

# THREE-DIMENSIONAL MODELLING AND SQUAT DEPTH TO EXAMINE GEOMETRIC HIP JOINT PARAMETERS OF CAM FEMOROACETABULAR IMPINGEMENT

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## ABSTRACT

Many patients with a cam deformity, quantified by the alpha angle, do not demonstrate symptoms of mechanical impingement of the hip. We included additional geometric hip joint parameters along with a maximal squat depth analysis to distinguish patients with cam femoroacetabular impingement (FAI). Twenty participants were recruited and classified as either symptomatic FAI, asymptomatic FAI, or a healthy control, based on the presence of a cam deformity and symptoms. Hip joint models were segmented from subject-specific CT data and then the femoral neck-shaft angle, anterior femoral head-neck offset, and acetabular version, in addition to conventional alpha angle parameters, were measured. Maximal squat depth kinematics was collected from each participant. The symptomatic FAI group had smaller femoral neck-shaft angles and could not squat as low. A discriminant function analysis determined that femoral neck-shaft angle and radial alpha angle were significantly the most suitable parameters to classify participants with their respective subgroups ( $p < 0.0001$ ;  $p = 0.003$ ). The femoral neck-shaft angle and squat depth were the significant parameters to distinguish FAI participants ( $p < 0.0001$ ). Femoral neck-shaft angle and squat depth parameters can be considered as additional classifiers for FAI, in addition to the conventional alpha angles, and can perhaps explain why some patients exhibit symptoms.

## INTRODUCTION

Cam type femoroacetabular impingement (FAI), characterized by an enlarged, aspherical femoral head-neck lesion, has been recognized

as a pathomechanical disease process of the hip and a cause for early osteoarthritis [1]. In the presence of a large cam deformity, it reduces the clearance between the femoral head-neck junction and the labrum, therefore, imposes an interference fit at the hip joint, decreasing hip ranges of motion and inducing elevated stresses.

The alpha angle has been traditionally used to measure the size of the deformity about the femoral head in the axial and radial planes [2,3]. This angle quantifies the severity of the cam deformity, measuring the extension of the femoral head-neck lesion, with higher angles associated with an increased risk of hip pain and joint degeneration [4]. However, the accuracy and sensitivity of the alpha angle has been often disputed [3,5] since it can sometimes underestimate the severity of the deformity and may not always explain the persistence of symptoms. Although other radiographic parameters have been suggested to identify symptomatic FAI [6-8] and symptomatic patients have demonstrated higher hip joint stresses [9] and different hip kinematics [10] during squat motions, it is still unclear why many patients with the cam deformity do not exhibit any symptoms. Possibly, FAI symptoms may be related to other geometric parameters that can consequently cause mechanical impingement of the hip.

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 geometric and anatomical parameters, in addition to the conventional alpha angles, along with a maximal squat depth analysis to classify FAI and distinguish differences between FAI patients.

## METHODS

Twenty participants ( $m = 17$ ,  $f = 3$ ; age =  $33.5 \pm 6.0$  years; BMI =  $25.3 \pm 4.2$  kg/m<sup>2</sup>) 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. A cam deformity was defined by an alpha angle greater than  $55^\circ$  in either plane. The participants were classified as either: symptomatic FAI (sFAI) if they demonstrated persistent symptoms of pain, had an alpha angle greater than  $55^\circ$ , and awaiting surgical intervention; asymptomatic FAI (aFAI) if they demonstrated no symptoms and no cartilage degeneration, but had an alpha angle greater than  $55^\circ$ ; or control (CON) if they demonstrated no symptoms, no lower-limb abnormalities, and an alpha angle below  $55^\circ$ . For sFAI ( $n=6$ ), each participant's affected hip was defined as the side with symptoms. For aFAI ( $n=8$ ), the affected hip was defined by the side that had the higher alpha angle. For CON ( $n=6$ ), the control-matching hip was defined by the side that had the smaller alpha angle.

Subject-specific, three-dimensional hip models were manually segmented and reconstructed from each participant's CT data using 3D-Doctor 4.0 (Able Software Corp., Lexington, MA, USA). The full region of the pelvic CT data was considered for segmentation, from the superior iliac crest of the pelvis to the proximal diaphysis of the femur (Figure 1).

The segmented models were blinded, randomized, then evaluated using SolidWorks (Dassault Systèmes, Concord, MA, USA). In addition to the axial and radial alpha angles, each participant's model was measured three times for femoral neck-shaft angle, anterior femoral head-neck offset, and acetabular version for both left and right hips. A femoral neck-shaft angle less than  $120^\circ$  was considered as varus and above  $135^\circ$  as valgus. The procedures for each radiographic CT measure were well-documented in [6, 7].

Three-dimensional hip joint kinematics were collected from each participant's maximal squat depth motion, using ten Vicon MX-13 cameras

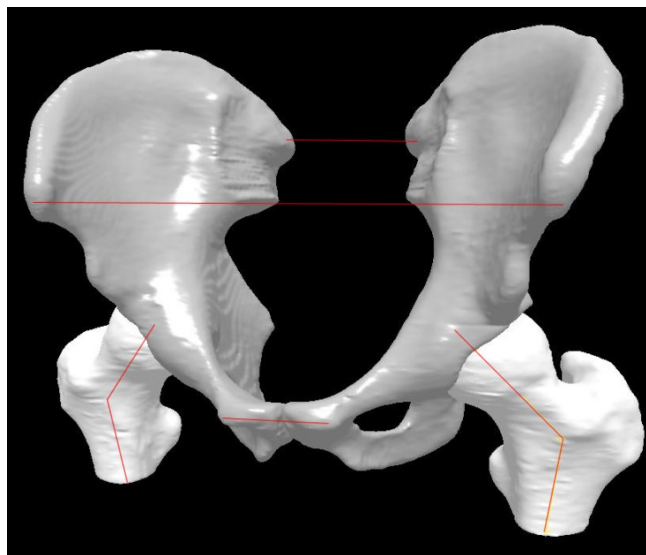


Figure 1: Three-dimensional model segmented from subject-specific CT data indicating the geometric features of the femoral head, proximal femur, and acetabulum.

(Vicon, Los Angeles, CA, USA) and retro-reflective markers placed on anatomical landmarks, according to a modified Helen-Hayes marker set [11]. Each participant performed maximal dynamic squats, where each squat was measured as a percentage with respect to leg height (where ground level would represent a leg height of 0%).

The resultant measures from the segmented models were then unblinded and matched with the maximal squat depth results. 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

All participants were initially classified in one of the three groups. No evidence of dysplasia or other hip morphologies, other than cam FAI, were observed. The geometric parameters were consistently measured according to the intraclass correlation coefficient (ICC) for femoral neck-shaft angle ( $ICC = 0.88$ ), femoral head-neck offset ( $ICC = 0.85$ ), and acetabular version ( $ICC = 0.96$ ).

Both sFAI and aFAI groups demonstrated similar elevated alpha angles in the axial and

radial planes, which were higher in comparison with the CON group (Table 1). The sFAI group demonstrated a substantially lower femoral neck-shaft angle ( $119.1 \pm 2.0^\circ$ ) and reduced squat depth ( $48.2 \pm 6.9\%$ ), in comparison with aFAI ( $126.6 \pm 3.1^\circ$ ;  $42.6 \pm 8.8\%$ ) and CON ( $128.6 \pm 2.2^\circ$ ;  $43.2 \pm 14.1\%$ ). The sFAI group also had a slightly lower femoral head-neck offset ( $8.8 \pm 1.8$  mm), in comparison with aFAI and CON ( $9.3 \pm 1.4$  mm and  $9.7 \pm 1.0$  mm, respectively). No differences in acetabular version were noticed among the three groups. Other than alpha angles, the aFAI group demonstrated similar geometric and squat depth parameters as the CON group. Table 1 summarizes the means from the geometric and squat depth results.

The multiple DFA determined that femoral neck-shaft angle and radial alpha angle were significantly the most suitable parameters to classify all participants (Figure 2), based on canonical discriminant functions (Wilk's  $\lambda_1=0.142$ ,  $p<0.0001$ ; Wilk's  $\lambda_2=0.584$ ,  $p=0.003$ ). In addition, femoral neck-shaft angle and squat depth were the significantly the best parameters to distinguish sFAI from aFAI using a DFA (Wilk's  $\lambda=0.201$ ;  $p<0.0001$ ).

## DISCUSSION

The advantage of the segmented models permitted us to visualise and measure a three-dimensional deformity, as opposed to the use of planar view radiographs. The three-dimensional models were easily re-oriented in SolidWorks, to correct for pelvic incline during CT imaging. The geometric parameters were consistently measured and reliable ( $ICC > 0.8$ ). The sFAI group had noticeably smaller femoral neck-shaft angles, with angles approaching coxa vara. This characteristic in combination

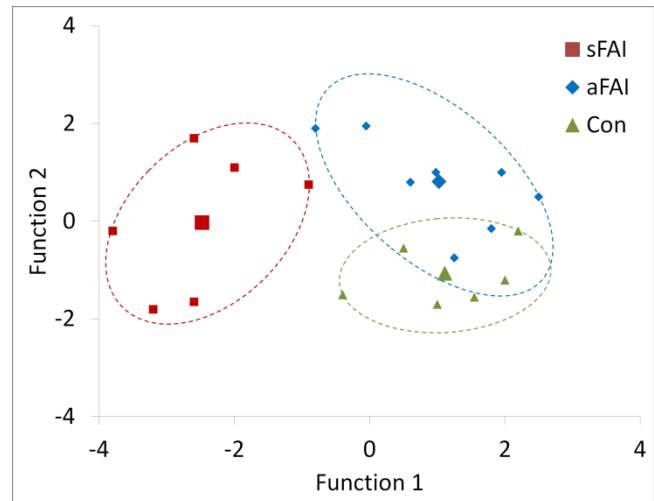


Figure 2: Discriminant function analysis with canonical discriminant functions classifying sFAI (red), aFAI (blue), and CON (green) based on femoral head-neck angle and radial alpha angle. Group envelopes (ellipses) are centered on the group centroids (larger markers).

with an elevated alpha angle, in the antero superior quadrant, and a slightly decreased anterior femoral head-neck offset could have contributed to the presence of symptoms and distinguishable squat kinematics [10]. The femoral neck-shaft angle and squat depth analysis were significantly the most suitable parameters to distinguish sFAI from aFAI.

Both FAI groups had slightly decreased femoral head-neck offsets, but this was not a significant determinant in the DFA. Other than alpha angles, aFAI demonstrated similar geometric and squat parameters as the CON group. Several aFAI and CON participants demonstrated low acetabular versions (retroversion), which contradict other radiographic findings associated with sFAI [6,7] and may not explain symptoms.

Our results for femoral neck-shaft angle coincided with studies found in literature [6,8];

Table 1: Summary of geometric and maximal squat depth parameters associated with each group

Group	n (m:f)	Age (year)	BMI (kg/m <sup>2</sup> )	Alpha Angle		Femoral Neck-Shaft Angle (°)	Femoral Head-Neck Offset (mm)	Acetabular Version (°)	Squat Depth (% leg height)
				Axial (°)	Radial (°)				
sFAI	6 (5:1)	38.8 ± 5.0	25.8 ± 6.2	54.4 ± 7.0	63.1 ± 6.4	119.1 ± 2.0	8.8 ± 1.8	19.2 ± 5.0	48.2 ± 6.9
aFAI	8 (7:1)	30.8 ± 5.3	24.5 ± 3.1	51.3 ± 7.1	61.7 ± 5.8	126.6 ± 3.1	9.3 ± 1.4	15.5 ± 4.5	42.6 ± 8.8
CON	6 (5:1)	31.7 ± 5.1	25.8 ± 3.8	42.8 ± 5.7	52.0 ± 3.0	128.6 ± 2.2	9.7 ± 1.0	18.7 ± 4.3	43.2 ± 14.1

also, our results suggest that a decreased femoral head-neck offset may be associated with sFAI [6,7]. However, our results for acetabular version were inconclusive as several aFAI participants demonstrated retroversion and crossover, but did not show symptoms.

## CONCLUSION

The DFA determined that femoral neck-shaft angle and radial alpha angle were significantly the most suitable parameters to classify the participants. Moreover, squat depth was used as a parameter to distinguish sFAI from aFAI. 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 [5,12]. It is suggested that in addition to the conventional alpha angle measurements, femoral neck-shaft angle and squat parameters can be considered as additional classifiers for FAI or preliminary diagnostic tools that can perhaps explain why some patients exhibit symptoms. Since there is a difference in squat depths between sFAI and aFAI, the elevated alpha angle and decreased femoral neck-shaft angle of the sFAI group suggests that there is an association between the location and severity of the cam deformity with hip joint mechanics, which can consequently influence a reduced squat depth. Therefore, elevated alpha angles could show symptoms if the decreased femoral neck-shaft angle approaches coxa vara.

This study indicates that an elevated alpha angle could show symptoms if the deformity is located in an exploited hip joint orientation. Thus for mechanical impingement to occur due to hip joint geometry, symptoms and hip pain could persist due to a combination of several geometric parameters. This would lead to the association of altered squat kinematics due to the location of the cam deformity, severity, and orientation of the anatomical structures. A higher number of participants would further confirm statistical significance between each group. Our future research will examine other geometric hip joint measures as additional discriminants to classify the groups and possibly delineate the role of muscle activity that could contribute to the onset of this pathomechanism.

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