Examining Anatomic Predictors of Symptomatic Cam FAI in Bilateral Patients using Statistical Shape Modelling

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INTRODUCTION: Femoroacetabular impingement (FAI) is one of the leading causes of early hip osteoarthritis and can be characterized by a bony overgrowth of the femoral head-neck junction (cam-type) and/or an overcoverage of the acetabulum (pincer-type). Although patients presenting with bilateral FAI morphologies are quite common, they typically only experience unilateral symptoms. This suggests that additional anatomic factors other than the cam and pincer deformities may contribute to earlier symptoms. Anatomic assessments from planar imaging are useful but often insufficient to capture the full 3D morphology. Therefore, a comprehensive 3D diagnostic imaging assessment is needed to better characterize additional anatomic parameters, delineate symptomatology, and understand how patients with bilateral FAI present only with unilateral symptoms. The purpose of this study was to compare the anatomic variations between the symptomatic and asymptomatic sides in bilateral FAI patients using planar imaging measurements and 3D statistical shape modelling.

METHODS: Twenty-seven patients who were awaiting surgery at our orthopedic clinic (n = 27, m:f = 15:12, age = 25 ± 6 years) were included in this study if they indicated bilateral cam FAI morphologies but unilateral symptoms (institutional review board #114897). Patients were excluded from this study if they indicated any other hip pathologies (e.g. dysplasia, slipped capital femoral epiphysis, Legg-Calve-Perthes) or history of lower-limb trauma or surgery. Each patient's pelvic and knee regions were imaged using a computed tomography (CT) scanner (512×512 resolution, 100 kVP, 0.625 mm slice, 0.78 mm pixel spacing; Somatom Perspective; SIEMENS, Germany) to confirm cam morphology (e.g. axial 3:00 alpha angle > 50.5° or radial 1:30 alpha angle > 60°). Anatomic measurements of the femoral neck (femoral neck-shaft angle, medial proximal femoral angle, femoral torsion), acetabular coverage (lateral center-edge angle, acetabular version at 1:00, 2:00, and 3:00) and spinopelvic parameters (sacral slope, pelvic tilt, pelvic incidence) were assessed from each patient's CT data. Paired sample t-tests were performed to compare the anatomic CT measurements between each patient's symptomatic and asymptomatic sides using statistical software (CI = 95%; Prism 9.0; GraphPad, USA). Each patient's symptomatic and asymptomatic 3D hip models (femur, pelvis, sacrum) were segmented and reconstructed using segmentation software (Simpleware ScanIP; Synopsys, USA), and were then imported into a statistical shape modelling program (ShapeWorks 6.4; SciUtah, USA) to compare anatomical differences in mean shape models between the symptomatic and asymptomatic sides. The shape variation modes within the symptomatic and asymptomatic sides were computed based on their optimized correspondence model using principal component analysis.

RESULTS: From the anatomic imaging data, symptomatic hips had smaller femoral neck-shaft angles ($p = 0.001$), medial proximal femoral angles ($p = 0.001$), and acetabular versions at 1:00 ($p = 0.004$) than the contralateral asymptomatic hips (Figure 1). Both symptomatic and asymptomatic hips showed similar femoral cam deformities, femoral torsions, lateral center-edge angles, and spinopelvic parameters. From the statistical shape models, the symptomatic group showed a slight extension to the femoral head-neck junction, a more varus neck, as well as a retroverted acetabulum with slightly increased anterosuperior and decreased posterior acetabular coverage (Figure 2). Additionally, the symptomatic side's corresponding sacroiliac joint and sacral alar were noticeably smaller and anteriorly tilted compared to their contralateral asymptomatic side.

DISCUSSION: The most important finding was that the symptomatic side indicated a more varus neck (e.g. lower femoral neck-shaft angle and medial proximal femoral angle), retroverted acetabulum (e.g. lower acetabular version at 1:00), and anterior sacral tilt in addition to the cam deformities. A varus neck can bring the cam deformity closer to the chondrolabral junction, resulting in earlier mechanical impingement and symptoms, while together with the higher greater trochanter can shorten the abductor muscles. Moreover, an anterior sacral tilt and retroverted acetabulum can further increase anterosuperior engagement of the cam deformity and decrease posterior stability of the hip joint. These structural variances may lead to muscle imbalance and frontal and sagittal plane instability, highlighting the need for targeted muscle strengthening to optimize hip stability and help alleviate symptoms. As the cam deformity alone may not be the only anatomic indicator for symptoms, these additional anatomic relationships through statistical shape modelling can help guide patient-specific diagnosis and treatment strategies for FAI.

SIGNIFICANCE/CLINICAL RELEVANCE: Additional anatomic relationships can help elucidate symptomatic FAI and can help provide better insights into patient-specific diagnostic and treatment plans. Identifying and treating symptomatic FAI earlier can improve patient outcomes and delay the progression of early hip degeneration and osteoarthritis.

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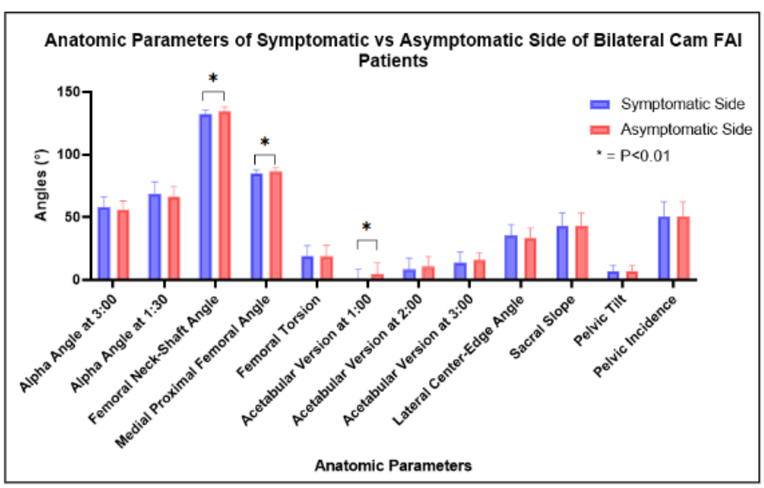

Figure 1: Anatomic parameters of symptomatic and asymptomatic sides reporting mean ± SD. *p<0.01.

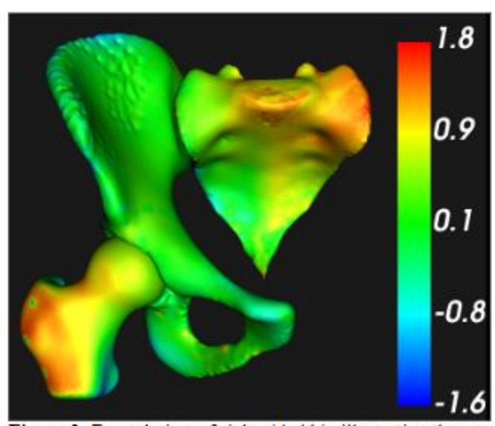

Figure 2: Frontal view of right sided hip illustrating the mean differences between the symptomatic and asymptomatic hips of bilateral cam FAI patients. Scale in mm and red indicates a relative increase.