Idiopathic Cam Morphology Is Not Caused by Subclinical Slipped Capital Femoral Epiphysis

An MRI and CT Study

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Background: Cam impingement as a known sequelae of slipped capital femoral epiphysis (SCFE) has led to speculation that subclinical SCFEs may be the causative factor in idiopathic cam morphology; alternatively, others have implicated an abnormal extension of the growth plate as a causative factor.

Hypothesis/Purpose: To investigate the growth plate tilt angle in 4 patient cohorts: normal patients, patients with idiopathic cam morphology (CamIP), patients with cam morphology secondary to known SCFE (CamSCFE), and patients with incidental findings of an asymptomatic cam (Camasymp).

Study Design: Case-control study; Level of evidence, 3.

Methods: A database of 192 computed tomography scans of abdomens/pelvises of patients (ages, 5-19 years) with no known orthopaedic issues, reformatted to neutral tilt, inclination, and rotation, were utilized for the normal cohort, the Camasymp cohort, and to create an age- and sex-matched control cohort. In addition, a retrospective review of all patients treated for femoroacetabular impingement (FAI) with preoperative advance imaging was conducted, and patients were separated to CamIP and CamSCFE cohorts. The alpha angle and tilt angle were measured on each hip. Statistical analysis was performed.

Results: The mean tilt angle among the normal patients was 12.1°, with 1.9% of the variation in tilt angle being explained by age; each additional year of age decreased the tilt angle by 0.27° (P = .008). The tilt angle for the CamSCFE cohort (mean, 44.5°) was found to be significantly greater than both the CamIP cohort (mean, 5.9°; P < .001) and the control cohort (mean, 12.8°; P < .001). The tilt angle for the CamIP cohort was found to be significantly less than the control cohort (P = .003). The alpha angle and tilt angle were positively correlated in the CamIP cohort, but no correlation was found in the other cohorts. The mean tilt angle of the 18 hips in the Camasymp cohort was 13.9° ± 11.5° (range, –12° to 37°), with 12 hips (67%) in the tilt angle range of CamIP cohort and 6 in the tilt angle range of CamSCFE.

Conclusion: The proximal femoral growth plate normally has a posterior tilt that becomes more anterior through maturation. Idiopathic cam morphology has a drastically different growth plate tilt angle than cam morphology secondary to SCFE, suggesting that a majority of idiopathic cam morphology is not the result of subclinical SCFEs.

Keywords: slipped capital femoral epiphysis (SCFE); CT; MRI; femoroacetabular impingement (FAI); cam morphology; growth plate; adolescent

The establishment of femoroacetabular impingement (FAI) as a precursor to osteoarthritis9,10 has led to a substantial effort in discovering the etiology of FAI and eventual preventative measures. Generally, FAI involves an abnormal “bump” on the proximal femur anterior-superior head-neck junction (cam morphology)17 and/or global or focal anterior-superior acetabular overcoverage (pincer morphology)33 that in isolation or in combination results in an abnormal abutment of the proximal femur and acetabulum.9

As early as 1936, Smith-Petersen35 described 2 cases of healed slipped capital femoral epiphysis (SCFE) with impingement of the femoral neck on the anterior acetabular margin (now known as FAI) that were treated successfully with acetabular wall trimming. Now, more than 75 years later, cam-type impingement is a commonly recognized sequela of SCFE.5,7,16,25,31,37 This relationship has led several investigators to speculate that mild subclinical SCFEs or Perthes disease may be the cause of cam morphology in patients considered to be idiopathic.12,26 Alternatively, Siebenrock et al34 implicated an abnormal extension of the growth plate potentially as a response to vigorous sporting...
activities during childhood as the cause of idiopathic cam morphology.\textsuperscript{3,24} Recently, a study conducted at our institution demonstrated that radiographic evidence of cam morphology becomes apparent at 10 years of age in an asymptomatic population, further implicating a childhood growth disturbance as an etiological factor in cam morphology.\textsuperscript{24} Unfortunately, there remains no clear evidence refuting or confirming “subclinical” SCFE or abnormal growth plate extension as an etiologic factor in idiopathic cam morphology.

We therefore sought to investigate the growth plates in 4 patient populations: normal patients, patients with idiopathic cam morphology, patients with cam morphology secondary to known SCFE, and patients with incidental findings of an asymptomatic cam. We asked the following questions: (1) What is the normal development of the proximal femoral growth plate tilt angle from ages 5 to 19 years? (2) How does the growth plate tilt angle compare between an idiopathic cam morphology (Cam\textsubscript{IP}) cohort, a cam morphology secondary to known SCFE (Cam\textsubscript{SCFE}) cohort, and a control cohort? (3) Does the growth plate tilt angle correlate with cam size in each of these cohorts? and (4) What is the growth plate tilt angle of an asymptomatic cam morphology (Cam\textsubscript{asym}) cohort as compared with symptomatic cam morphology cohorts?

**METHODS**

Institutional review board approval was obtained prior to conducting this study. Asymptomatic patients were recruited from a previous study’s database conducted at our institution.\textsuperscript{24} In this previous study, abdominal and pelvic computed tomography (CT) scans from November 2011 to January 2012 with no obvious evidence of orthopaedic surgery (eg, hardware implants) and with adequate imaging of the proximal femur were reformatted. Additionally, patients underwent a chart review to confirm that they had no prior history of hip complaints, no history of hip surgery, and a benign hip examination. Using GE Advantage Workstation version 4.3.05 software (GE Medical Systems, Chalfont St Giles, UK), the 0.6-mm thickness/0.6-mm inter-section gap images of the pelvis were reconstructed into standardized pelvic CT with neutral inclination, rotation, and tilt. Additionally, axial oblique images (2-mm thickness/2-mm inter-section gap) of each hip were created parallel to the femoral neck axis. For this study, we included from the database hips from patients 5 years of age and older with an alpha angle <55\textdegree. This resulted in the inclusion of 211 female hips and 155 male hips with a mean age of 12.1 years (range, 5-19 years). Eighteen patients in our asymptomatic cohort had an alpha angle >55\textdegree and were excluded from the “normal group.”

A second retrospective review was conducted of all patients from 2007 to 2012 who were treated for FAI at our institution, were less than 19 years of age, and underwent CT or magnetic resonance imaging (MRI) prior to treatment (n = 96 hips). Patients were diagnosed with FAI if they met all of the following criteria: presence of groin pain, a positive impingement test, radiographic evidence of a labral tear with an elevated alpha angle >55\textdegree, and intraoperative findings consistent with FAI. Hips with evidence of avascular necrosis, lack of axial-oblique imaging, inability to visualize the growth plate, or substantial metal distortion were excluded (n = 26 hips). A second qualitative review of the images, charts, and operative findings of the remaining patients was conducted by the senior author. This resulted in the exclusion of an additional 38 hips in which the FAI was primarily due to pincer morphology and lacked evidence of true characteristic cam morphology. A total of 33 hips, 11 hips with Cam\textsubscript{SCFE} (all CT images) and 22 hips (4 CTs, 18 MRIs) with Cam\textsubscript{IP}, were included in this study.

Utilizing MERGE PACS imaging software (version 6.4; Merge Healthcare, Hartford, Wisconsin, USA), the alpha angle as described by Notzli et al\textsuperscript{28} and the tilt angle\textsuperscript{19,36} were measured on an axial-oblique image corresponding to the center of the femoral head on MRI or CT for all hips included in the study. This specific plane was utilized because of its demonstrated sensitivity to the mostly posterior displacement involved in SCFE.\textsuperscript{25} The alpha angle is formed by a line from the center of the femoral head to the middle of the narrowest part of the femoral neck and a line from the center of the femoral head to where the femoral head deviates from the perfect circle contour (Figure 1A). The tilt angle is an angle formed by the line connecting the ends of the proximal femoral physis or scar (if physis is closed) and a line perpendicular to the femoral neck axis (Figure 1B). A posteriorly tilted physis was considered positive, and an anteriorly tilted physis was considered negative.

To validate the use of MRI and CT interchangeably for measuring the tilt angle, a separate analysis of the tilt angle of 18 hips that had both an MRI and CT was conducted. One observer measured tilt angles on CT and MRI for all modalities. All statistics were performed using SPSS (version 12; SPSS Inc, Chicago, Illinois, USA). Intermodality reliability for measuring tilt angle on CT and MRI was evaluated using the intraclass correlation coefficient (ICC). The ICC value for tilt angle measured on CT and MRI was 0.962 (95\% confidence interval, 0.902-0.986; P < .001).

The 366 normal hips were consolidated into the following age groups: 5-7, 8-9, 10-11, 12-13, 14-15, and 16-19 years. One-way analysis of variance (ANOVA) with the Bonferroni post hoc test was conducted to evaluate differences in mean tilt angle among age groups. Simple linear regression analysis was used to ascertain the relationship between age and tilt angle.

A comparison of the tilt angle was conducted between 4 cohorts: 22 hips with Cam\textsubscript{IP} (mean age, 16.6 years; range, 14-18 years; 3 female hips, 19 male hips), 11 hips with Cam\textsubscript{SCFE} (mean age, 14.1 years; range, 10-16 years; 3 female hips, 8 male hips), 30 normal control hips drawn from the 366 hip normal patient database (mean age, 15.6 years; range, 10-18 years; 6 female hips, 24 male hips), and 18 hips with Cam\textsubscript{asym} recruited from the normal database (alpha angle >55\textdegree; mean age, 13.4 years; range, 10-17 years; 3 females, 15 males). The control cohort was age- and sex-matched by recruiting all the age/sex combinations represented in the Cam\textsubscript{SCFE} and Cam\textsubscript{IP} cohorts from the normal database and then utilizing a randomization function to recruit a proportional age- and sex-matched sample.
The Levene test of homogeneity was performed, and the 3 test cohorts were found to have heterogeneous variances, indicating nonparametric statistical tests were required. The Kruskal-Wallis and Mann-Whitney tests were used for comparison of the tilt angle. Pearson correlation and simple linear regression analysis was performed to evaluate the relationship between alpha angle and tilt angle for each of the 3 test cohorts.

RESULTS

The mean tilt angle among the normal patients was 12.1° (Table 1). There were no statistically significant differences in mean tilt angle among any of the age groups evaluated (P = .052) in the normal patients. Linear regression analysis did demonstrate a small but significant effect of age on the tilt angle, with 1.9% of the variation in tilt angle being explained by age, with each additional year of age decreasing the tilt angle by 0.27° (P = .008).

The tilt angle for the CamSCFE cohort (mean, 44.5°) (Figure 2A) was found to be significantly greater than both the CamIP cohort (mean, 5.9°; P < .001) (Figure 2B) and the control cohort (mean, 12.8°; P < .001) (Table 2 and Figure 3). The tilt angle for the CamIP cohort was found to be significantly less than the control cohort (P = .003). The alpha angle and tilt angle were not correlated in the CamSCFE cohort (Pearson correlation, 0.50; P = .009), with 24.8% of the variation in tilt angle explained by the alpha angle. Each additional degree of increase in tilt angle increases alpha angle by 0.662° (P = .018).

There were a total of 18 hips of the 258 (14.3%) normal asymptomatic hips ≥10 years of age with an alpha angle ≥55°. The mean tilt angle of the 18 Camasymp cohort was

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**Table 1**

| Age Range, y | No. of Hips | Tilt Angle, Mean ± SD | Range |
|--------------|-------------|----------------------|-------|
| 5-7          | 24          | 15.0° ± 7.0°         | 4°-29°|
| 8-9          | 28          | 12.0° ± 5.6°         | 2°-25°|
| 10-11        | 23          | 16.0° ± 4.7°         | 4°-22°|
| 12-13        | 37          | 13.1° ± 5.6°         | 0°-28°|
| 14-15        | 22          | 12.0° ± 5.5°         | 2°-20°|
| 16-19        | 21          | 14.1° ± 7.0°         | 3°-30°|
| 5-19         | 155         | 13.6° ± 6.0°         | 0°-30°|

**Table 2**

| Cohort         | No. of Hips | Tilt Angle (mean ± SD) | 95% CI |
|----------------|-------------|------------------------|--------|
| Idiopathic     | 24          | 6.3° ± 7.8°            | 3.0°   |
| Secondary to SCFE | 11        | 44.5° ± 16.2°         | 33.6°  |
| Normal cohort  | 148         | 10.9° ± 7.0°           | 9.8°   |
| Total          | 183         | 12.3° ± 11.4°          | 10.6°  |

**SD, standard deviation.**
The Camasymp cohort tilt angle was significantly greater than the CamIP cohort and significantly less than the CamSCFE cohort. Of the 18 hips, 12 (67%) were within the tilt angle range of the CamIP cohort (range, –13° to 19°) and 6 (33%) were within the tilt angle range of CamSCFE (range, 18° to 65°) (Figure 4). Additionally, 13 (72%) of the 18 Camasymp were within 2 standard deviations from the control cohort mean. Of those hips outside the normal range, 3 were above (Figure 5A) and 1 was below 2 standard deviations of the control cohort mean (Figure 5B).

DISCUSSION

FAI diagnosis and treatment continue to evolve since Ganz’s group published their seminal article in 2001. Arthroscopic27,29 and open treatment2,6,8 options for symptomatic FAI have demonstrated good early to midterm results. As the understanding of cam impingement secondary to SCFE has evolved,5,7,16,22,31,37 new treatment methods aimed at preventing the progression to FAI at the time of initial slippage have been developed, but long-term results are yet to be published.23,39 Conversely, potential prevention methods for the development of idiopathic FAI have been stifled by the current lack of understanding of the etiology. Although a genetic component to FAI30 and osteoarthritis26 has been demonstrated, the most accepted theories as to the etiology of FAI include secondary development as a result of a subclinical or “silent” SCFEs, which have been found in the general population12,21 or an abnormal extension of the growth plate potentially as a response to vigorous sporting activities.3,52,14 Both prevailing theories implicate a childhood growth disturbance as the primary etiologic factor in idiopathic cam morphology, which is further supported by our previous study24 that
demonstrated the appearance of radiographic evidence of cam morphology around 10 years of age. In this study, the growth plate tilt angle decreased with age and significantly differed among CamₜSCFE, CamₜIP, and control cohorts, suggesting that the causation of the majority of idiopathic cam morphology is not from subclinical or “silent” SCFEs. The correlation of growth plate tilt angle and alpha angle in only the CamₜIP cohort additionally implicates a primary growth plate disturbance in the etiology of CamₜIP.

In the normal patient cohort, the proximal femoral growth plate tilt angle of patients aged 5 to 19 years was 12.1°, demonstrating a posterior tilt in relation to the neck axis. Additionally, a small but statistically significant overall trend toward a more anterior tilt (by 0.27° per year) was found with age, but no significant difference was found between age groups. Similarly, Kienle et al. found a mean tilt angle of 11.7° to 12.6° in patients with open growth plates and 10.7° to 11.2° in patients with closed growth plates and found no statistical difference at 1-year follow-up when analyzing the MRI of 64 asymptomatic volunteers (mean age, 12.8 years). Finally, the large range of tilt angle (–9° to 30°) of an asymptomatic normal population does suggest that having low or high tilt angle does not necessarily lead to cam morphology.

The proximal femoral growth plate tilt angle of the CamₜSCFE cohort (mean, 44.5°) was significantly higher than the CamₜIP cohort (mean, 5.9°) and the control cohort (mean, 12.8°). Only one of the 22 CamₜIP hips (tilt angle, 19°) fell into the range of the CamₜSCFE cohort. This significant difference in tilt angle in these cohorts suggests that CamₜIP morphology shows no radiographic evidence of subclinical or “silent” SCFE, and this is an unlikely causative factor in the CamₜIP hips. Additionally, tilt angle (which can be a measure of the SCFE severity4,38) was not found to be significantly correlated to alpha angle (ie, cam size) in the CamₜSCFE cohort or the control cohort but was significantly correlated in the CamₜIP cohort. Dodds et al. similarly found that in 49 SCFE hips followed for a mean 6.1 years, slip severity did not correlate with alpha angle or clinical impingement signs at final follow-up. The growth plate angle’s correlation to alpha angle in the CamₜIP but not the CamₜSCFE cohort further implicates differing causative mechanisms for each type of cam morphology.

Of the 18 hips in the CamₜAsympt cohort, tilt angles were mostly within the range of the CamₜIP cohort (n = 12, 67%), while 6 (33%) were within the tilt angle range of the CamₜSCFE cohort. It is important to note that 14 (78%) of the patients fell within 2 standard deviations of the control cohort. Goodman et al. found an overall 8% prevalence of “post-slip morphology” in a large cadaver population and found a 38% prevalence of grade 2 or 3 osteoarthritis in the “post-slip morphology” hips versus 26% in the nonslip morphology hips. Similarly, Lehmann et al. found that 6.6% of a population of young adults had a head-shaft angle indicating a potential previous slip, but there was no correlation found with cam morphology or focal prominence of the femoral neck. However, in both studies, these findings were never directly connected to symptomatic idiopathic FAI patients. Additionally, at the time of Goodman et al., FAI had not been well described, and a percentage of those described as “post-slip morphology” may have been simply cam morphology as some of their subjective criteria could relate to both types of morphology. In our study, there were a few hips with excessively posteriorly tilted growth plates, potentially suggesting a prior SCFE in the normal cohort but none in the CamₜIP cohort. The growth plate of the CamₜIP actually tended to be more anteriorly tilted as compared with the normal population. Our data (Table 1) demonstrate that overall there is large range of growth plate tilt among the normal population starting as early as 5 years of age. Potentially, our asymptomatic patients with excessively posteriorly tilted growth plates may be simply part of the normal spectrum.

Further investigation is warranted to understand which of the asymptomatic cam morphology will develop symptomatic cam impingement and/or osteoarthritis. This continues to be an important question as asymptomatic cam morphology has been reported in the adult literature in females from 3.3% to as high as 8.9% and in males from 8.6% to as high as 24.7%.1,11,13-15,18,20

As with any study, there are several limitations. First, the imaging of CamₜIP was predominately from MRI as this is standard at our institution, while the other cohorts had CT imaging. To address this limitation, a separate analysis was conducted testing tilt angle reliability between the 2 modalities when measured on the same axial oblique image, which demonstrated excellent reliability. Second, the retrospective design of this study did not allow us to examine or interview the normal patients with respect to musculoskeletal hip complaints. To account for this limitation, we performed a chart review of all patients ensuring that no patients had previously seen in the orthopaedic department for a hip complaint, and as the only tertiary pediatric orthopaedic center in the county, the likelihood of patients seeking orthopaedic care elsewhere is limited especially for the preadolescent patients. Future studies including larger patient numbers may allow further assessment of the developing growth plate of hip pathologies, which may improve our understanding of the etiology of FAI and SCFE.

Overall, we found that the proximal femoral growth plate tilt angle is normally tilted posteriorly (12.1°) in relation to the femoral neck and becomes slightly more anteriorly tilted with growth. Idiopathic cam morphology hips do not share the excessive posterior tilt found in patients with cam morphology secondary to known SCFE. Therefore, subclinical or “silent” SCFE is unlikely to be the cause of the majority of cam morphology in idiopathic FAI. The tilt angle did correlate with alpha angle in the idiopathic cam morphology group further supporting previous findings of a growth plate disturbance as a causative factor in idiopathic cam morphology.

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