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DISCRIMINANT FUNCTION ANALYSIS USING RADIOGRAPHIC AND SQUAT DEPTH PARAMETERS TO CLASSIFY CAM FEMOROACETABULAR IMPINGEMENT

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SUMMARY
We included additional radiographic and squat depth parameters to classify patients with cam femoroacetabular impingement, using a discriminant function analysis. Radial alpha angle and femoral neck-shaft angle were the best parameters, with squat depth and femoral head-neck offset as secondary indicators. There is an association between the severity and location of the cam deformity with hip joint mechanics, which can influence a reduced squat depth.

INTRODUCTION
The alpha angle has been traditionally used to measure the asphericity of the femoral head in the axial and radial planes. This angle quantifies the severity of the cam type deformity in femoroacetabular impingement (FAI), with higher alpha angles associated with elevated risks associated with early hip degeneration [1]. The sensitivity and accuracy of the alpha angle seems to underestimate the severity of the deformity [2]. Although radiographic parameters have been suggested to define FAI [3,4,5] and symptomatic patients have demonstrated different hip kinematics [6], it is still unclear why many patients with higher alpha angles do not demonstrate any symptoms. Therefore, symptoms of FAI could be related to other geometric hip joint parameters. The purpose of this study was to examine other geometric features of the hip joint that could be associated with symptoms due to the cam deformity. The objective was to include additional radiographic parameters along with a maximal squat depth analysis to examine differences between symptomatic and asymptomatic FAI patients.

METHODS
Forty-six participants (m = 42, f = 4; age = 33.9 ± 7.2 years; BMI = 25.6 ± 3.1 kg/m^2) were first classified based on the presence of the cam deformity and symptoms. Pelvic CT data were acquired from each participant to assess the size and severity of their cam lesion, as defined by the alpha angle in the axial or radial plane. The participants were classified as either: symptomatic FAI (sFAI) if they demonstrated symptoms and had an alpha angle greater than 55°; asymptomatic FAI (aFAI) if they demonstrated no symptoms, but had an alpha angle greater than 55°; or control (CON) if they demonstrated no symptoms and an alpha angle below 55°. For sFAI, each participant's affected hip was defined as the side with symptoms. For aFAI, the affected hip was defined by the side that had the higher alpha angle. For CON, the control-matching hip was defined by the side that had the smaller alpha angle.

The CT data were blinded, randomized, then evaluated using Onis 2.4 (DigitalCore, Tokyo, Japan). In addition to the axial and radial alpha angles, each participant CT was measured for femoral neck-shaft angles, anterior femoral head-neck offsets, acetabular versions, and centre-edge (CE) angles for both left and right hips. A femoral neck-shaft angle less than 120° was considered as varus and above 135° as valgus. Acetabular version less than 15° was considered as retroversion and a CE angle greater than 39° was considered as over-coverage. The procedures for each radiographic CT measure were well-documented in [4,5]. Three-dimensional hip joint kinematics were collected from each participant's maximal squat depth motion, using ten Vicon MX-13 cameras (Vicon, Los Angeles, CA, USA) and retro-reflective markers placed on anatomical landmarks. Each participant was instructed to perform maximal dynamic squats, averaged over five trials. The maximal squat depths were measured as a percentage with respect to leg height (where ground level would represent a leg height at 0%). Statistical analysis was performed using SPSS Statistics v.20 (IBM Corporation, Armonk, NY, USA). A discriminant function analysis (DFA) was used to identify which parameters were most suitable to classify each participant's affected hip with their respective subgroups.

RESULTS AND DISCUSSION
All participants were classified in one of the three groups. No evidence of dysplasia or other hip morphologies, other than cam FAI, were observed. Both sFAI and aFAI groups demonstrated similar elevated alpha angles in the axial and radial planes, and were significantly higher in comparison with the CON group ($p < 0.001$). A Tukey post-hoc test indicated that femoral neck-shaft angle was significantly higher for the aFAI (126.8 ± 3.6°, $p < 0.0001$) and CON (125.1 ± 2.1°, $p = 0.004$) groups, in comparison with the sFAI group (120.7 ± 3.7°). There was no significant difference between the aFAI and CON groups, in terms of femoral neck-shaft angle ($p = 0.343$). The sFAI group could not squat as low (46.5 ± 11.0%), in comparison with the aFAI and CON groups (40.8 ± 9.8% and 38.9 ± 8.3%, respectively); and also had a substantially lower femoral

head-neck offset (7.7 ± 1.6 mm), in comparison with aFAI and CON (8.7 ± 1.5 mm and 8.7 ± 1.4 mm, respectively). All three groups demonstrated similar acetabular versions and CE angles. Other than alpha angles, the aFAI group demonstrated similar radiographic and squat depth parameters as the CON group. Table 1 summarizes the means from the radiographic and squat depth results. Using the multiple DFA to assess all the parameters, it was determined that radial alpha angle and femoral neck-shaft angle were significantly the best parameters to classify all participants (Figure 1) based on canonical discriminant functions ($\lambda_1 = 0.559$, $p < 0.0001$; $\lambda_2 = 0.328$, $p < 0.0001$).

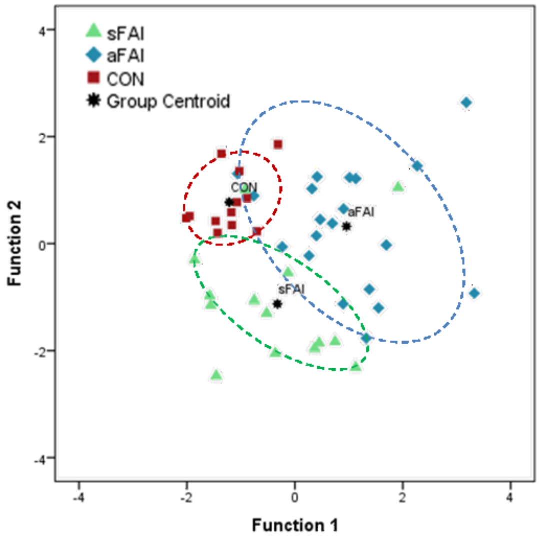

Figure 1: Canonical discriminant functions classifying sFAI, aFAI, and CON based on femoral neck-shaft angle and radial alpha angle. Group ellipses are centered on the group centroid.

The sFAI participants had noticeably smaller femoral neck-shaft angles, with angles approaching coxa vara. This characteristic in combination with elevated alpha angles, in the anterosuperior quadrant, and a decreased anterior femoral head-neck offset could have contributed to the presence of symptoms and distinguishable squat kinematics [6]. Although it was noticeable that most sFAI participants could not reach a deep squat, in comparison with the other two groups, the differences were still not yet significant due to the variance among sFAI participants. Furthermore, acetabular version and CE angle were not significant discriminants as classification parameters. Several aFAI and CON participants demonstrated low acetabular versions, which contradict other radiographic findings associated with sFAI [4,5]. A few sFAI participants showed over-coverage with slightly higher CE angles, which could have explained secondary reasons for symptoms due to pincer or mixed FAI. Our results for femoral neck-shaft angle coincided with earlier studies found in literature [3,5]; as well as our results for the femoral head-neck offset was also in agreement with associated sFAI studies [3,4]. However, our findings for acetabular version were inconclusive as several aFAI participants demonstrated retroversion and crossover, but did not show symptoms.

CONCLUSIONS

The DFA determined that radial alpha angle and femoral neck-shaft angle were significantly the most suitable parameters to classify the participants. The radial alpha angle should always be assessed, in addition to the axial alpha angle, in efforts to determine the location of the cam lesion [7]. Femoral neck-shaft angle should be considered as a radiographic parameter to predict if sFAI would persist [3,5], in addition to the conventional alpha angle measurements. Since there is a distinct difference in squat depths between sFAI and aFAI, the high alpha angle and lower femoral neck-shaft angle of the sFAI group suggests that there is an association between the severity and location of the deformity with hip joint mechanics, which can influence a reduced squat depth. This suggests that a squat depth could be implemented as a preliminary diagnostic tool. Anterior femoral head-neck offset can also be considered [4], but as a secondary parameter.

This study indicates that an elevated alpha angle could show symptoms if the deformity is located in an exploited hip joint orientation. Thus for impingement to occur due to hip joint geometry, symptoms could persist due to a combination of several radiographic parameters. This would lead to the association of altered squat kinematics due to the severity, location of the cam deformity, and orientation of the anatomical structures. Although hip joint geometries were examined and measured for the DFA, muscle activity was not yet considered. In efforts to further understand and explain symptoms of the pathomechanism, our future research would examine the role of muscle activation and other possible radiographic measures as additional discriminants to classify the three groups.

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Table 1: Summary of radiographic and squat depth parameters associated with sFAI, aFAI, and CON

Group	n (male: female)	Age (year)	BMI (kg/m^2)	Axial Alpha Angle (°)	Radial Alpha Angle (°)	Femoral Neck-Shaft Angle (°)	Femoral Offset (mm)	Acetabular Version (°)	Centre-Edge Angle (°)	Squat Depth (% of leg height)
sFAI	14 (13:1)	37.2 ± 8.2	25.3 ± 3.3	56.6 ± 8.8*	64.4 ± 8.5*	120.7 ± 3.7*	7.7 ± 1.6	18.4 ± 5.4	36.8 ± 5.0	46.5 ± 11.0
aFAI	20 (18:2)	31.4 ± 6.1	25.2 ± 3.0	56.8 ± 9.5*	65.9 ± 8.8*	126.8 ± 3.6	8.7 ± 1.5	17.3 ± 4.4	35.3 ± 4.0	40.8 ± 9.8
CON	12 (11:1)	34.3 ± 6.6	26.7 ± 3.1	43.5 ± 4.7	50.4 ± 2.9	125.1 ± 2.1	8.7 ± 1.4	20.5 ± 6.6	35.3 ± 3.8	38.9 ± 8.3

* significant difference, compared with CON