

# Increased body mass index percentile is associated with decreased epiphyseal tubercle size in asymptomatic children and adolescents with healthy hips

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## Abstract

**Purpose** To investigate whether body mass index (BMI) percentile impacts the morphology of the capital femoral epiphysis in children and adolescents without hip disorders.

**Methods** We assessed 68 subjects with healthy hips who underwent a pelvic CT for evaluation of appendicitis. There were 32 male patients (47%) and the mean age was 11.6 years (SD 2.3). The BMI (kg/m<sup>2</sup>) was calculated for sex- and age-related percentiles according to the Centers for Disease Control and Prevention growth charts. CT images were segmented, and the epiphysis and metaphysis were reformatted using 3D software. We measured the epiphyseal tubercle (height, width and length), the metaphyseal fossa (depth, width and length) and the peripheral cupping of the epiphysis. All measurements were normalized to the diameter of the epiphysis. Pearson's correlation analysis was used to assess the correlations between the variables measured and BMI percentile adjusted for age.

**Results** Following adjustment to age, increased BMI correlated to decreased tubercle height ( $r = -0.34$ ; 95% confidence interval (CI) -0.53 to -0.11;  $p = 0.005$ ), decreased tubercle length ( $r = -0.32$ ; 95%CI -0.52 to -0.09;  $p = 0.008$ ) and decreased

tubercle width ( $r = -0.3$ ; 95% CI -0.5 to -0.07;  $p = 0.01$ ). There was no correlation between BMI and metaphyseal fossa and epiphyseal cupping measurements.

**Conclusion** The association between increased BMI percentile and decreased epiphyseal tubercle size, without changes of the metaphyseal fossa and peripheral cupping suggests another morphological change of the femur that may be associated with decreased growth plate resistance to shear stress. Further study is necessary to investigate whether the epiphyseal tubercle size plays a role in the pathogenesis of slipped capital femoral epiphysis in obese children and adolescents.

**Level of Evidence:** Level IV

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**Keywords:** childhood obesity; body mass index; epiphyseal tubercle; slipped capital femoral epiphysis; peripheral cupping

## Introduction

Childhood obesity is associated with an increased risk of musculoskeletal conditions, including tibia vara and slipped capital femoral epiphysis (SCFE). In SCFE, the metaphysis rotates about the epiphysis creating a retroversion deformity, which may have a long-term impact with decreased function, hip osteoarthritis and pain.<sup>1</sup> The aetiology of SCFE is multifactorial, but childhood obesity is a well-described risk factor.<sup>2-4</sup> One recent study demonstrated a strong causal association of high body mass index (BMI) and SCFE based on the magnitude of the association, temporal relationship and dose-response.<sup>5</sup> Nevertheless, the pathological mechanisms by which obesity predisposes failure of the growth plate and leading to a slip remain unclear.

The effects of obesity on the proximal femur of a growing child may be attributed to metabolic and endocrine

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abnormalities that weaken the physis or to increased mechanical loading.<sup>6</sup> Obese children have been reported to have reduced femoral anteversion when compared with children of a healthy weight.<sup>7</sup> Notably, reduced femoral anteversion was found to be associated with SCFE.<sup>8</sup> Furthermore, higher BMI was associated with a more posteriorly tilted epiphysis, which can also increase the shear stress across the growth plate.<sup>9</sup>

The surface of the capital femoral epiphysis has recently been the focus of several studies that highlighted the importance of the epiphyseal tubercle; the correspondent metaphyseal fossa and the peripheral cupping of the epiphysis for the stability of the growth plate.<sup>10-15</sup> There is growing evidence suggesting that the epiphyseal tubercle serves as a pivot point for rotation of the metaphysis in SCFE.<sup>16-18</sup> As childhood obesity has been shown to affect the structure of the femur, including reduced femoral anteversion and a more posteriorly tilted epiphysis, higher BMI may be associated with variations of the capital femoral epiphysis surface that reduce physeal stability and predispose to a slip. To the best of our knowledge, information about the impact of obesity on capital femoral epiphysis morphology is lacking.

The purpose of this study was to investigate whether BMI percentile impacts the morphology of the capital femoral epiphysis surface in children and adolescents without hip disorders.

## Materials and methods

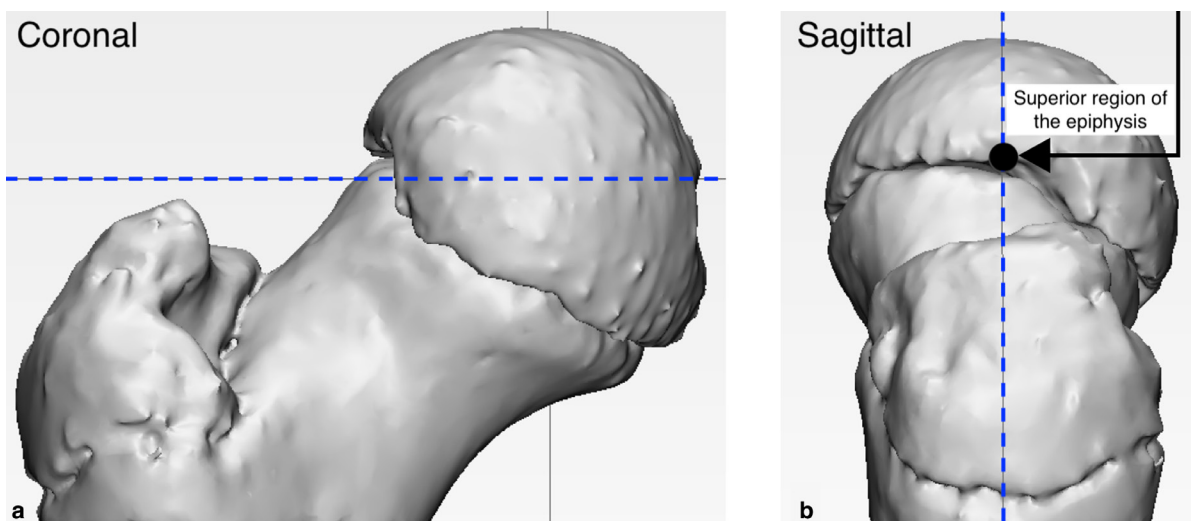
### Study population

This is a retrospective cohort study. Following institutional review board approval, we searched for the hospital

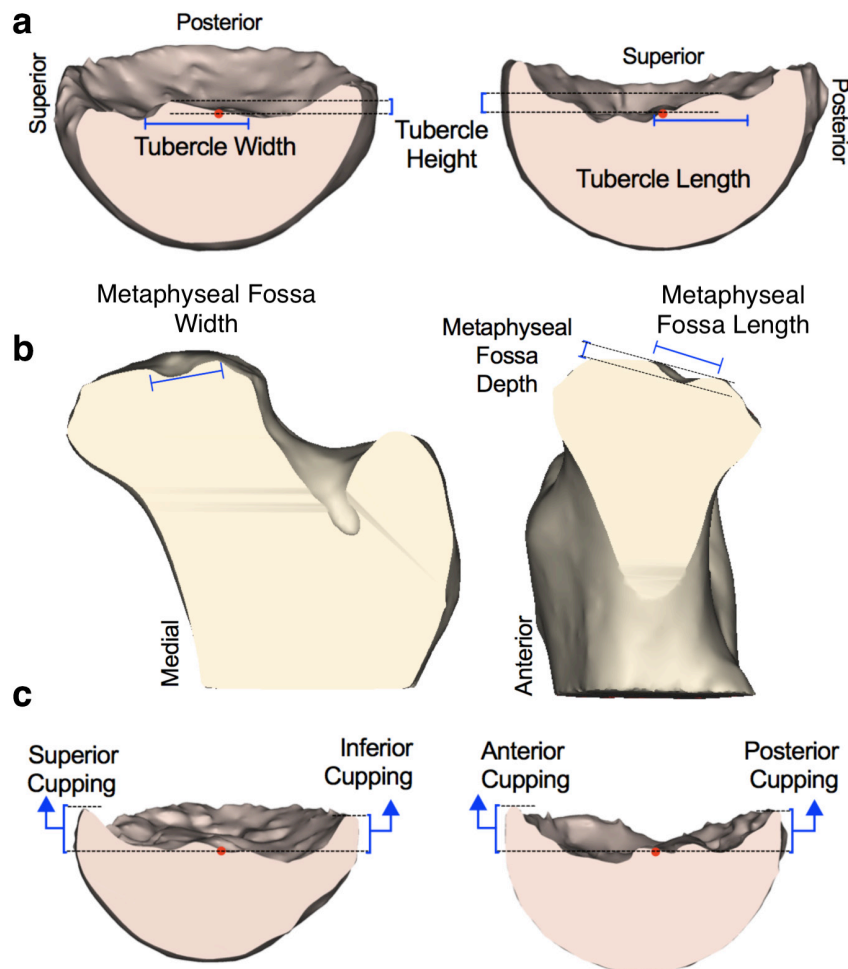
database to identify patients between ages eight and 15 years who underwent CT of the pelvis for the clinical assessment of abdominal pain in the setting of possible appendicitis between January 2008 and October 2010. Although a total of 94 patients were identified, eight were excluded because of diseases potentially associated with musculoskeletal system involvement (six with neurogenic disorders, one with multiple hereditary osteochondromas and one with craniosynostosis). Also, one patient was excluded because of hip symptoms and five were excluded because the quality of the CT was inadequate for image reformatting. Finally, 12 patients were excluded because height and weight were not obtained at the time of the pelvic CT. A total of 68 patients were included in the study. Demographics, including patient age, sex, height and weight at the time of the CT scan, and confirmation of a negative history of a hip disorder, were collected from the medical records. We calculated the BMI ( $k/m^2$ ) based on weight and height normalized for sex- and age-related percentiles using the growth charts from the United States Center for Disease Control.<sup>19</sup> The left or right hip of each patient was randomly selected. Some of the patients included in this study were previously included in other studies describing the impact of BMI on a 2D assessment of the femur and acetabulum<sup>9</sup> and the normal morphology of the epiphyseal tubercle in children and adolescents<sup>13</sup>. In the current study, we focused on investigating the associations between BMI percentile and key morphological features of the capital femoral epiphysis.

### Imaging protocol

CT of the pelvis was acquired on different CT scanners with the same imaging acquisition protocol with an imaging



**Fig. 1** Diagram representing the coronal (a) and sagittal (b) views of the 3D model of the hip. The superior region of the epiphysis was defined by the intersection of the epiphysis and the longitudinal axis of the neck (dashed blue line) passing through the greater trochanter.



**Fig. 2** Measured anatomical indices for the epiphyseal tubercle included the tubercle height, width and length (a). Measurements of the metaphyseal fossa included its width, depth and length (b). The peripheral cupping was measured in the superior, inferior, anterior and posterior aspects of the epiphysis (c).

resolution of 1 mm or less. An experienced member of the team (DAM) segmented the epiphysis and the metaphysis as two independent bodies and reconstructed 3D geometries of each body using a commercially available image processing software (Mimics v17.0, Materialise, Leuven, Belgium). We used another software (3-matics v9.0, Materialise, Leuven, Belgium) to measure the 3D anatomical indices of capital femoral epiphyseal morphology. For the measurement protocol, we defined the centre and the diameter of the epiphysis using a best-fit sphere. The superior region of the epiphysis was defined by the intersection of the epiphysis and the longitudinal axis of the neck passing through the greater trochanter (Fig. 1). The superior region was used as the origin to establish a coordinate system for the epiphyseal measurements.

We measured the epiphyseal tubercle height (distance between the tubercle peak and the plane of the epiphyseal centre), width and length in the coronal and

sagittal views and the mean values were used for the analysis as previously described (Fig. 2a).<sup>13</sup> We measured the metaphyseal fossa depth (distance between the deepest point of the fossa to the plane through the centre of the epiphysis), width and length (Fig. 2b). Finally, the peripheral cupping defined as the distance between the highest peripheral point and the plane of the epiphyseal centre was measured in the superior, inferior, anterior and posterior regions (Fig. 2c). The average epiphyseal cupping was calculated as the mean across the four anatomical regions. To avoid any effects of femoral size variability, we normalized all the measurements to the diameter of the epiphysis and presented them as a percentage.

*Statistical analysis*

Demographics and the anatomical indices of capital femoral epiphyseal morphology were summarized by mean and SD or median and interquartile range, as appropriate.

**Table 1** Baseline characteristics of the cohort (n = 68).

Demographic	Value
Mean age (SD); range	11.6 (2.3); 8 to 15
Median body mass index (BMI) percentile (interquartile range); range	76.0 (60.1 to 92.4); 6.1 to 99.2
BMI category, n (%); range	
Obese (> 95th percentile)	8 (12); 95.5 to 99.2
Overweight (> 85th percentile)	17 (25); 85.3 to 94.8
Healthy weight (5th to 84th percentile)	43 (63); 6.1 to 84.5
<b>Mean anatomical index (sd); range*</b>	
Anterior cupping	12.3 (5.7); 2.4 to 24.5
Posterior cupping	12.6 (6.3); -1.5 to 29.5
Superior cupping	7.7 (6.8); -4.7 to 24.6
Inferior cupping	8.3 (6.2); -4.6 to 18.5
Average cupping	10.2 (5.5); -0.5 to 21.0
Tubercle width	37.1 (7.1); 22.5 to 54.3
Tubercle length	44.1 (8.4); 28.6 to 62.0
Tubercle height	4.2 (4.0); -4.6 to 12.2
Fossa width	20.8 (7.0); 8.6 to 43.6
Fossa length	22.8 (7.3); 8.3 to 43.7
Fossa depth	3.9 (1.9); 1.1 to 9.1

\*all measurements were normalized to the epiphyseal diameter and presented as percentage

Pearson's correlation analysis was used to assess the unadjusted associations of BMI percentile and age with quantified anatomical features. To further adjust for the potential confounding effect of age, all anatomical measurements were adjusted for age (anatomical measurement/age). We then repeated the correlation analysis to assess the correlations between the quantified anatomical features (adjusted for age) and BMI percentile. Correlation coefficients along with 95% confidence intervals (CIs) were estimated for each association. All these statistical analyses were done using Prism (v8.0; GraphPad Software Inc., San Diego, California, USA).

## Results

A total of 68 subjects were included in the study. There were 32 (47%) male and 36 (53%) female cases with a

mean age of 11.6 (SD: 2.3) years. The baseline characteristics of the cohort are listed in Table 1. The majority of subjects (43/68; 63%) were considered a healthy weight (5th percentile to 84th BMI percentile). In all, 17 (25%) subjects were overweight (85th percentile ≤ BMI < 95th percentile) and eight (12%) were obese (BMI ≥ 95th percentile).

There was a significant negative correlation between increasing age and all measurements of the epiphyseal tubercle and metaphyseal fossa, while a positive correlation was observed between increasing age and measurements of the epiphyseal cupping (Table 2). Further, there was a significant association between higher BMI percentile and decreased epiphyseal tubercle height (r = -0.24; 95% CI -0.45 to 0; p = 0.005) and length (r = -0.25; 95% CI -0.46 to -0.01; p = 0.04). Following adjustment to age, increased BMI correlated to decreased tubercle height (r = -0.34; 95% CI -0.53 to -0.11; p = 0.005), decreased tubercle length (r = -0.32; 95% CI -0.52 to -0.09; p = 0.008) and decreased tubercle width (r = -0.3; 95% CI -0.5 to -0.07; p = 0.01) (Fig. 3). There was no association between BMI and metaphyseal fossa and epiphyseal cupping measurements after adjusting for age (Table 2; Fig. 4).

## Discussion

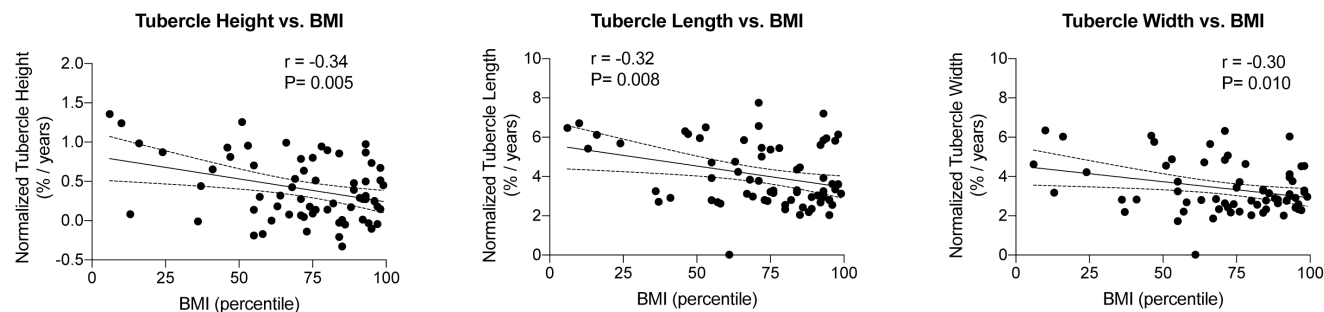
In this study, we investigated whether BMI percentile affects the 3D morphology of the capital femoral epiphysis surface in 68 children and adolescents with asymptomatic hips. We found a significant negative correlation between BMI percentile and all measurements of the epiphyseal tubercle. However, we did not observe a significant correlation between measurements of the metaphyseal fossa and the peripheral cupping and BMI percentile.

The epiphyseal tubercle is a beak-like projection located at the posterior and superior quadrant of the metaphyseal surface of the epiphysis.<sup>12-15</sup> The tubercle and its

**Table 2** Correlation summary between unadjusted and adjusted\* anatomical indices of capital femoral epiphyseal morphology with age and body mass index (BMI) percentile (n = 68). Significant associations are highlighted in bold (p < 0.05; two-sided tests for the Pearson's correlation coefficient)

Anatomical index	Unadjusted association with age			Unadjusted association with BMI percentile			Age-adjusted* association with BMI percentile		
	r	95% CI	p	r	95% CI	p	r	95% CI	p
Anterior cupping	0.54	0.35 to 0.69	< 0.001	0.24	0.00 to 0.45	0.06	0.18	-0.07 to 0.40	0.15
Posterior cupping	0.59	0.41 to 0.73	< 0.001	0.13	-0.12 to 0.35	0.30	0.05	-0.19 to 0.28	0.70
Superior cupping	0.63	0.46 to 0.75	< 0.001	0.11	-0.13 to 0.34	0.38	0.07	-0.17 to 0.30	0.57
Inferior cupping	0.60	0.42 to 0.73	< 0.001	0.18	-0.06 to 0.40	0.15	0.17	-0.07 to 0.40	0.16
Average cupping	0.67	0.51 to 0.78	< 0.001	0.18	-0.06 to 0.40	0.14	0.14	-0.10 to 0.37	0.25
Tubercle width	-0.39	-0.57 to -0.16	0.001	-0.14	-0.37 to 0.10	0.25	-0.30	-0.50 to -0.07	0.01
Tubercle length	-0.65	-0.77 to -0.49	< 0.001	-0.25	-0.46 to -0.01	0.04	-0.32	-0.52 to -0.09	0.008
Tubercle height	-0.32	-0.52 to -0.09	0.007	-0.24	-0.45 to 0.00	0.048	-0.34	-0.53 to -0.11	0.005
Fossa width	-0.36	-0.55 to -0.14	0.002	0.06	-0.18 to 0.29	0.65	-0.09	-0.32 to 0.16	0.49
Fossa length	-0.55	-0.70 to -0.36	< 0.001	-0.04	-0.27 to 0.20	0.78	-0.16	-0.38 to 0.08	0.19
Fossa depth	-0.57	-0.71 to -0.38	< 0.001	-0.11	-0.34 to 0.13	0.36	-0.21	-0.43 to 0.03	0.08

\*Anatomical indices adjusted for age (anatomical measurement / age). r, Pearson's correlation coefficient; CI, confidence interval



**Fig. 3** Scatter plots demonstrate a negative linear correlation between body mass index (BMI) percentile and epiphyseal tubercle measurements normalized to age. Large values of BMI percentile were associated with lower values of epiphyseal tubercle height, length and width.

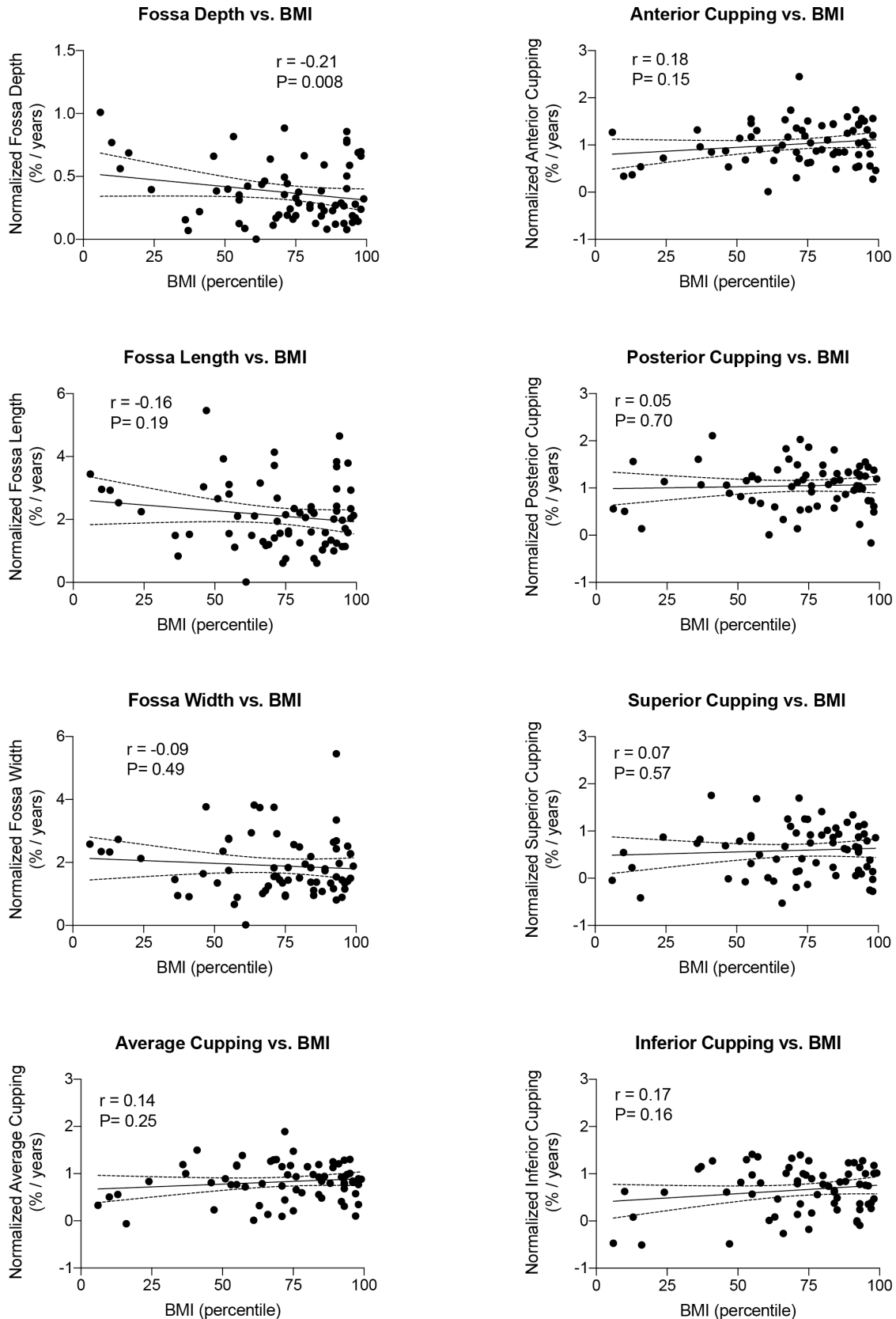
corresponding metaphyseal fossa act as an interlocking mechanism to counteract the slipping of the epiphysis.<sup>10</sup> In children younger than 12 years, the tubercle is typically a large structure that plays an essential role in epiphyseal stability.<sup>11</sup> However, with increasing age, the size of the tubercle reduces, and it becomes less important for epiphyseal stabilization. Decrease in tubercle size is accompanied by an increase in peripheral growth of the epiphysis with cupping around the metaphysis.<sup>13</sup> One previous study showed that epiphyseal stability is highly tubercle-dependent in children with a large tubercle, but peripheral cupping-dependent in patients with a small tubercle and large cupping.<sup>11</sup> SCFE is more prevalent in patients around 12 years old, which coincides with the period of transition of epiphysis stability between the epiphyseal tubercle and the peripheral cupping. In this study we observed a correlation between high BMI percentile and reduced epiphyseal tubercle height, length and width, suggesting that obese children may have a smaller epiphyseal tubercle. As we found no difference for the metaphyseal fossa, it is possible that the interplay between the tubercle and the fossa could be compromised. However, further research is necessary to investigate whether epiphyseal tubercle size is a risk factor for SCFE development in obese children and to determine whether a causal association exists.

Although several studies have shown that SCFE is strongly associated with childhood obesity, the exact pathophysiological mechanisms by which obesity leads to SCFE have not been completely elucidated. The relationship between obesity and SCFE may be explained by a metabolic and endocrine pathway affecting the physis and reducing the resistance to shear stress.<sup>6,20,21</sup> However, obesity is not essential to the development of a slip. Notably, one recent study showed an association between high levels of serum leptin and SCFE, independent of BMI.<sup>21</sup> Obesity may increase the stress of the capital femoral growth plate by a mechanical pathway due to overload. One previous study reported that the necessary forces to cause a slip are within the physiological range of the forces generated in overweight children.<sup>22</sup> Previous

studies have described the potential structural effects of obesity on the proximal femur that are recognized as risk factors for SCFE.<sup>7-9</sup> Reduced femoral anteversion, which may increase the shear stress through the growth plate, has been associated with SCFE<sup>8</sup> and observed in obese adolescents.<sup>7</sup> One study showed an association of higher BMI with an increased posterior tilt of the epiphysis, which is a factor associated with SCFE development.<sup>13</sup> The present study adds the smaller epiphyseal tubercle as another structural change of the femur associated with increased BMI percentile that could be an additional morphology that predisposes the capital femoral epiphysis to slip. Notably, a recent study showed that hips with SCFE have a smaller epiphyseal tubercle when compared with hips without a slip.<sup>23</sup>

We did not observe any correlation between BMI percentile and measurements of the metaphyseal fossa and the peripheral cupping. One previous study reported an association between higher BMI and reduced epiphyseal extension, a 2D measurement of peripheral growth of the epiphysis towards the metaphysis.<sup>9</sup> Increased epiphyseal extension has been suggested to confer physeal stability and reduce the risk of development of a contralateral slip in patients followed for unilateral SCFE.<sup>24,25</sup> It is possible that a small epiphyseal tubercle without compensatory changes of the peripheral cupping may play a role in the pathogenesis of SCFE in obese children, but additional research is necessary.

This study had some limitations. First, the BMI percentile was calculated at the time of CT scan, and no information was available about any previous BMI percentile for each subject, limiting our ability to investigate the length of exposure to elevated BMI percentile and morphological changes to the epiphyseal surface. Second, because this was an aleatory collection of patients with appendicitis over a specific period, our sample resembles the distribution of obesity amongst the general paediatric population. As such, only 12% of patients were obese, which limited the possibility of direct comparisons between obese patients *versus* non-obese patients. We used CT



**Fig. 4** Scatter plots showing no correlation between body mass index (BMI) percentile and metaphyseal fossa and epiphyseal cupping measurements.

scan imaging which limits the ability to discriminate on cartilaginous features of the epiphysis and the growth plate that would only be possible with MRI. This limitation can be overcome by a longitudinal study with MRI investigation of obese versus non-obese patients. The adjusted  $R^2$  values of the correlation between increased BMI percentile and decreased epiphyseal tubercle measurements were around 0.3 which implies that BMI percentile only partially explains the variation in the morphology of the epiphyseal tubercle. Further studies will be necessary to investigate whether increased BMI has a causal association with reduced epiphyseal tubercle size and whether a smaller epiphyseal tubercle is a factor for SCFE development. Finally, although we did not specifically assess inter- and intraobserver reliability of the measurements for epiphyseal tubercle, cupping and metaphyseal fossa, a previous study showed that the measures of capital femoral epiphysis geometry had good reproducibility, with intraobserver intraclass correlation coefficients ranging from 0.74 to 0.98.<sup>13</sup>

In conclusion, we report a negative correlation between BMI and the epiphyseal tubercle height, width and length in patients without hip disorders but no association between BMI and metaphyseal fossa and peripheral cupping. The epiphyseal tubercle is typically large and a crucial stabilizer of the epiphysis in children younger than 12 years, reducing in size with increasing age. The association between increased BMI percentile and smaller tubercle size may be another factor contributing to reduced epiphyseal stability and increased risk of SCFE development in obese children and adolescents.

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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.

### OA LICENCE TEXT

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### 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 study by our institutional review board.

**Informed consent:** Informed consent was not obtained from subjects in this retrospective study.

## ICMJE CONFLICT OF INTEREST STATEMENT

None declared.

## AUTHOR CONTRIBUTIONS

SH: Data collection and analysis, Manuscript preparation, Final revision of the study, Read and approved the final submitted manuscript.

AMK: Conceptualization and design, Statistical analysis, Manuscript preparation, Final revision of the study, Read and approved the final submitted manuscript.

DAM: Statistical analysis, Data interpretation, Manuscript preparation, Final revision of the study, Read and approved the final submitted manuscript.

SAE: Data collection, Data interpretation, Manuscript preparation, Final revision of the study, Read and approved the final submitted manuscript.

PM: Data analysis and interpretation, Manuscript preparation, Final revision of the study, Read and approved the final submitted manuscript.

Y-JK: Conceptualization and design, Data interpretation, Manuscript preparation, Final revision of the study, Read and approved the final submitted manuscript.

ENN: Conceptualization and design, Data interpretation, Manuscript preparation, Final revision of the study, Read and approved the final submitted manuscript.

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