cases with one Type III AIIS case were identified and added. The cohort in this stage of the study included therefore 78 cases, of which 13 were Type I, 57 were Type II, and eight were Type III. A 3-D CT-based dynamic software program (A2 Surgical, a subsidiary of Smith & Nephew, Andover, MA, USA) [4, 8] was used to measure and compare terminal hip flexion (degrees) and terminal internal rotation (degrees) at 90° of flexion among the three AIIS types. Validity and accuracy of the CT-based dynamic simulation software program were tested on a pelvic-hip-knee cadaveric specimen with preserved hip capsule and first layer of muscles covering the hip anteriorly, laterally, and posteriorly. The specimen was secured to a

viser anteriorly at the pubic bones and posteriorly at the upper sacral vertebra. Metal ball radioopaque markers (4-mm diameter each) were implanted on the proximal femoral cortex at six locations, and then another group of markers was implanted on the pelvic bone at six locations. Two electromagnetic (EM) reference trackers were installed on the specimen, one on the proximal anterior femoral cortex just distal to the intertrochanteric line and the second on the inner pelvis at the quadrilateral surface. CT scan cuts from the level of the ASIS to the femoral condyles were used to obtain 3-D reconstruction images of the specimen. The 3-D images were processed to manually identify all ball marker centers. Marker locations were digitized with a calibrated pointer, and image-to-cadaver registration was performed for each marker. ROM ($^\circ$) of the femur relative to pelvis was then recorded with the dynamic simulation software program and compared with the EM tracking system in three separate motions, which are commonly used to assess signs of hip impingement: (1) hip flexion; (2) hip internal rotation at 90° hip flexion; and (3) hip adduction at 90° hip flexion. Differences recorded between the systems were 3° in hip flexion, 5° in hip internal rotation at 90° hip flexion, and 0° in hip adduction at 90° hip flexion (114° versus 111° , 23° versus 18° , and 31° versus 31° , respectively). Accuracy of the images obtained on the dynamic simulation software

program from the CT cuts regarding bone surface reconstruction was assessed using a calibrated pointer and by computing the distance from the tip of the tracked pointer to the bone surface model while the pointer tip was actually on the bone surface. This showed a distance of 0.07 mm on the femur and 0.59 mm on the acetabulum.

Group differences among the three AIIS types were evaluated using the Kruskal-Wallis test for continuous variables. All pairwise comparisons were evaluated for variables with significant group differences using rank-transformed data in an analysis of variance model with Bonferroni adjustment for multiple comparisons. All analyses were performed using SAS Version 9.2 software (SAS Institute, Cary, NC, USA).

Results

Among the 53 hips of the 53 patients in the initial cohort that were used to define AIIS morphologies, prevalence of AIIS Types I, II, and III within each sex group was 14% (four hips), 75% (21 hips), and 11% (three hips), respectively, in males and 20% (five hips), 76% (19 hips), and 4% (one hip), respectively, in females (Table 1). Interobserver assessment of the three AIIS types in this cohort among the three independent examiners showed 100% agreement (ie, wKappa = 1.0 for Observer 1 versus Observer 2, for Observer 1 versus Observer 3, and for Observer 2 versus Observer 3).

Among the 78 patients who were used to compare terminal hip motion among the three AIIS types, 13 patients (13 hips [17%]) had AIIS Type I, 57 patients (57 hips [73%]) had AIIS Type II, and eight patients (eight hips [10%]) had AIIS Type III. Sex distribution and prevalence revealed that in this cohort there were 65 males (65 hips) of which nine (nine hips [14%]) were Type I, 48 (48 hips [74%]) Type II, and eight (eight hips [12%]) Type III and 13 females (13 hips) of which four (four hips [31%]) were Type I and nine (nine hips [69%]) Type II. In this cohort, there were no differences among the three AIIS groups with regard to age, alpha angle, femoral version, and acetabular version (Table 2).

Comparisons of terminal hip motion among the three AIIS types showed that mean hip flexion was limited to 120°, 107°, and 93° in hips with Type I, Type II, and Type

III AIIS, respectively ($p < 0.01$ for all comparisons) (Table 3). Mean terminal hip internal rotation at 90° of flexion was limited to 21°, 11°, and 8° in hips with Type I, Type II, and Type III AIIS, respectively ($p < 0.01$ for Type I versus Type II and for Type I versus Type III, and $p =$ nonsignificant for Type II versus Type III). Looking specifically at the location of impingement on the dynamic software, we observed that in hips with Type III AIIS, impingement in terminal hip flexion occurred between the distal part of the AIIS and the distal area along the anterior inferior femoral neck (Fig. 6A–B). In hips with Type II AIIS, impingement in terminal hip flexion was also observed between the area of the caudad extension of the AIIS and the femoral neck in some cases and in others, there was impingement against the rim resulting from acetabular overcoverage anterosuperiorly, but in hips with Type I AIIS, impingement in terminal hip flexion was observed between the acetabular rim only and the anterior femoral neck, and there was never involvement of the AIIS.

Discussion

Reduced femoral head-neck offset and asphericity [1, 5, 6, 9] as well as acetabular retroversion [11] are the most widely recognized bony dysmorphisms associated with abnormal contact hip mechanics in young adults with nondysplastic joints. Recent studies, however, indicate that AIIS dysmorphism may also be a potential source of symptomatic hip impingement and that decompression of a prominent AIIS results in improved hip motion and hip function [4, 8, 10]. Despite evidence supporting decompression at the AIIS for selected cases of hip impingement, the spectrum of AIIS morphology is unknown as is the relationship between different AIIS morphologies and hip ROM. We therefore developed a classification system of AIIS morphologies in patients with hip impingement and tested the association between specific AIIS types and terminal hip motion.

We note several limitations to our study. First, the advanced imaging modalities used for assessing AIIS morphologies may limit the applicability of our classification system to other facilities. Our 64-channel CT scanner allowed us low irradiation exposure and computer reconstructions enabled us to rotate all 3-D images in the axial plane, obtaining a consistent high-resolution morphological evaluation of all hips. This methodology, however, was important to achieve optimal investigation of our study purposes. Second, the CT scans were taken with the patient in the supine position. Thus, the appreciation of any AIIS shape in relation to the acetabular rim may be altered when compared with a more physiologic standing position. Nevertheless, the fact that our supine CT-based

Table 1. Distribution of AIIS variants among 53 patients with hip impingement

AIIS type	Males (n = 28)	Females (n = 25)
I	4	5
II	21	19
III	3	1

AIIS = anterior inferior iliac spine.

Table 2. Demographics and morphological variables (mean $\pm$ SD) in the three AIIS groups

Variable	Type I (n = 13)	Type II (n = 57)	Type III (n = 8)
Age at surgery (years)	20 $\pm$ 4	22 $\pm$ 2	22 $\pm$ 4
Sex (male/female)	9/4	48/9	8/0
Alpha angle (°)	72 $\pm$ 8	70 $\pm$ 6	65 $\pm$ 14
Femoral version (°)	15 $\pm$ 3	16 $\pm$ 3	15 $\pm$ 6
Acetabular version (°)	15 $\pm$ 3	13 $\pm$ 5	15 $\pm$ 4

$p > 0.05$ for all comparisons among the three AIIS groups regarding age, alpha angle, femoral version, and acetabular version; AIIS = anterior inferior iliac spine.

Table 3. Comparisons of hip range of motion (mean $\pm$ SD) among the three AIIS types

Hip motion	Type I (n = 13)	Type II (n = 57)	Type III (n = 8)	p values [†]
Flexion (°)	120 $\pm$ 12	107 $\pm$ 10	93 $\pm$ 20	< 0.01 (I–II); < 0.01 (I–III); 0.01 (II–III)
Internal rotation (°)*	21 $\pm$ 10	11 $\pm$ 9	8 $\pm$ 9	< 0.01 (I–II); < 0.01 (I–III); 1.0 (II–III)

* Internal rotation was measured with the hip flexed to 90°; [†]the Kruskal-Wallis test was used to compare flexion and internal rotation ROM among the three AIIS groups; AIIS = anterior inferior iliac spine.

Fig. 6A–B Dynamic software images of a right hip showing areas of impingement between a Type III AIIS (star) and a distal femoral neck. (A) Hip in neutral position. Arrows = area of impingement on AIIS. Ellipse and arrowheads = area of impingement on the femoral neck. (B) Hip in 108° flexion. Curved arrow = area of AIIS impingement.

AIIS characterization correlated with hip motion when tested with dynamic software supports the applicability of the suggested classification system to the functional dynamic situation. Third, the software we used for assessing areas of impingement is based on bone morphology only but it does not provide information relating to soft tissue impingement. Thus, although in Type III AIIS, bony impingement was clearly observed between the distal part of the AIIS and the distal femoral neck, in Type II AIIS, in which bony impingement was more subtle between the distal extension of the AIIS and the rim adjacent to the AIIS and against the femoral neck, it is possible that impingement of soft tissue (ie, anterosuperior labrum just under the AIIS) between the AIIS and the femoral neck at full flexion may occur in the clinical setting. However, we did not test soft tissue impingement and cannot comment on how it might influence the findings.

Based on 3-D CT reconstructions, we were able to identify three AIIS types: Type I, in which there was a smooth ilium wall between the most caudad level of the AIIS and the anterosuperior acetabular rim; Type II, in which the AIIS prominence extended to the level of the acetabular rim; and Type III, in which the AIIS extended distally to the acetabular rim. Previous studies have highlighted AIIS dysmorphism as a contributor for hip impingement related to only very specific AIIS shapes. These included a “spur” appearance of the AIIS (consistent with Type III variant) in one short series of 10 young males with a history of hip flexion injuries [4] and a rim level-based AIIS in two other case reports [8, 10]. None of these studies provided a systematic method to characterize AIIS variability in a population with hip impingement. In this regard, our classification system was reproducible and enabled us to perform a systematic assessment of this juxtaarticular portion of the pelvis. The complete interobserver agreement supports the use of this system. This agreement may relate to the fact AIIS morphologies were assessed on well-defined three-dimensional CT views, which could be easily identified for every hip by rotating the pelvis in the axial plane but also to the use of a high-resolution CT scanner, which provided excellent delineation of the AIIS adjacent to the acetabular rim. Some variability, however, may be observed with less advanced CT scanners.

Our observations suggest defining AIIS variability may have clinical relevance. Among the three variants, Type I was characterized by the lack of contribution from the AIIS to hip impingement. In Type III, however, and to a lesser extent in Type II cases, the AIIS had some contribution to hip impingement as observed by the limitation in flexion and internal rotation and the contact seen between the AIIS

and the femoral neck at terminal hip motions. Therefore, in Type III and Type II cases, the AIIS may need to be critically assessed as a potential contributor for hip impingement. This rationale is supported by a recent short-term outcomes series showing that for very prominent variants (likely Type III cases), arthroscopically performed AIIS decompressions were beneficial in improving function and ROM [4]. Long-term improvements, however, in relation to AIIS decompression or lack thereof may be difficult to assess in patients with signs of impingement because they often require concomitant FAI procedures (ie, cam decompression, rim trimming, and labral repair).

Relative prevalence of AIIS types in our cohorts showed Type II was the most common variant in both men and women, whereas Types I and III were substantially less frequent. This, however, may not accurately represent prevalence in patients with hip impingement as a result of the small sample sizes of both the initial cohort (53 patients), which was investigated to develop the classification system, and the second cohort (78 patients), which was generated by matching the three AIIS groups for age, alpha angles, and hip version. Larger populations are needed to assess with greater accuracy AIIS variant prevalence in patients with hip impingement.

In conclusion, the AIIS can be classified into three morphological types based on the relationship between the distal extension of the AIIS and the anterosuperior acetabular rim. When hips in patients with signs of impingement are matched for version and alpha angles, Type II and Type III variants are associated with a decrease in hip flexion and internal rotation, supporting the rationale for considering AIIS decompression for morphological types that extend to and below the acetabular rim. In this respect, the current investigation provides a reproducible approach for assessing AIIS morphologies and may ultimately help surgeons to address subtle mechanical sources of hip dysfunction with greater accuracy.

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