# Morphological Predictors of Internal Rotation in Patients with Hip Dysplasia: A 3D CT Analysis of Japanese and Caucasian Cohorts

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**INTRODUCTIONS:** Developmental dysplasia of the hip (DDH) is characterized by acetabular undercoverage and variable femoral morphology. Although increased hip range of motion (ROM) is often observed in DDH, paradoxically, limited internal rotation at 90° flexion (IRF) may occur due to structural abnormalities such as decreased femoral version (FV) and cam morphology. The influence of these morphological factors on IRF, and their variation across populations remains unclear. We conducted this study to clarify: (1) whether Japanese and Caucasian American patients with DDH differ in proximal femoral morphology and impingement-free hip ROM; (2) which morphological parameters are most strongly associated with IRF; and (3) whether interethnic differences in IRF can be explained by differences in hip morphology.

**METHODS:** Following IRB approval, we conducted a retrospective, two-center, propensity-matched cohort study of 110 hips (55 Japanese, 55 Caucasian American; 94.5% female; mean age ≈25 years) with symptomatic DDH (lateral center–edge angle <25°) and no prior hip surgery or trauma. A custom-developed and validated program (VirtualHip™, Boston Children's Hospital) was used to analyze the preoperative CT scans for 3D measurements of: femoral version (FV; Murphy method), radial alpha angle, and head–neck offset ratio (HNOR) at clock-face positions (12 to 3 o'clock), and center–edge (CE) angle at 12 to 3 o'clock. Impingement-free ROM was simulated to bony contact limits. Determinants of IRF were evaluated with univariate testing followed by multivariable linear regression (AIC-guided selection). Causal mediation analysis with nonparametric bootstrapping estimated the average causal mediation effect (ACME), average direct effect (ADE), and proportion mediated for FV, alpha at 2 o'clock, and CE at 1 o'clock.

**RESULTS:** Groups were matched for age and sex ($P = 0.557$); BMI was lower in the Japanese cohort (22.3 ± 3.0 vs 25.0 ± 4.8 kg/m², $P < 0.001$). Japanese hips demonstrated higher FV (30.0° vs 24.5°, $P = 0.020$) and greater IRF (59.1° vs 47.1°, $P < 0.001$), whereas American hips showed larger alpha angles at 2 o'clock (43.9° vs 46.8°, $P = 0.036$) and 3 o'clock (37.4° vs 41.9°, $P = 0.002$) and greater external rotation (53.6° vs 46.8°, $P = 0.007$). There were no other anatomical differences between the cohorts ($P > 0.17$). In univariate analysis, FV and HNOR (at 12, 1, 2, and 3 o'clock) were associated with increased IRF ($0.9 < \beta < 3$, $P < 0.02$; $0.05 < R^2 < 0.5$), while alpha angle (at 1, 2, and 3 o'clock) and CE angle (at 12, 1, 2, and 3 o'clock) were associated with decreased IRF ($-1.2 < \beta < -0.5$, $P < 0.03$; $0.05 < R^2 < 0.3$). In multivariable models, higher FV independently increased IRF ($\beta = 0.73$; $P < 0.001$), while greater anterior coverage (CE at 1 o'clock) and larger focal alpha at 2 o'clock independently decreased IRF ($\beta < -0.8$; $P < 0.001$), yielding an adjusted $R^2$ of ~0.68. Mediation analysis indicated that FV accounted for ~45% and the 2 o'clock alpha angle for ~29% of the interethnic difference in IRF. Very low IRF (<30°) was uncommon in Japanese hips (≈4%) and more frequent in American hips (≈13%).

**DISCUSSION:** In this study, we demonstrated that impingement-free internal rotation at 90° flexion (IRF) in patients with DDH is influenced by a combination of femoral and acetabular morphology. Among these, FV and localized alpha angle at the 2 o'clock position emerged as the most critical determinants of IRF. These findings highlight the clinical importance of region-specific morphological evaluation, particularly clock-face–based assessment of the femoral head–neck junction. This approach may enhance individualized preoperative planning in joint-preserving surgery for DDH. Although ethnic differences in morphology were observed, their functional consequences appear to be governed by shared biomechanical principles rather than population-specific mechanisms.

**SIGNIFICANCE:** Understanding interethnic differences in proximal femoral morphology and impingement-free hip motion among patients with DDH is clinically significant because it clarifies that functional disparities are morphology-mediated rather than ethnicity-based, guiding more precise surgical planning. These findings directly inform patient-specific strategies for periacetabular osteotomy and femoral osteochondroplasty, improving outcomes and avoiding reliance on generalized assumptions.

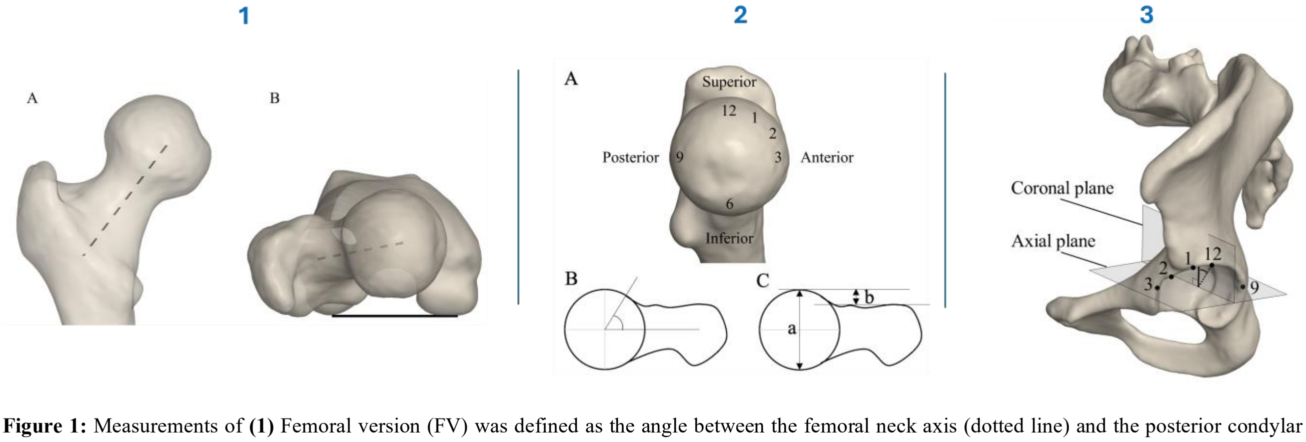


**Figure 1:** Measurements of **(1)** Femoral version (FV) was defined as the angle between the femoral neck axis (dotted line) and the posterior condylar axis (solid line) on axial CT slices, according to Murphy's method , **(2)** alpha angle and head–neck offset ratio (HNOR), were measured on radial planes generated around the femoral physis axis, starting at the 12 o'clock position and rotating clockwise in 30° increments. (A) Each radial plane was analyzed at its intersection with the femoral surface. (B) The alpha angle was defined as the angle between the femoral neck axis and the line connecting the femoral head center to the point where the femoral contour deviated from a best-fit circle. **(3)** The HNOR at 3 o'clock is also illustrated. To evaluate HNOR, two lines parallel to the femoral neck axis were drawn: one through the anterior-most point of the femoral neck and the other through the anterior-most point of the femoral head. The perpendicular distance between these lines (b) was divided by the femoral head diameter (a), yielding the HNOR as a ratio (b/a). and **(C)** center–edge (CE) angle was measured at each clockface position as the angle between the line connecting the femoral head center to the acetabular rim and its projection onto the sagittal plane