Original Clinical Article

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The metaphyseal fossa surrounding the epiphyseal tubercle is larger in hips with moderate and severe slipped capital femoral epiphysis than normal hips

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Abstract

Purpose To compare the 3D morphology of the metaphyseal fossa among mild, moderate and severe stable slipped capital femoral epiphysis (SCFE) and normal hips.

Methods We identified pelvic CT of 51 patients (55% male; mean 12.7 years (SD 1.9; 8-15)) with stable SCFE. In all, 16 of 51 hips (31%) had mild, 14 (27%) moderate and 21 (41%) severe SCFE. A total of 80 patients (50% male; mean age 11.5 years (SD 2.3; 8 to 15)) with normal hips who underwent pelvic CT due to abdominal pain made up the control cohort. CT scans were segmented, and the femur was reformatted using 3D software. We measured the metaphyseal fossa depth, width, length and surface area after the epiphysis was subtracted from the metaphysis in the 3D model.

Results The metaphyseal fossa width was significantly larger in severe (adjusted difference: 6.9%; 95% confidence interval (CI) 2.1 to 11.8; p = 0.001), moderate (6.5%; 95% CI 0.8 to 12.2; p = 0.02) and mild SCFE (6.2%; 95% CI 0.8 to 11.6; p = 0.01), in comparison with normal hips. Severe SCFE showed larger fossa length compared with mild SCFE (6.8%; 95% CI 0.6 to 13.0; p = 0.02) and normal hips (6.0%; 95% CI 1.4 to 10.6; p = 0.004). The fossa surface area was larger in severe (3.5%; 95% CI 1.3 to 5.7; p < 0.001) and moderate SCFE (2.7%; 95% CI 0.1 to 5.2; p = 0.03) when compared with normal hips. There were no differences in fossa depth between SCFE and normal hips.

Conclusion The metaphyseal fossa is wider and more extensive but not deeper in hips with moderate and severe SCFE in comparison with normal hips. Although hips with severe SCFE had larger length and surface area than mild SCFE hips, further research is needed to clarify whether enlargement of the metaphyseal fossa is a consequence of slip progression.

Level of Evidence: III

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Keywords: slipped capital femoral epiphysis; SCFE; epiphyseal tubercle; metaphyseal fossa

Introduction

The perichondral fibrocartilaginous complex,[1] surrounding periosteum[2,3] and interdigitations or ridges between the epiphysis and metaphysis[4,5] provide stability to the capital femoral epiphysis. The epiphyseal tubercle is a large bone-peg prominence located at the posterior and lateral quadrant of the epiphysis, intimately connected to a correspondent socket or fossa at the metaphyseal surface.[6-8] The epiphyseal tubercle is a keystone stabilizer of the capital femoral epiphysis.[9-11] The tubercle halts the slide of the epiphysis and abuts against the metaphyseal fossa when specific loads are applied to a porcine proximal femoral growth plate.[12]

As the epiphyseal tubercle and the metaphyseal fossa are basic structures for epiphyseal stabilization, their morphology is likely affected in hips with slipped capital femoral epiphysis (SCFE). One recent study showed that hips with SCFE have a smaller epiphyseal tubercle when compared with normal hips.[13] As the rotational SCFE deformity progresses, the epiphyseal tubercle displaces posteriorly with potential enlargement of the metaphyseal fossa.[14] Notably, lucency around the metaphyseal fossa was described as an early radiographic sign of SCFE in the contralateral hip of patients followed for unilateral SCFE.[15] However, abnormalities of the metaphyseal fossa have not been completely described in patients with SCFE.

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The purpose of this study was to compare the 3D morphology of the metaphyseal fossa in hips with mild, moderate and severe SCFE with the morphology of normal hips.

Patients and methods

Study population

Following institutional review board approval, we extracted the data regarding the surgically treated SCFE patients between 1st January 2000 and 31st December 2018 from our institutional database. The inclusion criteria were: 1) age between eight and 15 years; 2) stable SCFE as defined by patients being able to walk with or without crutches at the time of hospital admission; and 3) available preoperative CT of the pelvis before surgery. The indication for obtaining a CT scan was based on the treating surgeon's preference to improve the understanding of the proximal femoral morphology to decide and plan the surgical treatment accordingly. A total of 51 patients (51 hips) met the inclusion criteria. There were 28 males (55%) and 23 females (45%), and the mean age (and standard deviation) was 12.7 years ± 1.9 years. We measured the head-shaft angle on the preoperative frog-leg lateral radiography to classify the SCFE into mild (< 30°), moderate (30° to 60°) and severe (> 60°) as described by Southwick.[16] There were 16 (31%) mild, 14 (27%) moderate and 21 (41%) severe SCFE hips. These hips have been the subject of a previous study describing the morphology of the epiphyseal tubercle in hips with SCFE.[9]

We used a historical database of pelvic CT scan imaging obtained from 2008 to 2010 in patients aged eight to 15 years for evaluation of abdominal pain in the setting of suspected appendicitis to identify a control group with normal hip morphology. The cohort was made up of 80 patients (50% male) with a mean age of 11.5 years (SD 2.3). This cohort has been previously used for a study investigating the morphology of the epiphyseal tubercle and the peripheral cupping in normal children.[7] We confirmed that hips included in the control group were normal by measuring the epiphyseal tilt angle, alpha angle and the acetabular index angle and compared the measurements with normative values.[17-19]

3D image analysis

Imaging data of each hip was segmented to create a 3D model of the femur with Mimics software (v17.0; Materialise, Leuven, Belgium). The epiphysis and metaphysis were segmented as two independent bodies (Fig. 1). Segmented geometries were then used to reconstruct 3D models of the capital femoral epiphysis and the metaphysis. The reconstructed 3D geometries for the epiphysis and metaphysis were transferred to 3-matics software (v9.0; Materialise, Leuven, Belgium). Finally, the metaphyseal 3D body was subtracted from the epiphysis to measure and analyze the reconstructed model of the metaphyseal surface of the proximal femoral growth plate. True coronal and sagittal planes passing through the centre of the fossa were used to measure the width and length of the fossa (Fig. 2).

We assessed the metaphyseal fossa depth with respect to the metaphysis surface by measuring the perpendicular distance between the deepest surface of the fossa and a plane fitted to the metaphyseal surface. The metaphyseal fossa width was measured in the coronal plane and represents the extension of the fossa from medial to lateral while the fossa length was measured on the sagittal plane and represents the anterior to posterior extension of the fossa. Length and width were then used to estimate fossa surface area assuming elliptical fit. All measurements were expressed as a percentage of the epiphyseal diameter to normalize for variations in size.

Statistical analysis

Analysis of variance was used to compare the quantified anatomical features of the metaphyseal fossa between

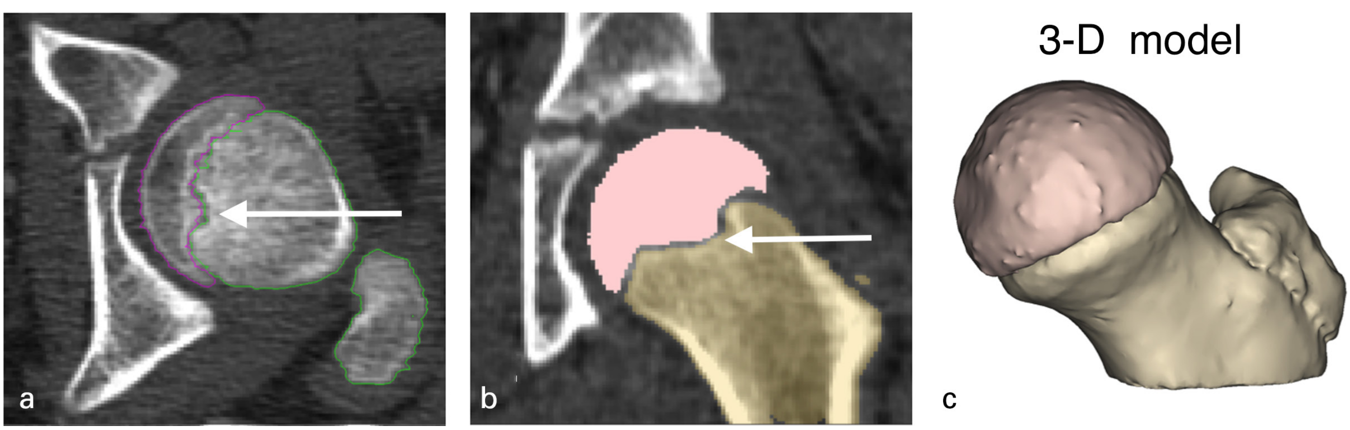

Fig. 1 CT imaging of a normal hip and 3D model. **(a)** Axial plane and **(b)** coronal plane images were segmented to create the 3D model of the proximal femur **(c)**. A white arrow points to the metaphyseal fossa.

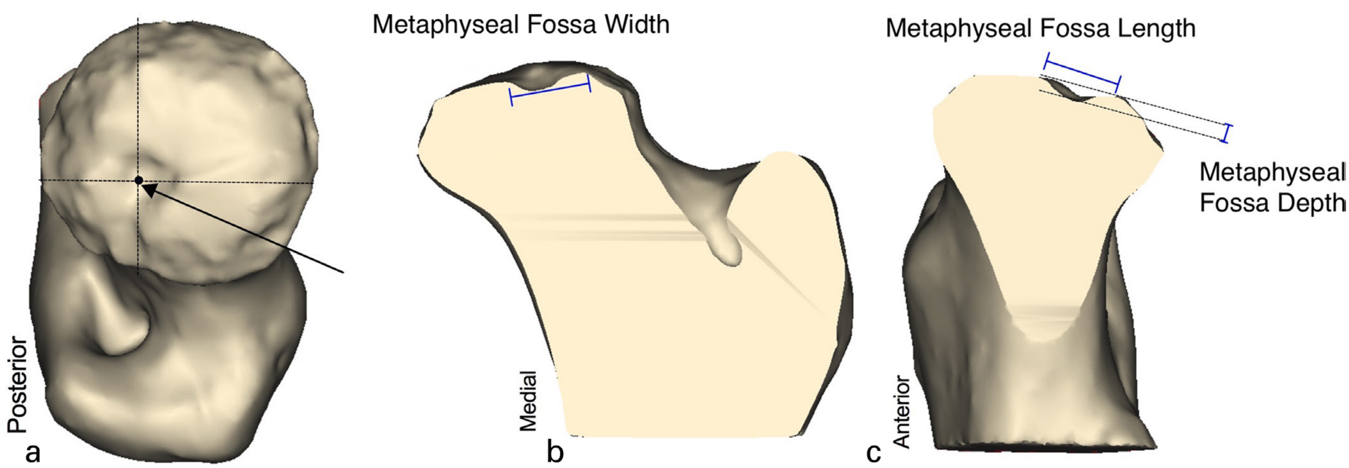

Fig. 2 Diagram representing the measurements of the metaphyseal fossa: **a)** 3D representation of the metaphyseal surface of the capital femoral growth plate. The metaphyseal fossa is located in the posterior superior quadrant. The black arrow points to the centre of the metaphyseal fossa; **b)** coronal representation of the proximal femur used to measure the metaphyseal fossa width; **c)** sagittal representation of the proximal femur used to measure the metaphyseal fossa depth and the length.

Table 1 Differences in metaphyseal fossa morphologic measurements between control subjects with normal hips (n = 80) and those with mild (n = 16), moderate (n = 14) and severe (n = 21) stable slipped capital femoral epiphysis (SCFE)

			Adjusted p-values* for pairwise comparisons		
Anatomical index	Group	Mean (SD)**	Normal	Mild SCFE	Moderate SCFE
Fossa depth	Normal	3.9 (1.8)	-	-	-
	Mild SCFE	4.5 (2.2)	0.99	-	-
	Moderate SCFE	5.4 (2.2)	0.13	0.99	-
	Severe SCFE	5.1 (2.0)	0.16	0.99	0.99
Fossa length	Normal	22.9 (7.2)	-	-	-
	Mild SCFE	22.1 (6.8)	0.99	-	-
	Moderate SCFE	26.8 (7.1)	0.36	0.41	-
	Severe SCFE	28.9 (6.9)	< **0.01**	**0.02**	0.99
Fossa width	Normal	21.3 (7.2)	-	-	-
	Mild SCFE	27.5 (7.2)	**0.01**	-	-
	Moderate SCFE	27.9 (7.5)	**0.02**	0.99	-
	Severe SCFE	28.3 (7.3)	< **0.01**	0.99	0.99
Fossa surface area	Normal	5.1 (3.6)	-	-	-
	Mild SCFE	6.0 (3.2)	0.99	-	-
	Moderate SCFE	7.8 (3.4)	**0.03**	0.89	-
	Severe SCFE	8.6 (3.2)	< **0.01**	0.12	0.99

*ANOVA with Bonferroni *post hoc* after adjusting for age and sex
**adjusted for age and sex and reported as a percentage of the diameter of the femoral epiphysis
Significant differences are highlighted in bold, $p < 0.05$

normal hips (controls) and SCFE hips (mild, moderate and severe) after adjusting for age and sex. Bonferroni *post hoc* was used to adjust for multiple comparisons. All data are reported as mean and SD. All p-values are two sided and considered statistically significant at $\alpha = 0.05$. The analysis was done using SPSS (v24; IBM Corp., Armonk, New York).

Results

The metaphyseal fossa width was significantly larger in hips with mild (adjusted difference: 6.2%; 95% confidence interval (CI) 0.8 to 11.6; p = 0.01), moderate (adjusted difference: 6.5%; 95% CI 0.8 to 12.2; p = 0.02) and severe SCFE (adjusted difference: 6.9%; 95% CI 2.1 to 11.8; p = 0.001) when compared with normal hips (Table 1; Fig. 3a). Hips with severe SCFE had significantly larger metaphyseal fossa length compared with normal hips (adjusted difference: 6.0%; 95% CI 1.4 to 10.6; p = 0.004) and mild SCFE hips (adjusted difference: 6.8%; 95% CI 0.6 to 13.0; p = 0.022) (Table 1; Fig. 3b). There were no significant differences in metaphyseal fossa depth between hips with SCFE and normal hips (Table 1; Fig. 3c). Finally, the metaphyseal fossa surface area was significantly larger in hips with moderate (adjusted difference: 2.7%; 95% CI 0.1 to 5.2; p = 0.032) and severe SCFE (adjusted difference: 3.5%; 95% CI 1.3 to 5.7; p < 0.001) SCFE when compared with normal hips (Table 1; Fig. 3d).

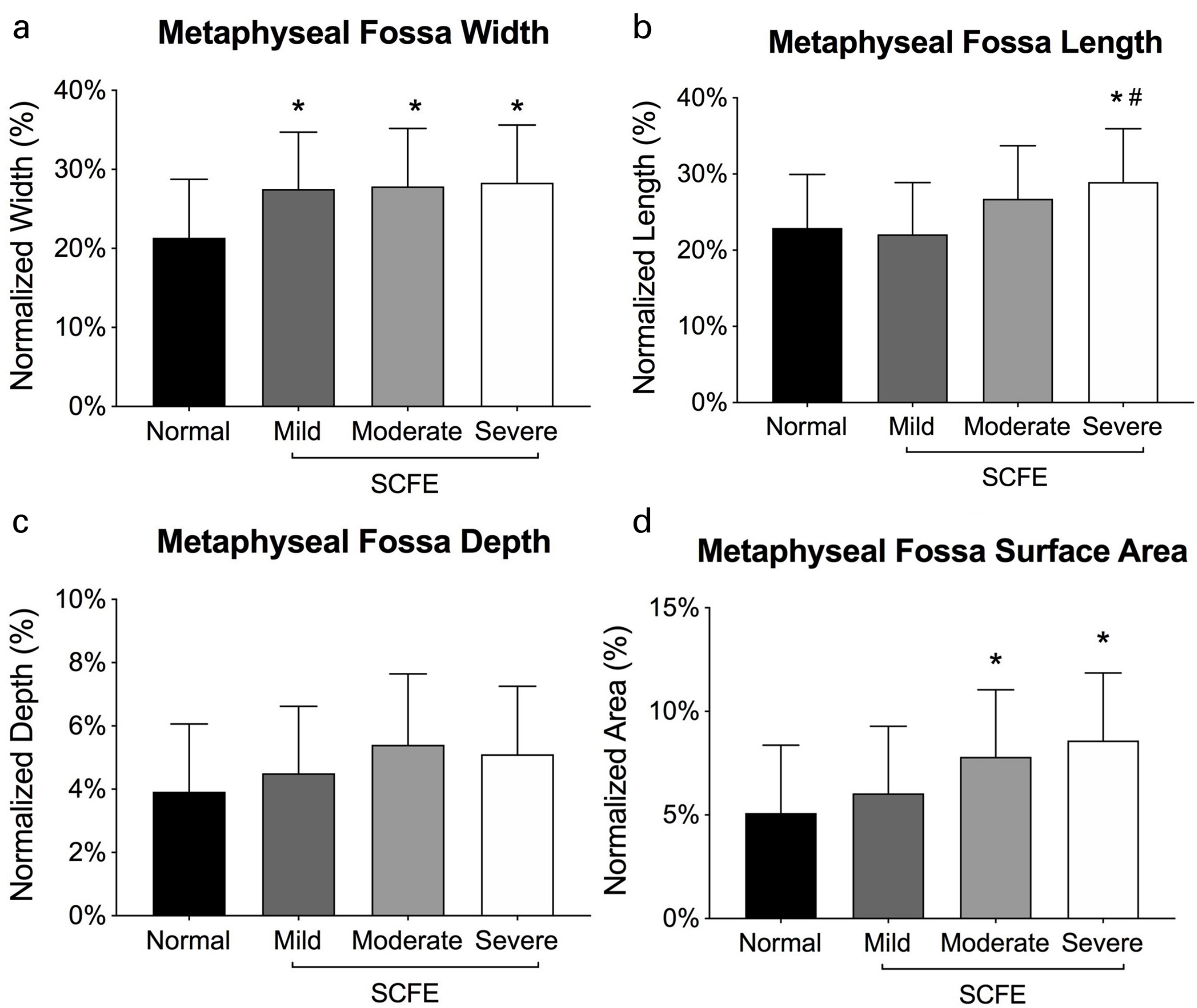

Fig. 3 Graphs representing the mean changes in metaphyseal fossa width **(a)**, length **(b)**, depth**(c)** and surface area **(d)** between normal hips and hips with slipped capital femoral epiphysis (SCFE) (*$p < 0.05$ compared with normal hips; #$p < 0.05$ compared with mild SCFE).

Discussion

The surface anatomy of the capital femoral epiphysis growth plate has irregularities and interdigitations that provide stability.[1,4] The epiphyseal tubercle is a sizeable inner projection of the epiphysis into the metaphyseal fossa, and acts as an interlocking mechanism halting epiphyseal translation.[6,8-11] In SCFE, the metaphysis rotates around the epiphyseal tubercle that serves as a fulcrum, which can lead to abnormalities of the tubercle and the corresponding fossa.[10,11,14] Although the epiphyseal tubercle is smaller in patients with SCFE,[9] abnormalities of the metaphyseal fossa have never been quantitatively investigated with advanced imaging. In this study, we evaluated the surface anatomy of the metaphysis in 3D-CT models in hips with SCFE and hips without disorders. We found that the metaphyseal fossa is wider (medial to lateral measurement) in hips with mild, moderate and severe SCFE compared with normal hips. Hips with severe SCFE were found to have a greater metaphyseal fossa length (anterior to posterior measurement) when compared with mild SCFE and normal hips. The metaphyseal surface area was more extensive in hips with moderate and severe SCFE than in normal hips. However, no differences were noted for the metaphyseal fossa depth between SCFE and normal hips.

The enlargement of the metaphyseal fossa may be due to an increased mechanical stress from the epiphyseal tubercle against the metaphyseal fossa leading to

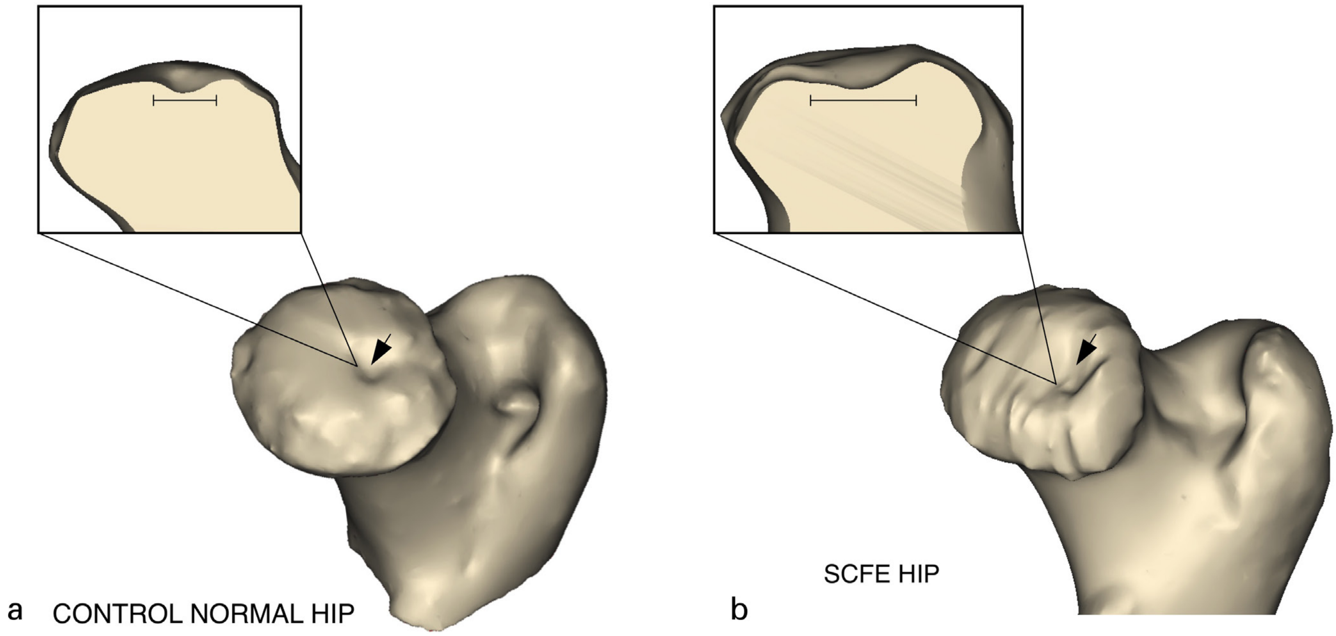

Fig. 4 Representative 3D models of average femoral metaphyseal fossa (black arrows) in normal **(a)** and slipped capital femoral epiphysis **(b)** hips.

bone resorption. An experimental biomechanical study of porcine femoral epiphyseal plate showed that the epiphyseal tubercle presses against the medial aspect of the metaphyseal fossa avoiding the slide of the epiphysis when the epiphysis is loaded laterally and vertically.[12] In our study, the metaphyseal fossa was enlarged from the medial to lateral dimension (width) in all stages of SCFE but we found no changes in the metaphyseal depth between SCFE and normal hips. The lack of changes in metaphyseal depth may be related to the mechanism of epiphyseal tubercle pressing against the walls of the fossa as previously described.[12] We did not find differences in metaphyseal fossa length and surface area between mild SCFE hips and normal hips. Thus, we hypothesize that the metaphyseal fossa enlarges with SCFE progression. Notably, radiographic evidence of the metaphyseal fossa enlargement has been described in the early stage of SCFE.[15] In this study, we characterized the 3D morphology of the metaphyseal lucency previously described in early onset of SCFE. However, further studies will be necessary to determine whether 3D analysis of the epiphyseal tubercle and the corresponding fossa would enhance the diagnosis of SCFE at an early stage.

Previous studies described a rotational mechanism of SCFE and suggested that, with slip progression, the epiphyseal tubercle may dislodge from the correspondent metaphyseal fossa.[6,10,11,14] In the early slip stage there is normal congruence between the epiphyseal tubercle and the metaphyseal fossa. With advanced slip and rotation, the epiphyseal tubercle starts to press against the posterior and medial walls of the metaphyseal fossa, increasing the adjacent bone reaction. Then, the morphology of the epiphyseal tubercle and metaphyseal fossa alters. While a previous study[13] reported a smaller epiphyseal tubercle, we showed that the metaphyseal fossa was wider, longer and had a more extensive surface area in more severe SCFE hips (Fig. 4). A smaller tubercle and larger fossa may affect the interlocking between the two structures and losing the interlocking mechanism may contribute to additional epiphyseal instability. As the deformity progresses, the epiphyseal tubercle loses the connection with the enlarged fossa and reaches or surpasses the posterior cortex of the femoral neck. Eventually, further slip progression may lead to full disengagement of the epiphysis from the metaphysis.[6,10,11,14]

Our study has several limitations. First, our SCFE cohort was small following dividing the cohort into three subgroups of SCFE severity. Subsequently, we were unable to directly match the SCFE hips and normal hips based on specific age groups and sex. Despite this limitation, we tried to overcome that by implementing proper statistical methods, adjusting the analysis for age. Second, this study was a cross-sectional evaluation of a heterogeneous group of SCFE patients regarding the severity and duration of symptoms (a large proportion of patients had moderate to severe SCFE). The reason for this is that CT scans are performed more frequently for moderate and severe deformities, usually to assist the surgical decision-making and osteotomy planning for femoral realignment. Third, although we hypothesized herein that the enlargement of the fossa is an acquired abnormality as a result of the SCFE progression, we cannot exclude the possibility of inherent or native morphological variation of the metaphyseal fossa in patients with SCFE and acknowledge that further research is necessary.

In conclusion, we found that the metaphyseal fossa is wider and has a more extensive surface area, but it is not deeper in hips with moderate and severe SCFE in comparison with normal hips. Because we did not observe a consistent enlargement of the metaphyseal fossa in hips with mild SCFE, it is possible that the fossa enlargement is a consequence of the slip process and progression. Our findings help to clarify the pathological relationship between the epiphyseal tubercle and the metaphyseal fossa in SCFE. However, further studies are needed to clarify the temporal and causal association between the changes observed in the metaphyseal fossa and the epiphyseal tubercle.

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COMPLIANCE WITH ETHICAL STANDARDS

FUNDING STATEMENT

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

ETHICAL STATEMENT

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study was approved as a retrospective comparative study by our institutional review board.

Informed consent: Informed consent was not obtained from the patients involved in this study given its retrospective nature.

ICMJE CONFLICT OF INTEREST STATEMENT

None declared.

AUTHOR CONTRIBUTIONS

SH: Data collection and analysis, Manuscript preparation.

AMK: Conceptualization and design, Statistical analysis, Manuscript preparation.

DAM: Statistical analysis, Data interpretation, Manuscript preparation.

SAE: Data collection, Data interpretation, Manuscript preparation.

GP: Data collection, Manuscript preparation.

Y-JK: Conceptualization and design, Data interpretation, Manuscript preparation.

ENN: Conceptualization and design, Data interpretation, Manuscript preparation.

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