Shared Morphology of Slipped Capital Femoral Epiphysis and Femoroacetabular Impingement in Early-onset Arthritis

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abstract

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A subclinical form of slipped capital femoral epiphysis (SCFE) can lead to subtle morphologic abnormalities, such as cam-type femoroacetabular impingement (FAI). Femoroacetabular impingement is a mechanical hip abnormality that typically affects young populations and leads to hip pain and premature osteoarthritis. Imaging is critical to diagnosis, whether by radiograph, magnetic resonance imaging, or computed tomography. The authors investigated the use of imaging to detect characteristics of subclinical SCFE and cam-type FAI in patients undergoing hip resurfacing. They retrospectively assessed computed tomography scans of 81 hips from 75 patients. Measurements were taken of the proximal femur and included the alpha angle, head-neck tilt, and anterior offset taken in both the conventional oblique axial plane and the radial plane. The cohort consisted of 68 men and 13 women with an average age of 52 years. Ninety percent of hips on the oblique axial view and 95% of hips on the radial view were found to have pathologically increased alpha angles. Negative correlations were found between the alpha angle and head-neck tilt and positive correlations between head-neck tilt and anterior offset ratio. Sixty percent and 68% of hips in the oblique axial and radial planes, respectively, were abnormal for the alpha angle, head-neck tilt, and anterior offset ratio, strongly suggesting SCFE morphology. This study’s results show similarity in morphology between cam-type FAI and SCFE, known precursors to osteoarthritis, in an early arthritic patient population.

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Figure: Oblique sagittal plane, with a best-fit circle around the cortex to find the center of the femoral neck (ie, the center of rotation); 45° anterior of superior was measured and the scan resliced in this plane to produce the radial 1:30 images.
Femoroacetabular impingement (FAI) is a condition of mechanical abutment between the proximal femur and acetabulum. The etiology is thought to be subtle morphologic abnormalities, and the natural history is discomfort, decreased range of motion, and osteoarthritis (OA). Three types of FAI are commonly described: pincer, or overcoverage by the acetabulum; cam, or a growth or lack of concavity at the femoral head-neck junction; and mixed, in which both cam and pincer coexist.

A number of preexisting hip diseases have been identified that may contribute to impingement. These include femoral neck fracture, Legg-Calvé-Perthes disease, acetabular retroversion, and slipped capital femoral epiphysis (SCFE). Femoroacetabular impingement is often detected late because of the subtle nature of the disease and because the previously mentioned conditions that lead to this endpoint are themselves inconspicuous. For this reason, it has been proposed that subclinical SCFE not acute enough to come to medical attention may be a major contributor to the development of cam-type FAI.

Femoroacetabular impingement may be detected clinically, but imaging is crucial to the diagnosis. Recent advances in imaging and methods for measurement of the proximal femur have led to better characterization of this variant of FAI. Plain radiographs are commonly used, but magnetic resonance imaging (MRI) has been found to be more reliable and can be used for more detailed investigation. Methods have also been adapted to allow the use of computed tomography (CT) imaging.

The conventional plane used for the measurements of reformatted CT and MRI is the oblique axial plane. Recently, the radial plane has been used more frequently because it optimally shows the anterosuperior femoral head-neck junction, which has been shown in previous studies to produce both the highest alpha angle values and the most frequent occurrence of increased alpha angles.

The characteristic slip of the femoral head occurring in SCFE (ie, translation and angulation) differentiates it from the other potential etiologies of FAI. Common measurements used to detect cam-type FAI include the alpha angle, indicating a lack of head-neck concavity, and the anterior offset ratio (AOR), measuring the relationship of the femoral head to neck and potentially providing information about eccentric placement of the head. The current authors also used head-neck tilt to measure the angulation. They expected that patients with proximal femurs displaying decreased head-neck tilt, with or without decreased AOR, would be suspect for SCFE, whereas those with an abnormal alpha angle (ie, positive for FAI) but normal tilt would not likely be caused by SCFE.

The current investigation had 3 objectives: (1) to determine the prevalence of cam-type FAI in a group of patients with early-onset arthritis (aged younger than 65 years) undergoing hip resurfacing; (2) to explore the relationship between the 3 main variables, namely alpha angle, AOR, and head-neck tilt, and determine their use in evaluating prior subclinical SCFE; and (3) to attempt to retrospectively assess the prevalence of SCFE morphology among this population.

**Materials and Methods**

This study is a retrospective case series. Since 2007, orthopedic surgeons at the authors’ institution have been performing computer-assisted hip resurfacing based on segmented CT scans. To date, 81 procedures have been performed on 75 patients, all of whom consented to the procedure and to the use of their scan data for research purposes. This study was approved by the institution’s research ethics board.

One independent author (A.E.G.) confirmed satisfactory segmentation for all scans and, in the case of scans that were segmented before use of the current software, segmented missing scans. The same author completed multiplanar reformation on all CT scans. Segmentation was completed in Mimics version 13.0 or 14.0 (Materialise, Leuven, Belgium), and all multiplanar reformation and measurements were conducted in Mimics version 14.0.

In a similar fashion to the methods described by Beaule et al, the center of rotation of the femoral neck was determined (Figure 1). The scan was resliced in the plane of the long axis of the neck, producing 3 image planes: oblique axial, oblique sagittal, and oblique coronal. The oblique sagittal plane was used to es-
establish the new center of rotation of the femoral neck; a clock face represented the radial planes where 12:00 is superior, 3:00 is anterior, and so forth. The 1:30 radial position was determined by drawing a line 45° anterior of superior, and the scans were resliced in this plane (Figure 1B).

The 2 views of interest chosen from these successive reformations were the oblique axial, which is equivalent to 3:00 radial, and the radial 1:30 view.

All measurements in both the oblique axial view and the radial 1:30 view were taken initially by 1 observer (A.E.G.). Inter- and intrarater reliability were determined by measuring a randomized subset of 50 scans repeated 2 weeks later by the same observer and separately by another observer (N.A.C.) for each view.

Several measurements were selected to allow a broad analysis of the efficacy of the reformatted CT scans and permit comparison with other image protocols. The alpha angle has been extensively studied in the literature and is an index of anterior or an- terosuperior femoral neck concavity. The beta angle, a measure of posterior neck concavity, is executed in the same fashion as the alpha angle except the first line is drawn from the center of the best-fit circle to the point where the radius of the posterior neck intersects the femoral head (Figure 2A).

Head-neck tilt, based on the Goodman et al study on subclinical SCFE, was composed of the angle between a line drawn from the anterior loss of the sphere to the posterior femoral head-neck junction and a line drawn along the long axis of the femoral neck although not necessarily intersecting the center of the femoral head (Figure 2B). In the original study, postslip morphology was defined as 86° or less of head-neck tilt.

Anterior offset ratio is largely considered pathologic below 0.15. Continuous variables were summarized by means with ranges, and categoric variables were summarized by counts with percentages. The Pearson product-moment correlation coefficient (r) was used to assess the linear relation between each measurement variable (alpha, beta, ratio, tilt, offset, femoral head, and AOR). Cronbach alpha was the statistical measure used to determine reliability within and between observers, with the criteria of less than 0.39 for poor reliability, 0.40 to 0.74 for fair, and 0.75 to 0.99 for excellent. Independent-sample t tests were used to determine statistically significant differences in the measurement variables grouped by view and then again by sex, side, and age (50 years and younger vs older than 51 years). A P value less than or equal to .05 was considered statistically significant.

**RESULTS**

A total of 81 hips from 75 patients were included in this study. Of these, 33
(41%) were left hips, and 48 (59%) were right hips. The study composition was 13 (16%) women and 68 (84%) men. Average patient age at the time of surgery was 51.5 years (range, 34-65 years). No strong correlation existed between age and alpha angle, head-neck tilt, or AOR (Table 1).

Reliability results yielded excellent intraobserver reliability for all measures in both the oblique and radial views. Interobserver reliability was also excellent for all parameters in the oblique axial plane. Interobserver reliability was fair to excellent for all measures in the radial plane, with the exception of poor agreement for the alpha angle, beta angle, and alpha-beta ratio (Table 2).

On oblique axial images, average alpha angle was 72.8°, AOR was 0.11, and head-neck tilt was 76.4°. On radial images, average alpha angle was 75.4°, AOR was 0.07, and head-neck tilt was 81.9°. A statistically significant difference existed between female and male sex for alpha angle (67.0° vs 73.9°, respectively; \( P<.05 \)), head-neck tilt (82.4° vs 75.3°, \( P<.05 \)), femoral head diameter (45.4 vs 50.9 mm, \( P<.05 \)), and AOR (0.13 vs 0.11; \( P<.05 \)) on the oblique view (Figure 3). On the radial view, the sex difference was observed only for the femoral head diameter (45.28 vs 52.35 mm; \( P<.05 \)), suggesting that either no difference exists between sexes at the anterosuperior head-neck junction or the radial view is unreliable at detecting true differences in this study.

In the oblique axial plane, a negative correlation was found between the alpha angle and head-neck tilt (\( P<.000 \)). Similarly, the radial view yielded a correlation of \( r=-0.722 \) (\( P<.000 \)) for the alpha angle and head-neck tilt. No significant correlation existed between the alpha angle and AOR on either view (oblique, \( r=-0.143 \); \( P=.20 \); radial, \( r=0.003 \); \( P=.981 \)). On both the oblique axial and radial views, a positive correlation existed between head-neck tilt and AOR (\( r=0.49 \), \( P=.000 \); and \( r=0.398 \), \( P=.000 \), respectively).

This group of patients displayed largely pathologic values for the key measurements used to detect cam-type FAI. The alpha angle is a cornerstone for this diagnosis, and in both the oblique axial and radial planes, greater than 90% (73/81 and 77/81, respectively) of the hips had abnormal values for this variable. Sixty percent (49/81) of hips on the oblique axial view and 68% (55/81) of hips on the radial view had abnormal values for the alpha angle, AOR, and head-neck tilt. Taken together, this strongly suggests a prevalence of at least 60% to 70% of the study population having cam-type FAI. Additional support for the notion that FAI was a factor contributing to the need for surgery is provided by demographics. The patients studied were young; 63% (51/81) of the patients were under the age of 55, and 88% (71/81) were younger than 60 years.

To assess the prevalence of SCFE morphology, variables were examined individually and in combination. Eighty-nine percent of hips in the oblique axial plane and 78% of hips in the radial plane displayed tilt, meeting one of the requirements. Sixty percent (49/81) of hips in the oblique axial plane and 68% (55/81) of hips in the radial plane had abnormal values for the alpha angle, head-neck tilt, and AOR. This suggests a high prevalence, over half of the study population, displaying morphology that is similar to what would be expected in subclinical SCFE.

**DISCUSSION**

Slipped capital femoral epiphysis is known to be an important precursor to FAI and osteoarthritis. Goodman et al studied human skeleton femora to identify the association between postslip morphology, considered to be caused by SCFE, and the severity of osteoarthritis.
The current authors have applied their methodologic principles to this radiologic investigation to achieve an aim of the current study: to determine if it is possible to combine the main variables to retrospectively identify postslip morphology. Theoretically, a scan displaying normal (ie, 86°-90°) head-neck tilt but decreased AOR would represent a hip in which the femoral head translated but did not tilt. An increased (more than 86°) head-neck tilt with normal AOR could be described as a tilted hip with no translation. Decreased AOR and increased head-neck tilt would represent a tilted and translated hip. One would expect that patients with subclinical SCFE would fall under the latter 2 categories. Further strength is lent to this notion by the correlations between the key variables. In both the oblique axial and radial planes, negative correlations were found between the alpha angle and head-neck tilt (−0.748, P<.000; and −0.722, P<.000, respectively). Likewise, positive correlations were found between head-neck tilt and AOR on both views (0.490, P<.000 and 0.398, P<.000, respectively). This would suggest that in this study population, the relationship between these variables could allow inference of SCFE morphology. The results found that 60% of hips in the oblique plane and 68% of hips in the radial plane were abnormal for the alpha angle, head-neck tilt, and AOR. Based on this framework, a majority of the hips studied displayed SCFE morphology.

This study’s radiologic results complement those of Goodman et al on a population of adult human skeletons. They found no correlation between age and the alpha angle, AOR, or head-neck tilt. Skeleton femora with postslip morphology had more severe osteoarthrosis compared with both matched controls and contralateral normal hips. Likewise, the authors found that in a population of early arthritics, a significant proportion have the same morphologic characteristics.

Limitations of this study include the lack of a control group and the relatively small patient population with female underrepresentation, limiting generalizability. Head-neck tilt was a measurement adapted from an earlier study with no prior description in the literature. Further investigations must be conducted to establish this as a validated measurement. The alpha angle measured in the radial plane, shown to be robust in other studies, had poor interrater reliability in this study.
This may be caused by successive reformatations of the CT scans resulting in distorted image quality and making interpretation challenging.

An important consideration in the design of this observational cohort study is that one can only establish similarities between his or her patients and what one would expect of a femur with SCFE or cam-type FAI. To establish causality, a longitudinal study with serial imaging would be required. However, if radiologic indices can be developed that have an association with factors that are involved in progression of hip arthrosis, then it is important to identify these and consider early intervention. It is with this aim in mind that this study was conducted.

CONCLUSION

The results of this study complement the growing body of evidence that FAI is a highly prevalent, measureable cause of early-onset OA. Although a study with this design cannot assess causality, similarities were found in morphology between patients with early-onset OA and morphology expected of proximal femora affected by SCFE and cam-type FAI. A majority of patients were younger than 55 years and had pathologic values for the alpha angle, AOR, or head-neck tilt. The combination of the alpha angle, AOR, and head-neck tilt provides information as to the possible etiology of FAI. Further evaluation of head-neck tilt as a measurement must be undertaken to determine its validity. With better understanding of these measurements, they may have a role in the early detection of precursor conditions for cam-type FAI and hip osteoarthritis.

REFERENCES