**Spinopelvic Variations in Hip Impingement and Dysplasia using Multi-Domain Statistical Shape Modelling**

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INTRODUCTION: Hip osteoarthritis arises secondary to morphological abnormalities, namely femoroacetabular impingement (FAI) and developmental dysplasia of the hip (DDH). Current evidence suggests a large asymptomatic population of FAI and DDH patients is present within the general population [1], however, the underlying pathomechanics and their relationships with symptoms remain poorly understood. Recent studies suggest that spinopelvic alignment (namely higher pelvic incidence) and extreme femoral neck-shaft angles may play a key role in the development of symptomatic FAI and DDH. The aim of this study was to examine secondary anatomical predictors and range of motion (ROM) in hips with cam FAI, acetabular retroversion, and DDH.

METHODS: Fifty-two cadaveric hips (n = 52; m:f = 28:24, age = 44 ± 11 yrs, BMI = 25 ± 6 kg/m$^2$; approved ethics #MEC-AA-13-032) were acquired and computed tomography (CT) imaged as a whole body (Somatom Perspective; SIEMENS, Germany). Each hip was then sorted into the following cohorts: cam FAI (CAM; axial 3:00 alpha angle > 50.5° or radial 1:30 alpha > 60°), acetabular retroversion (RETRO; crossover sign, posterior wall sign, retroversion index), dysplasia (DDH; lateral centre-edge angle < 20°, Tönnis angle > 10°, femoro-epiphyseal acetabular roof index > 2°), or control (CON; no morphologies). Three-dimensional (3D) femur, pelvis, and sacrum models were reconstructed from their respective CT images using segmentation software (Slicer; Slicer Community) and then imported into statistical shape modelling software (ShapeWorks 6.4; SciUtah, USA). Mean shapes were generated to compare anatomical differences between each pathological group (i.e., CAM, RETRO, DDH) and the CON group; and principal component analysis examined the shape variation modes within each of the groups. The pelvis and sacrum models were analyzed through a multi-domain approach while the femur was examined independently. All left-sided hips were mirrored to the right as the comparison index. To evaluate hip range of motion (ROM), each cadaveric hip was denuded to the bone-and-capsule and tested in a 6-DOF robot (Stäubli TX90; Switzerland) to full internal-external rotations in five sagittal positions (full extension, neutral 0º, flexion 30º, flexion 60º, and flexion 90º). One-way ANOVA examined range of motion differences between groups and were compared to the statistical shape models to associate anatomical morphology with hip mobility.

RESULTS: In addition to their characteristic morphologies, the CAM group displayed a greater anterosuperior acetabular coverage while the RETRO group had a slight femoral head asphericity (Figure 1). The CAM and RETRO groups also displayed a slightly elevated greater trochanter in comparison with the other groups. Interestingly, the CAM group indicated a deeper sacral promontory and anteriorly tilted sacral endplate, leading to a larger pelvic incidence. The RETRO group also showed a slight anterior tilt of the sacral endplate, while the DDH group was associated with a narrower pelvic width, posterior sacral endplate tilt, and smaller pelvic incidence angle (Figure 1). Regarding hip ROM, the CAM group showed the most restricted ROMs in deep flexion at 90° (58 ± 12°), while the DDH group was the most hypermobile in the same position (80 ± 16°; $p = 0.01$). The RETRO group also demonstrated posterior acetabular instability with the largest ROM in hip extension compared to all other groups ($p < 0.01$).

DISCUSSION: The most important finding was that the CAM and RETRO groups showed a more pronounced sacral promontory with anterior sacral tilt. This suggests that a greater pelvic incidence may be predictive of symptomatic FAI and restricted sagittal pelvic ROM [2]. Among DDH hips, a smaller pelvic incidence may be associated with hypermobility, suggesting a potential role in DDH pathomechanics. In contrast, Both CAM and RETRO cohorts displayed a more superior greater trochanter, suggesting a smaller femoral neck-shaft angle is associated with mechanical impingement [2]. In comparison with CON, the statistical shape models of the pathological cohorts also demonstrated anatomical variances that would influence important muscle origin and insertion points (i.e., higher greater trochanter, lower lesser trochanter, anterior pelvic tilt). This would directly affects the gluteus medius, iliopsoas, and iliocapsularis muscle moment arms and their roles towards optimally stabilizing and mobilizing the hip joint. Thus, secondary spinopelvic anatomy may be additional indicators of symptomatic hip impingement and dysplastic hypermobility.

SIGNIFICANCE: In addition to the femoral and acetabular morphology that characterizes FAI and DDH, secondary spinopelvic characteristics may play a critical role in the pathomechanics of such conditions. Secondary spinopelvic characteristics may enable clinicians to better identify asymptomatic patients who are at an elevated risk of chondrolabral injury and determine which patients are best suited for surgical vs. non-surgical management.

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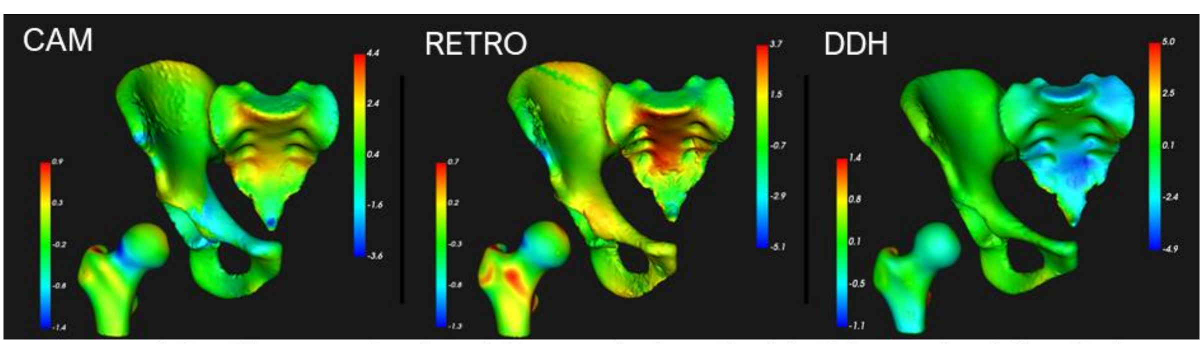


**Figure 1**. Frontal view of the cam FAI (CAM), acetabular retroversion (RETRO), and dysplasia groups (DDH), illustrating the mean models and shape differences of the femur (left colour bars) and pelvis and sacrum (right colour bars) compared to the control group. Each pathological group indicated their characteristic anatomical deformities and also showed secondary features of higher-or-lower greater trochanters and anterior-or-posterior tilt of the sacral endplate. (Scale in mm.)