Is the Acetabulum Retroverted in Slipped Capital Femoral Epiphysis?

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Abstract

Background Recent biplanar radiographic studies have demonstrated acetabular retroversion and increased superolateral femoral head coverage in hips with slipped capital femoral epiphysis (SCFE), seemingly divergent from earlier CT-based studies suggesting normal acetabular version.

Question/purposes We therefore asked: Are there differences in (1) acetabular version at the superior ¼ of the acetabular dome (AV_{sup}), (2) acetabular version at the center of the femoral head (AV_{cen}), and (3) superolateral femoral head coverage (lateral center-edge angle [LCEA]) among affected SCFE hips, unaffected hips, and normal controls?

Methods We identified 32 patients with SCFE who underwent CT between 2007 and 2012. Twenty-three met our inclusion criteria. Seventy-six age- and sex-matched normal patients comprised the control group. Pelvic

rotation, tilt, and inclination were corrected on each CT. AV_{sup} , AV_{cen} , and LCEA were measured.

Results The mean AV_{sup} of the affected hips (-1.71°) demonstrated retroversion compared to the unaffected hips and the control group; the mean AV_{sup} of the unaffected hips was similar to that of the normal controls. Mean AV_{cen} was similar among the three groups. The LCEA was higher in affected and unaffected SCFE hips than in the control group (34.3° versus 34.5° versus 28.9° , respectively), but we found no difference between affected and unaffected hips.

Conclusions Our data suggest an association of superior acetabular retroversion and increased superolateral femoral head coverage in SCFE. Whether this represents a primary abnormal morphology or a secondary pathologic response remains unclear. Further studies investigating the role of acetabular morphology in SCFE and its implications for development of symptomatic femoroacetabular impingement are warranted.

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.

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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.

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Introduction

Slipped capital femoral epiphysis (SCFE), with an incidence of 8.8 per 100,000 children, is one of the most common pediatric hip disorders [17, 20]. While its origin remains an enigma [5, 8, 27, 37, 38], treatment methods have continued to evolve [21]. Gelberman et al. [10] reported an association of SCFE and femoral retroversion. More recently, many studies have shown an association between cam morphology resulting from the process of capital epiphyseal slippage and the eventual occurrence of symptomatic femoroacetabular impingement (FAI) [7, 9, 12, 18, 28, 33, 35]. On the acetabular side, recent studies have proposed increased acetabular coverage [15, 30]. Sankar et al. [30] reported a high association of acetabular retroversion in the contralateral hips of patients with SCFE.

In contrast to Sankar et al. [30], who used biplanar radiography and the crossover sign [29] to demonstrate acetabular retroversion, previous studies finding no relationship between acetabular retroversion and SCFE utilized two-dimensional (2-D) and three-dimensional (3-D) CT [16, 23, 34]. These CT-based studies evaluated acetabular retroversion based on only a single axial slice corresponding to the center of the femoral head. Recent evidence has indicated this method may not be sensitive to a localized superior acetabular retroversion, which may cause focal superoanterior acetabular rim overcoverage leading to symptomatic FAI [6, 19, 29]. Given the association of SCFE with FAI [7, 9, 12, 18, 28, 33, 35], the postulated coexistence of femoral retroversion with acetabular retroversion [3], and newly developed CT acetabular version quantifying methods [6], we questioned whether SCFE-affected hip would be associated with an alteration in acetabular morphology, including increased superior but not central acetabular retroversion and increased superolateral femoral head coverage as quantified by the lateral center-edge angle (LCEA).

We therefore asked the following questions: Are there differences in (1) the acetabular version at the superior $\frac{1}{4}$ of the acetabular dome (AV_{sup}), (2) the acetabular version at the center of the femoral head (AV_{cen}), and (3) the superolateral femoral head coverage as measured by LCEA among affected SCFE hips, contralateral (unaffected) hips, and normal controls?

Patients and Methods

We reviewed our institutional database to identify all 32 patients with SCFE treated from 2007 to 2012 who had undergone a CT study. None of the 32 patients had undergone surgical intervention that directly changed the morphology of the acetabulum, but such patients would have been excluded. We excluded nine patients who had a CT of only one hip, which therefore did not allow correction of tilt, inclination, and rotation (two patients), and patients who had CTs greater than 18 months from the initial SCFE (seven patients). These nine exclusions left 23 patients with SCFE. Of the CT scans evaluated in patients with SCFE, 14 were performed preoperatively and nine were performed after postoperative closed treatment of SCFE with pinning (average 6.6 months postoperatively). The postoperative CT scans were in patients who had surgery at other institutions but presented to our tertiary hip referral center with hip symptoms and then underwent CT imaging as part of their workup. Of the nine postoperative CTs, three were performed due to avascular necrosis, one was performed due to pin migration resulting in contralateral SCFE, and five were performed due to FAI

symptoms from SCFE-related cam morphology. Five of the 23 patients presented with unstable SCFE and 18 with stable per the classification of Loder et al. [22]. Two were acute (symptoms < 3 weeks), eight were acute-on-chronic (symptoms > 3 weeks with an acute exacerbation), and 14 were chronic (symptoms > 3 weeks) at the time of presentation. Based on chart and radiographic review, 22 unaffected hips and 24 affected hips (one patient had bilateral SCFE) were identified. There were nine girls and 14 boys among the patients with SCFE. The average age was 12.5 years (range, 10–16 years) for the affected group and 12.7 years (range, 10–16 years) for the unaffected group. We established three groups: affected hips in patients with SCFE, unaffected hips (ie, contralateral hips without evidence of SCFE) in patients with SCFE, and the age- and sex-matched non-SCFE control group. We had prior institutional review board approval.

The control group of 76 age- and sex-matched patients (23 girls, 53 boys) (152 hips) was taken from a database that included all 225 pediatric patients who underwent abdominal CTs during the workup of nonorthopaedic-related abdominal complaints from November 2011 to January 2012; these patients were used as the normal comparison. The average age was 12.7 years (range, 10–16 years) for the control group. We carefully reviewed each patient's chart and emergency room evaluation to ensure there were no orthopaedic hip complaints or disease, scoliosis, or other major developmental disorders. The most common indication for abdominal CT was to rule out appendicitis. The abdominal CTs with 0.6-mm thickness and 0.6-mm intersection gap were then reoriented by the process described in detail below to create standardized coronal and axial slices with 2-mm thickness and 0.6-mm intersection gap.

Using GE Advantage Workstation® Version 4.3_05 software (GE Medical Systems, Chalfont St Giles, UK), each CT was temporarily reconstructed in 3-D to standardize the position of the pelvis. This method was previously validated using cadaver pelvises [1]. The 3-D pelvis was then reoriented to a standard anatomic position by aligning the left and right anterior superior iliac spines (ASISs) in the axial view to correct rotation (Fig. 1A), aligning the superior portion of the right and left ASISs in the coronal plane to correct inclination (Fig. 1B), and finally by aligning the pubic symphysis and the ASIS in the sagittal plane to correct the pelvic tilt (Fig. 1C). Once reoriented, the CTs were reconstructed into axial and coronal slices with 2-mm thickness and 0.6-mm intersection gap resulting in a total standardized CTs of 99 patients (198 hips).

In the reoriented CTs, one observer (SM) measured the acetabular version on the axial slice corresponding to the proximal $\frac{1}{4}$ of the line joining the acetabular roof to the

Fig. 1A–C The 3-D pelvis was reoriented to standard anatomic position (A) first by aligning the left and right ASISs in the axial view, (B) second by aligning the superior portion of the right and left

ASISs in the coronal plane, and (C) third by aligning the pubic symphysis and the ASIS in the sagittal plane.

inferior pelvic teardrop (AV_{sup}), as described by Dandachli et al. [6] (Fig. 2A–B), and on the axial slice of the acetabulum corresponding to the center of the femoral head (AV_{cen}) (Fig. 2A–C) [2, 14]. The LCEA was measured using a coronal slice corresponding to the center of the acetabulum [4, 26]. In measuring LCEA in an SCFE-affected hip when the femoral head was nonspherical, we utilized the medial part of epiphysis as a guide and assumed a spherical shape from that contour. In the three cases of avascular necrosis, the acetabular contour was utilized to find the center of rotation as described by Visser [36]. Kitadai et al. [15] compared LCEA measurement to the Visser method and found no difference at different SCFE severity levels, concluding LCEA can be accurately measured in a hip with SCFE. Interobserver variability ICCs reported in the literature are 0.83 for AV_{sup} [6], 0.69 for AV_{cen} [11], and 0.78 for LCEA [11] measured on CT.

We used Levene's test to determine equality of variances among the three groups at both measurement locations. One-way ANOVA was used to identify differences in acetabular version among the three groups at both measurement locations. Pairwise comparison of the three groups was made using the Bonferroni post hoc test. The process outlined previously was also used to identify differences in LCEA among the three groups, as measured on CT. We conducted all statistical analyses using SPSS[®] Version 12 (SPSS Inc, Chicago, IL, USA).

Results

We found a difference ($p < 0.001$) in mean AV_{sup} among affected hips (-1.71°), unaffected hips (5.0°), and the normal age- and sex-matched control group (6.68°). Based on a Bonferroni post hoc test, the mean AV_{sup} was lower in affected hips than in unaffected hips ($p = 0.022$) and the control group ($p < 0.001$). The mean AV_{sup} of unaffected hips was not different ($p = 1.0$) from that of controls.

We found no difference ($p = 0.726$) in mean AV_{cen} among affected hips (13.67°), unaffected hips (14.91°), and the control group (14.08°).

We found a difference ($p < 0.001$) in mean LCEA among affected hips (34.3°), unaffected hips (34.5°), and the control group (28.9°). There were no differences in mean LCEA between affected and unaffected hips ($p = 1.0$), whereas both were different ($p < 0.001$) from the control group (Table 1).

Discussion

The association between SCFE and FAI [7, 9, 33, 35] and femoral retroversion [10] is well documented. In addition, both FAI and femoral retroversion (one study) are reportedly associated with acetabular retroversion [3, 32]. Sankar et al. [30] demonstrated increased superior acetabular retroversion as measured by the crossover sign and increased superolateral femoral head coverage as measured by the LCEA in unaffected SCFE hips. However, several studies utilizing CT have not found acetabular retroversion in hips with SCFE [10, 16, 34]. Given these studies measured retroversion only at a single plane, we question whether a CT quantification method more sensitive to localized superior acetabular retroversion would demonstrate increased superior acetabular retroversion in the SCFE-affected hip. Additionally, utilizing CT, we sought to confirm acetabular morphology in patients with SCFE is associated with bilateral increased superolateral femoral head coverage. We therefore addressed the following questions: Are there differences in (1) AV_{sup} , (2) AV_{cen} , and (3) LCEA among affected SCFE hips, contralateral (unaffected) hips, and normal controls?

Several limitations are apparent in this study. First, in nine of the patients, the CTs were performed postoperatively, which could theoretically include components of postoperative changes to the acetabulum. However, a chart

Fig. 2A–C The method for measuring (A, B) AV_{sup} and (A, C) AV_{cen} is shown. AV_{sup} is measured on the axial slice corresponding to the proximal $\frac{1}{4}$ ($1/4D$) of the distance (D) joining the acetabular roof to the inferior pelvic teardrop on the coronal slice. AV_{cen} is measured on the axial slice corresponding to the center of the femoral head on the coronal slice.

Table 1. Acetabular version and LCEA results

Group	AV_{sup} ($^{\circ}$)	AV_{cen} ($^{\circ}$)	LCEA ($^{\circ}$)
Affected SCFE hip	-1.7 ± 8.9 (-19 to 12)	13.7 ± 4.8 (5 – 26)	34.3 ± 5.2 (24 – 46)
Unaffected SCFE hip	5.0 ± 9.5 (-16 to 21)	14.9 ± 4.9 (4 – 25)	34.5 ± 6.4 (21 – 48)
Normal controls	6.7 ± 8.1 (-18 to 31)	14.1 ± 5.6 (1 – 29)	28.9 ± 6.2 (16 – 47)

Values are expressed as mean $\pm$ SD, with range in parentheses; LCEA = lateral center-edge angle; AV_{sup} = acetabular version at the superior $\frac{1}{4}$ of the acetabular dome; AV_{cen} = acetabular version at the center of the femoral head; SCFE = slipped capital femoral epiphysis.

and radiographic review ensured each operation did not include an acetabular component. Additionally, we excluded patients with CTs taken more than 18 months postoperatively to limit any theoretical postoperative acetabular remodeling that may have occurred as a reaction to the treated SCFE. Second, we did not examine or interview the age- and sex-matched control patients. This resulted in a reliance on chart review, which did not contain the patients' BMI and contained a limited musculoskeletal examination. Some of these patients may have had symptomatic or undiagnosed hip disease, but radiographically none showed evidence of SCFE. Additionally, BMI may have been notably different between the normal control group and patients with SCFE. Therefore, any associated acetabular morphology may be possibly secondary to a high BMI typically found in patients with SCFE [24]. Finally, our affected and unaffected groups had only 24 and 22 hips, respectively. An increase in sample size would have yielded findings that could more reliably represent the larger population. Further investigations with larger sample

sizes and long-term followup will be needed to fully understand acetabular growth, morphology, and changes that may result from or be associated with a SCFE.

The AV_{sup} showed substantial retroversion (mean, -1.71°) in SCFE-affected hips compared to unaffected hips (mean, 5.0°) and the normal controls (mean, 6.68°), but unaffected hips were not different from the normal control group. This is in contrast to Sankar et al. [30], who demonstrated a difference in the percentage of hips with a crossover sign in unaffected hips in patients with SCFE (78%) compared with the control group (21%). We are not aware of any correlation study between AV_{sup} and the crossover sign, but in contrast to Sankar et al. [30], we were able to correct pelvic tilt, which when uncorrected has the potential to overestimate acetabular version [31]. This may explain our divergent findings.

The mean AV_{cen} was 12.7° in SCFE-affected hips, 14.9° in unaffected hips, and 14.1° in the control group. Previous studies investigating acetabular retroversion and SCFE using CT demonstrated ranges from 11.1° to 13.5° for

Fig. 3 A 3-D CT reconstruction of a posterior view of the acetabulum of an affected hip in a patient with SCFE demonstrates superior acetabular anterior rim overcoverage (arrow).

unaffected hips and 11.9° to 15.7° for affected hips; these results are similar to ours [16, 23, 34]. Consistent with previous literature, our study did not demonstrate any difference in AV_{cen} among affected hips, unaffected hips, and the normal control group, suggesting the retroversion found in AV_{sup} is localized to the superior part of the acetabulum.

The mean LCEA for both affected (34.3°) and unaffected (34.5°) hips in SCFE were considerably increased compared to that of the normal control group (28.9°). This is consistent with both Kitadai et al. [15], whose results revealed the average LCEA of affected hips and unaffected hips to be higher than normal controls, and with Sankar et al. [30], whose results revealed the average LCEA of unaffected hips to be higher than normal controls. The LCEA of the affected hips in our study (range, 24° – 46°) demonstrated a normal to increased acetabular coverage. An LCEA of greater than 39° was found in 16.7% (four of 24) of the affected hips, 22.7% (five of 22) of the unaffected hips, and 6.5% (10 of 152) of the controls. Additionally, biomechanical etiology theories of SCFE have demonstrated increase in femoral retroversion, coxa vara, and varus displacement of the load vector will increase physeal shear forces [8, 27, 38]. The medialization of the femoral head of patients with SCFE (as demonstrated in our study by the increased LCEA) may cause varusization of the force vector, increasing the shear forces across the physis and therefore potentially increasing the risk for SCFE [8, 13, 25].

The increased retroversion of AV_{sup} , the normal AV_{cen} , and the increased LCEA of the affected hips in the patients with SCFE suggest a morphology of a focal pincer with anterosuperior acetabular rim overcoverage (Fig. 3). Whether this is a primary acetabular morphology or

secondary adaption phenomenon remains unclear. It is also unclear whether the femoral retroversion associated with SCFE hips [10] is a primary or secondary adaption to the acetabular morphology. Further studies will be needed to investigate acetabular coverage and retroversion as potential contributors to increased shear forces across the physis in SCFE and their implication for development of symptomatic FAI with time.

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