Sex- and Obesity-Related Changes in Capital Femoral Epiphysis Morphology During Skeletal Development and Maturation: A Population-Based Study of 17,434 Hips

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INTRODUCTION: Slipped capital femoral epiphysis (SCFE) is one of the most common disorders of adolescent hips, with a prevalence of about 10 per 100,000. Obesity is the major risk factor for SCFE in children and adolescents. Previous studies have found a relationship between BMI-for-age percentiles and SCFE. Increased weight may lead to SCFE through increasing shear forces across proximal physis. Higher weight during skeletal growth may also lead to abnormal development in proximal femur anatomy, which is not clearly understood. Recent studies have shown significantly smaller tubercles and larger epiphyseal extensions in patients with SCFE compared to matched controls. These are major anatomic stabilizers of the head neck-junction which have been shown to undergo developmental changes during skeletal growth in pilot studies. Here we aimed to conduct an in-depth analysis of how the development of these morphological features would be affected by sex and obesity in a large cohort of asymptomatic hips.

METHODS: Following IRB approval, a validated natural language processing pipeline was used to process the clinical notes and radiology reports of all the patients (7-19 years of age) undergoing pelvic CT scans from 2012-2022 in our institute (accuracy of 0.98). We identified a total of 8,717 CT scans (17,434 hips) which had no documented bone or joint conditions and adequate CT quality for 3D segmentation (Age: 13.3 ± 3.5 years; 50% females; 13% obese). A validated custom software (VirtualHip, Boston Children's Hospital) was used to automatically segment the femoral head and neck, and to measure epiphyseal tubercle height, peripheral cupping (between 12 to 3 o'clock), and femoral head tilt in axial and coronal planes. Tubercle and cupping measurements were normalized to femoral head diameter to account for size differences. Mix linear models with pairwise comparisons (Bonferroni posthoc) was used to investigate the effect of age on quantified features to conduct comparisons between males and females, and normal and obese.

RESULTS: Epiphyseal diameter, peripheral cupping, and axial tilt angle increased by age, whereas epiphyseal tubercle and coronal tilt angle decreased by age ($P<0.001$; Figure 1). Females had smaller epiphyseal diameter (all ages), larger cupping (up to 16 years of age), smaller tubercle (up to 15 years of age), larger coronal tilt angle (up to 15 years of age), and smaller axial tilt angle (up to 10 years of age); $P<0.01$. Obese patients had larger epiphyseal diameter (up to 12 years of age), larger cupping (up to 12 years of age) followed by smaller cupping after 14, smaller tubercle height (between 9-17 years), and larger axial tilt angle (up to 13 years of age); $P<0.04$.

DISCUSSION: The current large-scale study confirms age-related changes in capital femoral epiphysis size, morphology, and alignment, which are significantly affected by sex and BMI. Most importantly, these differences are age dependent with most of the sex differences diminishing by late adolescence. Obese patients have smaller cupping and tubercle and a more posteriorly oriented epiphysis, which are all related to increased risk of SCFE. Interestingly, these changes are only in the early stages, which correspond to peak SCFE risk. However, the trends in peripheral cupping reverses in later stages which suggests an effect on skeletal maturation rate that warrants further investigation.

CLINICAL RELEVANCE: The important stabilizers of the head-neck junction involved in SCFE and FAI undergo significant change by age, with different trends in females and obese patients. The potential role of obesity in SCFE can be, in part, explained by the altered morphology of the femoral epiphysis.

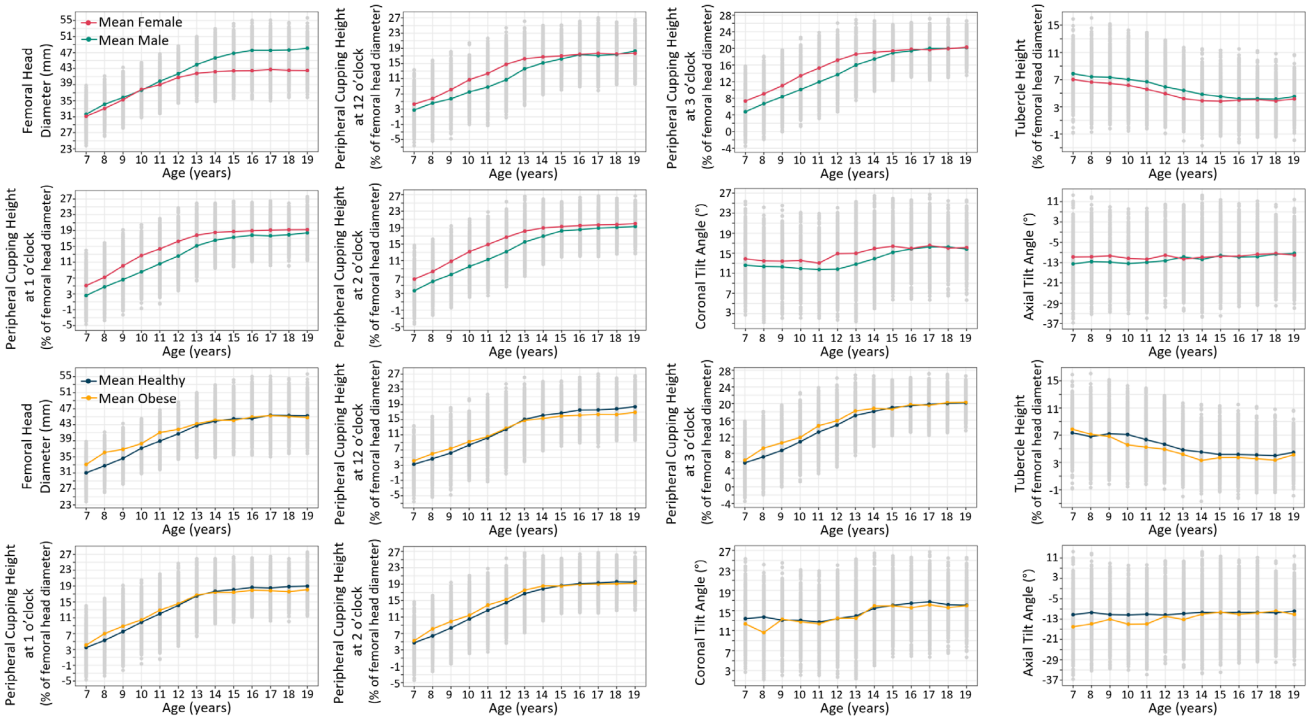

Figure 1. Sex (top 2 rows) and obesity (bottom 2 rows) related differences in epiphyseal morphology during skeletal growth and maturation.