**Discriminant Function Analysis Using Radiographic And Biomechanical Parameters In Determining At-Risk Patients With A Cam Deformity**


**Disclosures:**

**Introduction:** The alpha angle is often used to measure the asphericity of the femoral head in the oblique-axial or radial views, with elevated angles associated with a larger deformity in cam type femoroacetabular impingement (FAI). Despite its use, the sensitivity does not adequately characterize symptoms of mechanical impingement due to the high prevalence of this deformity in the asymptomatic population [1]. Although knowing that some radiographic parameters were previously measured [2-4] and that FAI patients have demonstrated different hip kinematics [5] and joint stresses [6] during squatting, the severity of the cam deformity alone still does not explain differences in pathomechanisms between symptomatic and asymptomatic cam FAI. The purpose of this study was to include additional radiographic parameters combined with a maximal squat motion to determine anatomical characteristics contributing to the development of symptoms due to cam FAI.

**Methods:** Pelvic CT data were acquired from fifty male participants (n = 50; age = 33.7 ± 8.2 years; BMI = 26.1 ± 3.2 kg/m2). Each participant was initially assessed and diagnosed as either: symptomatic FAI (sFAI, n = 15), if they showed clinical signs and symptoms, an alpha angle above 55° in the axial or radial view, and were awaiting surgical intervention; asymptomatic FAI (aFAI, n = 20), if they showed no clinical signs or symptoms, but had an alpha angle above 55°; or control (CON, n = 15), if they showed no clinical signs or symptoms and had an alpha angle below 55°. Each participant’s CT data was then blinded, randomized, and evaluated by two observers, each performing two observations, using Onis 2.4 (DigitalCore, Tokyo, Japan) measuring for: axial alpha (AA) angle, radial alpha (RA) angle, femoral neck-shaft angle (FNSA), modified proximal femoral angle (MPFA), anterior femoral head-neck offset (FHNO), femoral version (FV), acetabular version (AV), and centre-edge (CE) angle, according to [2, 3, 7-9]. Each participant’s maximal dynamic squat motion was captured using ten Vicon MX-13 cameras (Vicon, Los Angeles, CA, USA) and retro-reflective anatomical markers, measuring maximal squat depth as a percentage of leg height and pelvic range of motion (ROM). The radiographic measures were then unblinded and the affected hip’s results were matched with the squat motion results. Statistical analysis was performed using SPSS Statistics v.21 (IBM Corporation, Armonk, NY, USA). Intra- and inter-rater reliability was quantified using the intraclass correlation coefficient (ICC), while a stepwise discriminant function analysis (DFA) was computed to identify the most suitable parameters to classify each participant with their respective subgroups.

**Results:** The intra- and inter-rater observations were deemed reliable among the observers for all radiographic parameters (0.860 ≤ ICCobs1 ≤ 0.983; 0.867 ≤ ICCobs2 ≤ 0.970; 0.720 ≤ ICCobs1-2 ≤ 0.872). The sFAI and aFAI groups had significantly higher AA and RA angles than the CON group (p < 0.0001). The FNSAs were also significantly higher for the aFAI and CON groups (127.1 ± 2.5° and 127.5 ± 2.2°, respectively), in comparison with the sFAI group (122.7 ± 2.0°, p < 0.0001)(Table 1). The sFAI group had a significantly lower FHNO (p < 0.0001) and prominent femoral anteversion (p = 0.041), in comparison with the CON group, but did not show any significant differences in MPFA, AV, or CE angle. Moreover, the sFAI had a substantially reduced squat depth (45.9 ± 10.3%) and pelvic ROM (10.7 ± 3.6°), in comparison with the aFAI (39.9 ± 10.4%; 15.9 ± 7.6°) and CON groups (39.1 ± 10.5%; 14.0 ± 6.4°). The stepwise DFA determined that RA angle (Wilk’s λ1 = 0.433), FNSA (Wilk’s λ2 = 0.248), and pelvic ROM (Wilk’s λ3 = 0.208) were the best parameters for classification (p < 0.0001). The resultant two predictive equations based on the standardized canonical discriminant function coefficients were:

Function 1 = (0.792•zRA) - (0.496•zFNSA) - (0.152•zROM)Eq. 1

Function 2 = (0.633•zRA) + (0.850•zFNSA) + (0.568•zROM)Eq. 2

where zRA represents the standardized RA angle, zFNSA represents the standardized FNSA, and zROM represents the standardized pelvic ROM. Inputting an additional participant’s RA angle, FNSA, and pelvic ROM z-values into the predictive equations (Equations 1 and 2), the functions would provide a visual indication of classification, based on their proximity to a group centroid (Figure 1).

**Discussion:** The FNSA should be examined to predict if sFAI would persist [2]. The coxa vara and the elevated alpha angles were anatomical parameters characteristic to the sFAI group; thus, along with a combination of a decreased FHNO and elevated FV, these parameters could have contributed to the reduced squat depth and risk of developing hip symptoms. Although MPFA for the sFAI group was slightly lower, it was not a significant parameter in our study [2]. Also, AV was not a significant discriminant in our study, as several more aFAI and CON participants demonstrated acetabular retroversion, contradicting other findings associated with sFAI [3, 8, 9]. The FV for all groups was consistently low, but did fall within range with previous studies [10]. Since participants were expected to not have pincer FAI, it was reasonable that CE angle was not a significant discriminant. There was a noticeable difference in squat depth, suggesting that there is an association between the severity, location, and orientation of the cam deformity with hip and pelvic motion. This further suggests that pelvic ROM is associated to the limitation
of squat depth, which could be used to determine if individuals are at risk of developing hip symptoms in the presence of a cam deformity.

**Significance:** This study implements an asymptomatic FAI group and examines radiographic and biomechanical indicators that lead to better tools in predicting individuals with a cam deformity at risk of developing FAI. In the presence of a large cam deformity, a decreased femoral neck-shaft angle, along with a combination of other secondary anatomical parameters, and the maximal squat depth can help better stratify those at risk of symptomatic FAI.

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**References:**

<table>
<thead>
<tr>
<th>Group (n)</th>
<th>Axial Alpha Angle (<em>) and Radial Alpha Angle (</em>)</th>
<th>Femoral Neck-Shaft Angle (*)</th>
<th>Modified Proximal Femoral Angle (*)</th>
<th>Femoral Head-Neck Offset (mm)</th>
<th>Femoral Version (*)</th>
<th>Acetabular Version (*)</th>
<th>CE Angle (*)</th>
<th>Squat Depth (% Leg Height)</th>
<th>Pelvic ROM (*)</th>
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<tbody>
<tr>
<td>sFAI (15)</td>
<td>56.2 (6.8)* 67.0 (5.3)*</td>
<td>122.7 (2.0)*</td>
<td>80.8 (3.6)</td>
<td>6.2 (1.7)*</td>
<td>14.1 (8.3)*</td>
<td>22.4 (5.0)</td>
<td>34.0 (4.7)</td>
<td>45.9 (10.3)</td>
<td>10.7 (3.6)</td>
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<td>aFAI (20)</td>
<td>55.4 (8.1)* 68.5 (7.9)*</td>
<td>127.1 (2.5)*</td>
<td>82.9 (4.3)</td>
<td>7.2 (1.8)*</td>
<td>11.3 (8.1)</td>
<td>18.4 (3.7)</td>
<td>33.0 (3.2)</td>
<td>39.9 (10.4)</td>
<td>15.9 (7.6)</td>
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<tr>
<td>CON (15)</td>
<td>42.9 (3.3) 52.8 (4.0)</td>
<td>127.5 (2.2)</td>
<td>82.1 (3.7)</td>
<td>9.4 (1.1)</td>
<td>6.9 (6.4)</td>
<td>19.2 (5.6)</td>
<td>33.8 (3.6)</td>
<td>39.1 (10.5)</td>
<td>14.0 (6.4)</td>
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<tr>
<td>Total (50)</td>
<td>51.9 (8.8) 63.3 (9.3)</td>
<td>125.9 (3.1)</td>
<td>82.0 (3.9)</td>
<td>7.5 (2.0)</td>
<td>10.8 (8.0)</td>
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<td>33.6 (3.7)</td>
<td>41.5 (10.6)</td>
<td>13.7 (6.5)</td>
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* significant difference (p < 0.05), compared with CON
@ significant difference (p < 0.05), compared with aFAI
**Figure 1.** Discriminant function analysis with canonical discriminant functions classifying sFAI (blue), aFAI (red), and CON (green) based on femoral head-neck angle, radial alpha angle, and pelvic range of motion. Group envelopes (ellipses) are centered on the group centroids (star markers).