

## Comprehensive Three-Dimensional Proximal Femoral Morphology in Cerebral Palsy

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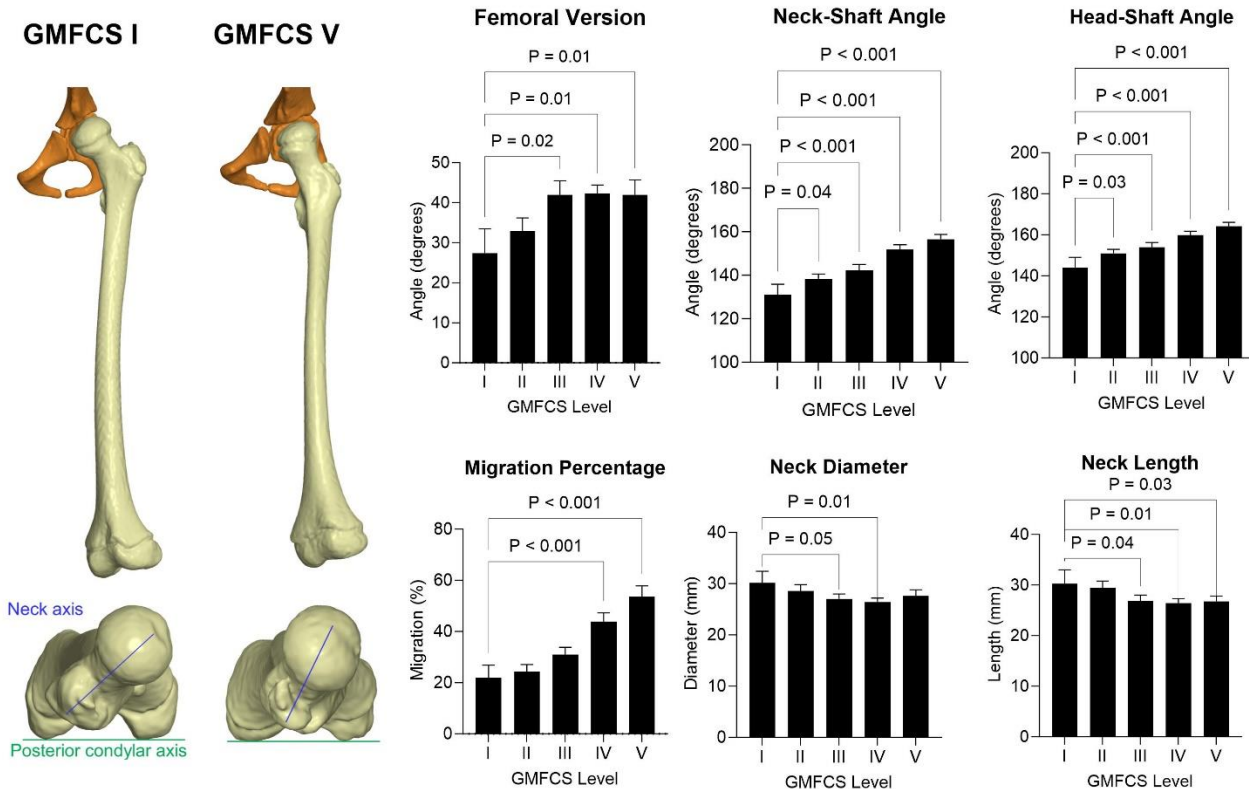
**INTRODUCTION:** Neuromuscular hip dysplasia is the second most common orthopedic condition in children with cerebral palsy (CP), affecting up to one-third of children with CP. The etiology of neuromuscular hip dysplasia is believed to be multifactorial including muscle spasticity, asymmetric muscle forces, and subsequent pathologic proximal femoral anatomy and acetabular deficiency. Despite extensive investigations of acetabular dysplasia in CP patients, little is known about the abnormal development of the proximal femur in these patients. The aim of this study is to comprehensively characterize the three-dimensional (3D) morphology of the proximal femur in children with CP using 3D-computerized tomography (CT). We hypothesized that the proximal femur of patients with CP have abnormalities in 3D, with their severity corresponding to Gross Motor Function Classification System (GMFCS) levels.

**METHODS:** Over a 12-year period at a single tertiary care institution, a consecutive sample of 285 children with CP were retrospectively identified across all GMFCS levels (age range: 3-22 years, age average: 9.3±3.5 years, 43% females; GMFCS I: n=12, GMFCS II: n=48, GMFCS III: n=55, GMFCS IV: n=92, GMFCS V: n=78). Patients with other neuromuscular conditions or prior hip surgery were excluded. Using a validated automatic segmentation and anatomy measurement program (VirtualHip, Boston Children's Hospital), 3D femur models from CT scans were developed (Dice =0.98) to measure femoral version, neck-shaft angle (NSA), head-shaft angle (HSA), migration percentage (MP), neck diameter, and neck length on both hips of each patient. Analysis of variance (ANOVA) with Dunnett posthoc was used to determine if the aforementioned measures showed any significant differences across the GMFCS levels.

**RESULTS:** Femoral version was significantly higher in GMFCS levels III, IV, and V compared to GMFCS level I, indicating increased anteversion at greater GMFCS levels (all P<0.05; Figure 1). Both NSA and HSA were also significantly higher at all GMFCS levels above GMFCS I, demonstrating coxa valga with increasing GMFCS levels (all P<0.05; Figure 1). MP was significantly higher for GMFCS IV and V compared to GMFCS I (P<0.001; Figure 1), denoting greater hip subluxation and dislocation with higher GMFCS levels. Finally, increasing GMFCS was significantly associated with decreased femoral neck length in GMFCS III, IV, and V (P<0.05; Figure 1), with a trend toward decreased femoral neck diameter as well.

**DISCUSSION:** Abnormal morphology of the proximal femur contributes to hip subluxation, dislocation, and disability in children with CP. In our large cohort, we conclude that children with greater functional limitations (higher GMFCS levels) tend to have increased femoral anteversion, coxa valga, femoral head valgus, dislocation, and decreased neck length. There was also a trend toward smaller femoral neck diameters with greater GMFCS levels. This study validates previous population-based plain film investigations of the hip in CP but illustrates additional complex anatomic subtleties captured on 3D-CT.

**SIGNIFICANCE:** The current findings highlight the importance of 3D CT in the surveillance of hip health in CP patients. Such detailed information helps with preoperative planning to properly address hip dysplasia.



**Figure 1.** Group differences in mean femoral version, neck-shaft angle, head-shaft angle, migration percentage, neck diameter, and neck length (GMFCS I: n=24 hips, GMFCS II: n=96 hips, GMFCS III: n=110 hips, GMFCS IV: n=184 hips, GMFCS V: n=156 hips). All data are presented as means (95% CI). Significant differences are labeled with their respective P-values.