Relationships between Severity of Deformity and Impingement in Acute Slipped Capital Femoral Epiphysis

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Introduction: Slipped capital femoral epiphysis (SCFE) is a disorder of the adolescent hip where the femoral head slips off the femoral neck at the growth plate (physis). SCFE occurs in about 11 in 10,000 children, and can result in premature hip osteoarthritis, pain, and disability. Acute SCFE, defined as a slip that has been symptomatic for less than three weeks, typically does not exhibit bony remodelling, which is characteristic or chronic SCFE (>3 weeks symptomatic). In situ surgical pinning is a low risk treatment that prevents further slipping, but leaving the slipped femoral head in place may reduce joint range of motion (ROM) and cause impingement. It is not clear what degree of severity should be pinned and when a more complex surgery should be considered because the relationships between severity, impingement and motion loss are unknown. Our research questions were:
1. Do more severe acute SCFE deformities (without bony remodeling) result in a greater loss of flexion ROM?
2. Does the presence or location of impingement on the pelvis vary with severity of acute SCFE deformity?

Methods: Ethics board approval was obtained from our institution for this study. We developed a 3D geometric model of acute SCFE deformity from one CT scan of a normal right hip (16 years old, female, resolution 0.6 X 0.6 X 0.4 mm\textsuperscript{3}). The right hemi-pelvis, epiphysis and sub-physeal femur were segmented semi-automatically. The segmented images were used to create 3D geometrical bone models of acute SCFE deformity. The original neck and epiphyseal axes of the model were found by fitting a cylinder to the femoral neck in the original un-deformed position. SCFE deformities were simulated by combining posterior and inferior slips in the axial and coronal planes respectively defined as angles between the neck and epiphyseal axes\textsuperscript{1} (0° (no deformity) to 90°, in 1.5° steps, 60 steps/plane). The sub-physeal femur was rotated with respect to the epiphysis, and the centre of the sphere fit to the physis surface was the centre of rotation. Combinations of axial and coronal angular rotations were applied to the sub-physeal femur model while maintaining the original epiphysis position in the acetabulum to create 3,721 SCFE deformities. The final deformed sub-physeal femur and epiphysis combinations were treated as rigid bodies for the remainder of the analysis.
Southwick (SW) angles were estimated from a frog-leg lateral projection of the original model. Three experienced surgeons determined the projection plane in three trials each. Deformities were divided into mild (0-30°), moderate (30-60°), and severe (≥60°) groups based on estimated SW angles.

Joint motion was simulated with respect to a constant centre of rotation defined by a sphere fit to the epiphysis. Each joint was flexed in combination with internal and external rotation. Joints were flexed until the femur contacted the pelvis. Locations of contact and joint angles at contact were recorded in each trial of movement. 120° was considered to be the approximate physiological limit of flexion. In cases where the initial positions of the deformed bones caused impingement, the femur was internally or externally rotated until there was no impingement, and the testing began from that rotation angle.

Results: There were 42 moderate cases (mean SW 52.7° (3.9°)) and 321 severe cases (mean SW 89.7° (16.0°)) in which the femur could not be rotated to a position where there was no impingement. These cases were not included in the analysis. 3355 remaining simulated SCFE deformities, as well as the undeformed geometry, were analyzed. These deformities covered all three SW severity categories (mild: n=488, moderate: n=1111, severe: n=1757). 121 ROM trials, each at a different degree of internal or external rotation (0 to 90° at 1.5° steps) were performed for each deformity.

Increasing slip severity reduced the range of flexion across the range of internal/external rotation (Fig 1). The femur impinged on the pelvis for most, but not all, deformities in the mild group in at least one trial, while contact in the moderate and severe groups occurred for all of the deformities over many of the trials considered. This contact occurred mainly on the anterosuperior aspect of the acetabulum (Fig 2).

Discussion: We used a 3D geometric model to predict the effect of slip severity on flexion ROM and impingement between the femur and the acetabulum. Increasing slip severity in acute SCFE reduced flexion and increased incidence of impingement, which was primarily observed on the anterosuperior aspect of the acetabulum.

Our finding of very low ROM in the severe slip group is likely because only acute SCFE deformities were produced and we would expect that metaphyseal remodeling would lead to increased ROM in chronic SCFE.

Our finding of impingement at the anterosuperior aspect of the acetabulum is consistent with areas of cartilage damage seen in clinical literature. While we saw similar patterns of impingement for the three groups, the location of impingement was more anterior in the severe slip group, and more extra-articular impingement was present.

Our results are consistent with previous work in modeling impingement and ROM in SCFE using existing patient data² ³ or simplified geometric shapes⁴, and in in vivo experiments on one subject using an open MR scanner², showing limited ROM in flexion with impingement occurring at the anterosuperior aspect of the acetabulum.

One strength of this study is that we used one normal bone model to create a range of clinically relevant acute SCFE deformities, eliminating intersubject variability. Because of the relative rarity of this disorder, studies relying on patient data will necessarily examine only a limited selection of the total possible range of deformity. Also, patients may vary in other ways that confound comparisons between levels of deformity, such as metaphyseal remodeling, CCD angle, retroversion/torsion, and acetabular geometry. One limitation is the lack of soft tissue in the model, which may otherwise limit ROM. However, we observed impingements at ROMs smaller than normal physiological ranges, which supports the conclusion that certain deformities impinge during normal daily activity. A second limitation is that the
epiphysis remained in a normal anatomical orientation and the rest of the femur was rotated to create deformity. In reality, we would expect some compensatory change in orientation of the epiphysis within the acetabulum, such as a fixed flexion deformity, which may account for the deformities that could not be moved out of a position of impingement and the increase in extra-articular impingement in the severe slip group.

Reduced flexion with increased deformity confirms our understanding of the effect of SCFE on function. Knowing that a more severe acute slip causes a greater functional deficit may influence treatment decisions.

**Significance:** Moderate and severe acute slips in SCFE lead to reduced range of motion and impinged with the acetabulum. This suggests that pinning may only be suitable for mild slips.

![Graph](image)

**Figure 1:** Mean range of flexion for original (un-deformed) geometry, and mild, moderate and severe SW categories. Mean initial internal rotation angles (relative to the epiphysis) were: mild 0.2° (0.9°); moderate 11.2° (10.8°); and severe 37.0° (18.0°). Mean initial external rotation angles were: mild -0.2° (0.9°); moderate -11.2° (10.8°); and severe -37.0° (18.0°).
Figure 2: Maps of impingement locations for (a) all deformities and un-deformed, (b) mild SW, (c) moderate SW, and (d) severe SW. Heat maps show percentages of deformities in each group colliding in flexion at each location. 79% of the mild deformities impinged (n=386, mean SW 21.9° (5.3°)). All moderate (100%, n=1111, mean SW 45.8° (8.5°)) and severe (100%, n=1757, mean SW 83.3° (8.5°)) deformities impinged.

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