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Are cam morphology size and location associated with self-reported burden in football players with FAI syndrome?

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Abstract

Cam morphology size and location might affect the severity of reported burden in people with femoroacetabular impingement (FAI) syndrome. We investigated the relationship between cam morphology size (i.e., alpha angle) and self-reported hip/groin burden (i.e., scores for the International Hip Outcome Tool-33 (iHOT-33) and Copenhagen Hip and Groin Outcome Score (HAGOS)), examined separately for the anteroposterior pelvis (AP) and Dunn 45° radiographs in football players with FAI syndrome. In total, 118 (12 women) subelite football (soccer or Australian football) players with FAI syndrome with cam morphology (alpha angle ≥60°) participated. One blinded assessor quantified superior and anterosuperior cam morphology size by measuring alpha angles for the AP and Dunn 45° radiographs, respectively. Linear regression models investigated relationships between alpha angle (continuous independent variable, separately measured for the AP and Dunn 45° radiographs) and iHOT-33 and HAGOS scores (dependent variables). Larger anterosuperior cam morphology (seen on the Dunn 45° radiograph) was associated with lower (i.e., worse) scores for the iHOT-Total, iHOT-Symptoms, iHOT-Job, and iHOT-Social subscales (unadjusted estimate range −0.553 to −0.319 [95% confidence interval −0.900 to −0.037], $p = 0.002$ to 0.027), but not the iHOT-Sport ($p = 0.459$) nor any HAGOS scores ($p = 0.110$ to 0.802). Superior cam morphology size (measured using the AP radiograph) was not associated with any iHOT-33 or HAGOS scores ($p = 0.085$ to 0.975). Larger anterosuperior cam morphology may be more relevant to pain and symptoms in football players with FAI syndrome than superior cam morphology, warranting investigation of its effects on reported burden and hip disease over time.

KEYWORDS

cam morphology, femoroacetabular impingement syndrome, football, hip joint, hip-related pain, patient-reported outcome measure, rehabilitation

1 | INTRODUCTION

Femoroacetabular impingement (FAI) syndrome is a cause of hip and/or groin (hip/groin) pain in football players[1,2] and may contribute to their greater lifetime risk of hip osteoarthritis (OA) when compared to controls.[3] Diagnosis of FAI syndrome requires symptoms, clinical signs, and imaging evidence of cam and/or pincer morphology.[4,5] Primary cam morphology is determined by an alpha angle threshold value of 60°[4,6,7] and has been associated with chondrolabral pathology,[8,9] lower hip range of motion (ROM),[10,11] and the development of hip OA.[12] However, symptomatic adults with and without cam morphology report similar patient-reported outcome measure scores,[13,14] indicating a less certain relationship between cam morphology and reported burden in people with hip/groin pain.

Defining FAI syndrome using an alpha angle threshold value (i.e., ≥60°) may not identify the potential effect of cam morphology size on self-reported hip/groin burden severity. A dose-response relationship was observed between cam morphology size and hip joint physical findings, where people with large cam morphology (alpha angle ≥78°) had worse chondrolabral pathology[8,9] and lesser hip ROM[11] when compared to those with cam morphology (alpha angles 60–78°). However, it is not known whether a similar relationship exists between cam morphology and self-reported pain and symptoms in people with FAI syndrome. Cam morphology size might affect reported burden in football players with FAI syndrome, as they require considerable hip function and ROM during their sporting activities.

The anatomical location of cam morphology may also affect reported burden in people with FAI syndrome. Anteroposterior pelvis (AP) and Dunn 45° radiographs visualize cam morphology at the superior and anterosuperior femoral head-neck junction, respectively, and together are recommended as the first-line assessment for patients with suspected FAI syndrome.[4,5] Larger superior cam morphology (seen on AP radiograph) has been associated with worsening hip joint disease over time;[7,12] however, maximum alpha angles mostly occur in the anterosuperior femoral head-neck,[4,15-17] where Dunn 45° radiographs may more accurately quantify cam morphology size.[15] Discerning the impacts of both cam morphology location and size on the severity of reported burden could inform future prospective studies of hip joint disease and guide treatments for football players with FAI syndrome.

Therefore, the primary aim of this study was to investigate the relationship between cam morphology size (i.e., continuous alpha angle) and self-reported hip/groin burden (i.e., scores for the International Hip Outcome Tool-33 (iHOT-33) and the Copenhagen Hip and Groin Outcome Score (HAGOS)), examined separately for the AP and Dunn 45° radiographs in football players with FAI syndrome.

2 | MATERIALS AND METHODS

2.1 | Study design and participants

Participants in this study were a subset of a larger prospective cohort study of 18- to 50-year-old subelite (nonprofessional) football (soccer or Australian football) players with hip/groin pain who continued to participate in competitive sport.[18] Briefly, for inclusion in the larger cohort, football players were required to report more than six months of hip/groin pain and have a positive flexion-adduction-internal rotation (FADIR) test. Football players with hip/groin pain were excluded if they had the following: (1) radiographic hip OA defined by a Kellgren and Lawrence (KL) score[19] of ≥2; (2) undergone hip or pelvic surgery; or (3) reported a history of significant hip condition (e.g., hip fracture or congenital dislocation of the hip). To be included in this cross-sectional study, participants from the larger cohort needed to have cam morphology (defined by an alpha angle of ≥60° using the supine AP or Dunn 45° radiograph[4,12]) and be free from acetabular dysplasia (defined by a lateral center-edge angle (LCEA) of <20° using the supine AP radiograph[12,14]). Ethical approval was obtained from the La Trobe University Human Ethics Committee (HEC015-019) and the University of Queensland Human Ethics Committee (2015000916). Written informed consent was obtained prior to participation in the study.

2.2 | Procedures

Football players with hip/groin pain attended La Trobe University or University of Queensland for testing between August 2015 and August 2018. Participant characteristics (e.g., age, sex, height, body mass, football code, and duration of symptoms) were recorded. Radiographs were undertaken at radiology clinics in Melbourne (Imaging @ Olympic Park) and Brisbane (Q-Scan), Australia. Participants completed the iHOT-33 and HAGOS, two self-reported questionnaires that are recommended for assessing active adults with hip/groin pain.[20-22] The iHOT-33 measures five dimensions of hip/groin burden: (1) hip-related quality of life (iHOT-Total); (2) symptoms and functional limitations (iHOT-Symptoms); (3) sport and recreational activities (iHOT-Sport); (4) job-related concerns (iHOT-Job); and (5) social, emotional, and lifestyle concerns (iHOT-Social). The HAGOS explores six dimensions of hip/groin burden: symptoms (HAGOS-Symptoms), pain (HAGOS-Pain), physical function in activities of daily living (HAGOS-ADL), physical function during sport and recreational activities (HAGOS-Sport), participation in physical activities (HAGOS-PA), and hip and/or groin-related quality of life (HAGOS-QOL). Scores for the iHOT-33 and HAGOS have acceptable validity and reliability in active adults with hip/groin pain.[20,22]

2.3 | Radiographs

Participants underwent a supine AP and Dunn 45° radiograph of each hip according to standardized protocols[18] to determine eligibility for the study and quantify femoral head-neck asphericity.[4,12] One blinded assessor (JJH) determined the presence of cam and pincer morphology using quantitative methods,[12] as detailed in Appendix A. Briefly, a point set was placed on predetermined locations on the surface of the femur and acetabulum with statistical shape modeling software (ASM toolkit, Manchester University, Manchester, UK). The alpha angle and LCEA were then calculated using MATLAB software v7.1.0 (MathWorks Inc., Natick, Massachusetts, USA), with the alpha angle separately calculated for the AP and Dunn 45° radiographs. An LCEA ≥40° on the AP radiograph defined the presence of global pincer morphology.[4,23] As all participants in this study had hip/groin pain and cam morphology, those with global pincer morphology were determined to have FAI syndrome with mixed morphology,[12,23-25] while all other participants had FAI syndrome with cam morphology.[12,23-25] Excellent intra-rater reliability (intraclass correlation coefficient (ICC) alpha angle AP = 0.92; alpha angle Dunn = 0.93; LCEA = 0.94) and moderate-to-good inter-rater reliability (ICC alpha angle AP = 0.76; alpha angle Dunn = 0.93; LCEA = 0.63) were demonstrated for bony hip morphology measures.[2] Methods for determining intra-rater (JJH) and inter-rater (JJH and RA) have been previously described.[2]

2.4 | Data management

Participants defined their most symptomatic hip on the iHOT-33 (reported from the question *"which (hip) gives you the most trouble?"*), and this hip was used for analyses. Three participants did not have useable iHOT-33 scores (i.e., their reported most symptomatic hip from the iHOT-33 did not meet the inclusion criteria of a positive FADIR test result), and another three did not complete the HAGOS; these six participants were removed from the respective analyses.

2.5 | Statistical analysis

Data were assessed for normality using boxplots and Shapiro-Wilk analyses. Continuous demographic data were summarized using means and standard deviations or medians and interquartile range (IQR) values, as appropriate. Linear regression models investigated the relationships between alpha angle (continuous independent variable, measured separately using AP and Dunn 45° radiographs) and patient-reported outcome measure (PROM) scores (dependent variable – HAGOS and iHOT-33 scores of 0 to 100). Prior to interpreting results, models were assessed for violations of assumptions. Residual scatter plots assessed linearity and homoscedasticity, and variance inflation statistics (VIF) >10 indicated problematic multicollinearity. Normality of regression model residuals was assessed using residual scatter plots and Shapiro-Wilk analyses. Relationships between alpha angle and PROM scores were analyzed unadjusted and adjusted for the covariates of age, sex, and body mass index (BMI). Pseudo R^2 values quantified the strength of modeled relationships. For adjusted (multivariable) linear regression models, interaction effects between sex and alpha angle (sex*alpha angle) were examined and removed if not significant. Due to the relatively small number of female football players compared to men, modeled relationships for women may have been unduly influenced by individual participants. Therefore, models with significant sex*alpha angle interaction terms ($p < 0.05$) were examined for data outliers using box plots and residual scatter plots. If removing data outlier(s) from affected linear regression models nullified the sex*alpha angle interaction term (i.e., $p > 0.05$), then the influential case(s) were removed from the main analysis. Sensitivity analyses involving men only were then undertaken to validate the findings of the main analysis. If the statistical significance of the interaction term was unchanged after removing data outliers (i.e., $p < 0.05$), then all available data were stratified by sex and linear regression models were separately built for men and women. As iHOT-33 and HAGOS scores are anchored by values of 0 and 100, they may not always be optimally modeled using linear regression. To validate the results of our main analysis, we conducted sensitivity analyses using models with arcsine-transformed[26] iHOT-33 and HAGOS scores. The method for transforming the dependent variables is described in Appendix B. Statistical analyses were completed using the General Analyses for Linear Models module in Jamovi version 1.8.1.0 (the jamovi project, Sydney, Australia). Level of significance was set at 0.05.

3 | RESULTS

In total, 118 football players (12 women) with FAI syndrome were included in this study. Figure 1 summarizes participant recruitment and flow. Demographic characteristics of football players with FAI syndrome are summarized in Table 1.

3.1 | Linear models and Dunn 45° radiograph

Results for linear regression models (unadjusted and adjusted) for the Dunn 45° radiograph are presented in Table 2. Larger alpha angles were associated with lower (i.e., worse) scores for the iHOT-Total, iHOT-Symptoms, iHOT-Job, and iHOT-Social subscales (unadjusted estimate range −0.553 to −0.319 [95%CI −0.900 to −0.037], $p = 0.002$ to 0.027). Adjusted model estimates found that for every 10° increase in alpha angle above 60°, iHOT-33 scores decreased by 3.7-points (iHOT-Total), 3.5-points (iHOT-Symptoms), 4.9-points (iHOT-Job), and 5.8-points (iHOT-Social) (Figure 2). Alpha angles were not associated with the iHOT-Sport score ($p = 0.459$) nor any HAGOS scores ($p = 0.110$ to 0.802).

3.2 | Linear models and AP radiograph

The results for linear regression models for the AP radiograph are presented in Table 3. Alpha angles measured using the AP radiograph were not associated with any iHOT-33 or HAGOS scores ($p = 0.085$ to 0.975).

3.3 | Sensitivity analyses

There were significant sex*alpha angle interaction effects for all linear models involving the AP radiograph (except iHOT-Job and iHOT-Social). Larger alpha angles were associated with worse burden in women but not men due to one influential female case (see figures in Appendix C). Therefore, data for this one female participant were removed from the main analysis (for affected AP models only), nullifying the significant sex*alpha angle interaction terms. Sensitivity analyses undertaken in men only confirmed the findings of the main analysis (Appendix D), indicating that our inclusion of women in the main analysis did not alter the statistical significance of the models. Sensitivity analyses with arcsine-transformed dependent variables also confirmed the findings of the main analysis (Appendix B), indicating

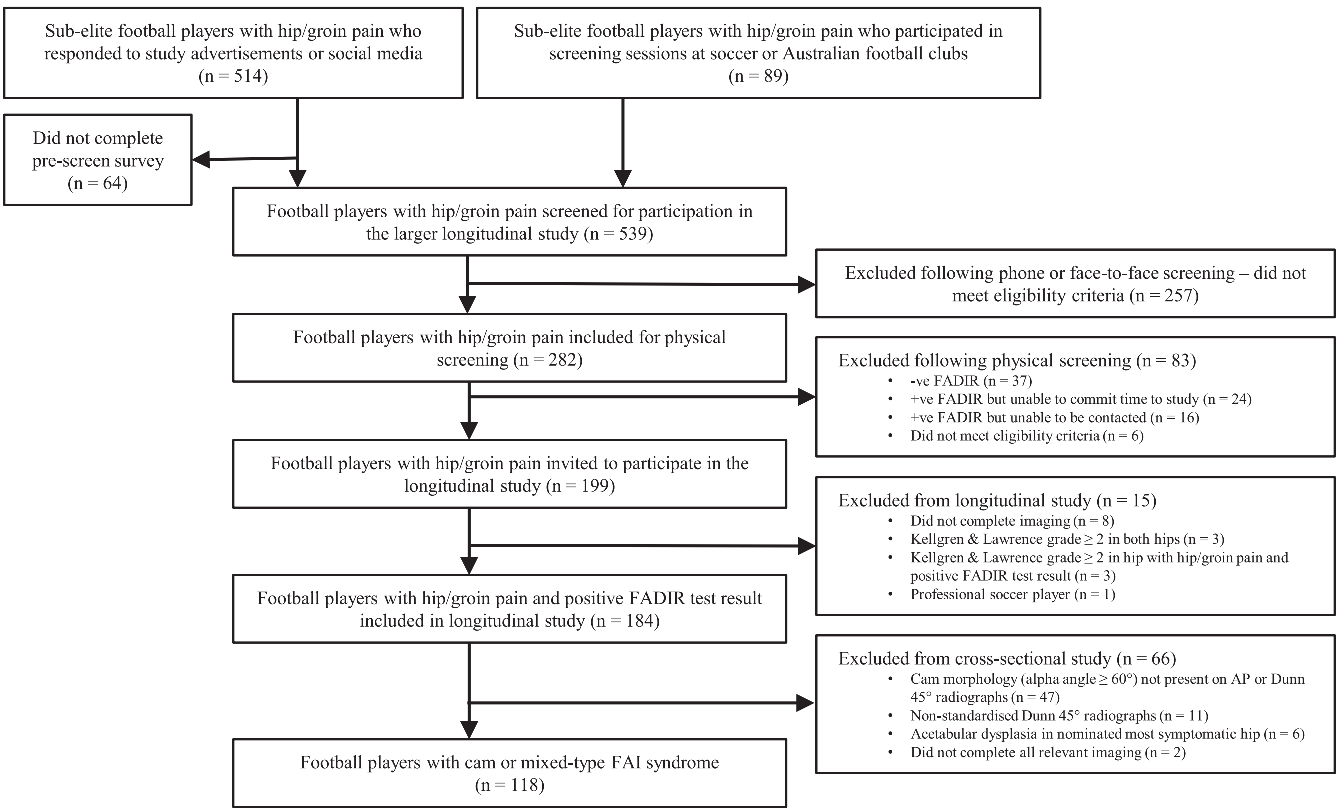

FIGURE 1 Participant flow for football players with hip/groin pain. Abbreviation: AP = anteroposterior pelvis; FADIR = flexion-adduction-internal rotation

TABLE 1 Demographic characteristics of football players with FAI syndrome

	All participants (n = 118)		Cam morphology using Dunn 45° radiograph (n = 110)		Cam morphology using AP pelvis radiograph (n = 77)	
	Women (n = 12)	Men (n = 106)	Women (n = 9)	Men (n = 101)	Women (n = 8)	Men (n = 69)
Age (years)	24 [7]	26 [6]	23 [5]	26 [6]	24 [10]	26 [6]
Body mass index (kg/m^2)	22.4 [2.4]	24.5 [2.7]	22.9 [2.9]	24.4 [2.7]	22.4 [1.8]	24.4 [2.7]
Symptom duration (months)	18 [30]	24 [32]	24 [38]	24 [33]	14 [12]	30 [41]
Soccer player	5 (42%)	43 (41%)	4 (44%)	40 (40%)	3 (38%)	28 (41%)
KL grade 0	12 (100%)	98 (92%)	9 (100%)	93 (92%)	8 (100%)	63 (91%)
FAI syndrome – Mixed	1 (8%)	10 (9%)	1 (11%)	9 (9%)	1 (13%)	7 (10%)
Alpha angle (degrees)	-	-	67.5 [13.2]	77.9 [15.1]	77.0 [3.7]	77.0 [13.2]
Cam morphology using both radiographic views	5 (42%)	64 (60%)	-	-	-	-
Cam morphology using Dunn 45° view only	4 (33%)	37 (35%)	-	-	-	-
Cam morphology using AP pelvis view only	3 (25%)	5 (5%)	-	-	-	-

Note: Data presented as medians and interquartile ranges [IQR] or counts and proportions (%). Cam morphology determined to be present for each radiographic projection when alpha angle ≥60° was recorded. "FAI syndrome – Mixed" indicates femoroacetabular impingement syndrome with mixed morphology. Abbreviations: AP = anteroposterior, KL = Kellgren and Lawrence, and - = not applicable.

that the distribution of PROM scores did not affect the modeled relationships.

4 | DISCUSSION

We investigated the relationships between alpha angle (measured separately using the AP and Dunn 45° radiographs) and iHOT-33 and HAGOS scores in active football players with FAI syndrome with cam or mixed morphology. Football players with larger cam morphology reported worse iHOT-Total, iHOT-Symptoms, iHOT-Job, and iHOT-Social scores when alpha angle was measured using the Dunn 45° radiograph but not the AP. Larger anterosuperior cam morphology, as visualized using the Dunn 45° radiograph, may be more relevant for reported pain and symptoms in football players with FAI syndrome than superior (AP visualized) cam morphology.

We found a location-specific relationship between cam morphology size and reported hip/groin burden in football players with FAI syndrome. Maximum alpha angle measurements are frequently observed at the anterosuperior region of the femoral head-neck junction,[4,15-17] where larger and more anterior cam morphology has been found to impinge the acetabulum at smaller degrees of hip flexion.[27] While mechanical impingement between the femoral neck and acetabulum may increase hip joint stresses,[28] restrict ROM,[11,29] and cause chondrolabral pathology,[8,9] the effect of cam morphology on reported burden has been less certain. Cam morphology presence[13,14] and size[2,30,31] have been unrelated to PROM scores in various symptomatic populations, including those undergoing hip arthroscopy,[30,31] adults with self-reported hip OA,[13] and football players with hip/groin pain.[2,14] Our findings, which contrast previous reports investigating cam morphology size,[2,30] might be explained in part by our location-specific analysis[30] and more homogenous cohort.[2,30] By only including football players with FAI syndrome with alpha angles ≥60°, cam morphology was more likely to be relevant for participants' clinical presentation when compared to symptomatic football players (or other populations) with alpha angles <60°.[4,6,25] Consistent with our findings, anterosuperiorly located cam morphology optimally discriminated between people undergoing surgery for hip pain and pain-free people, compared to other femoral head-neck regions.[17,32] Larger anterosuperior cam morphology, therefore, might be related both to the presence and severity of hip/groin pain; however, the cross-sectional nature of our study and others[17,32] means that determining causality remains elusive. Our findings support calls for prospective studies to understand the effect of anterosuperior cam morphology size on reported burden and joint disease over time,[5,12] particularly in high-impact athletes who may be at greater risk of hip OA.[3]

Modest relationships between anterosuperior cam morphology size and iHOT-33 scores suggest that factors other than cam morphology may influence self-reported burden in football players with FAI syndrome. It is unclear why relationships were limited to the iHOT-33 only, considering that the HAGOS and iHOT-33 examine equivalent dimensions of hip/groin pain[22] and share many similar questions.[33] Differences in the scoring (ordinal

TABLE 2 Relationship between alpha angle and (A) iHOT-33 and (B) HAGOS scores using Dunn 45° radiograph

(A)

$N = 110$[a]		iHOT-Total		iHOT-Symptoms		iHOT-Sport		iHOT-Job[b]		iHOT-Social	
Model		**Unadjusted** $R^2 = 0.055$	**Adjusted** $R^2 = 0.12$ ($p = 0.010$)	**Unadjusted** $R^2 = 0.046$	**Adjusted** $R^2 = 0.125$ ($p = 0.008$)	**Unadjusted** $R^2 = 0.005$	**Adjusted** $R^2 = 0.098$ ($p = 0.032$)	**Unadjusted** $R^2 = 0.059$	**Adjusted** $R^2 = 0.090$ ($p = 0.067$)	**Unadjusted** $R^2 = 0.087$	**Adjusted** $R^2 = 0.129$ ($p = 0.006$)
Cam size	*b*-value	−0.349	−0.374	−0.319	−0.349	−0.138	−0.147	−0.473	−0.487	−0.553	−0.577
	95%CI	(−0.630, −0.069)	(−0.650, −0.097)	(−0.601, −0.037)	(−0.626, −0.073)	(−0.504, 0.229)	(−0.505, 0.210)	(−0.856, −0.090)	(−0.879, −0.096)	(−0.900, −0.206)	(−0.923, −0.230)
	p value	$p = 0.015$	$p = 0.009$	$p = 0.027$	$p = 0.014$	$p = 0.459$	$p = 0.416$	$p = 0.016$	$p = 0.015$	$p = 0.002$	$p = 0.001$

(B)

$N = 110$[a]		HAGOS-Symptoms		HAGOS-Pain		HAGOS-ADL		HAGOS-Sport		HAGOS-PA[c]		HAGOS-QOL	
Model		**Unadjusted** $R^2 = 0.024$	**Adjusted** $R^2 = 0.096$ ($p = 0.034$)	**Unadjusted** $R^2 = 0.003$	**Adjusted** $R^2 = 0.126$ ($p = 0.008$)	**Unadjusted** $R^2 = 0.007$	**Adjusted** $R^2 = 0.056$ ($p = 0.205$)	**Unadjusted** $R^2 = 0.011$	**Adjusted** $R^2 = 0.028$ ($p = 0.569$)	**Unadjusted** $R^2 < 0.001$	**Adjusted** $R^2 = 0.022$ ($p = 0.629$)	**Unadjusted** $R^2 = 0.022$	**Adjusted** $R^2 = 0.061$ ($p = 0.168$)
Cam size	*b*-value	−0.173	−0.192	−0.057	−0.081	−0.113	−0.135	−0.162	−0.175	−0.057	−0.071	−0.214	−0.231
	95%CI	(−0.387, 0.040)	(−0.402, 0.018)	(−0.269, 0.155)	(−0.284, 0.123)	(−0.379, 0.153)	(−0.401, 0.131)	(−0.465, 0.141)	(−0.483, 0.132)	(−0.502, 0.389)	(−0.524, 0.381)	(−0.493, 0.065)	(−0.510, 0.049)
	p value	$p = 0.110$	$p = 0.072$	$p = 0.595$	$p = 0.434$	$p = 0.402$	$p = 0.316$	$p = 0.291$	$p = 0.260$	$p = 0.802$	$p = 0.754$	$p = 0.131$	$p = 0.105$

Note: R^2 indicates pseudo R^2 values. Sample size variations: $n^a = 107$ (unless otherwise indicated), $n^b = 97$, $n^c = 106$.

Abbreviations: ADL, activities of daily living; HAGOS, Copenhagen Hip and Groin Outcome Score; iHOT-33, International Hip Outcome Tool-33; PA, participation in physical activity; QOL, quality of life.

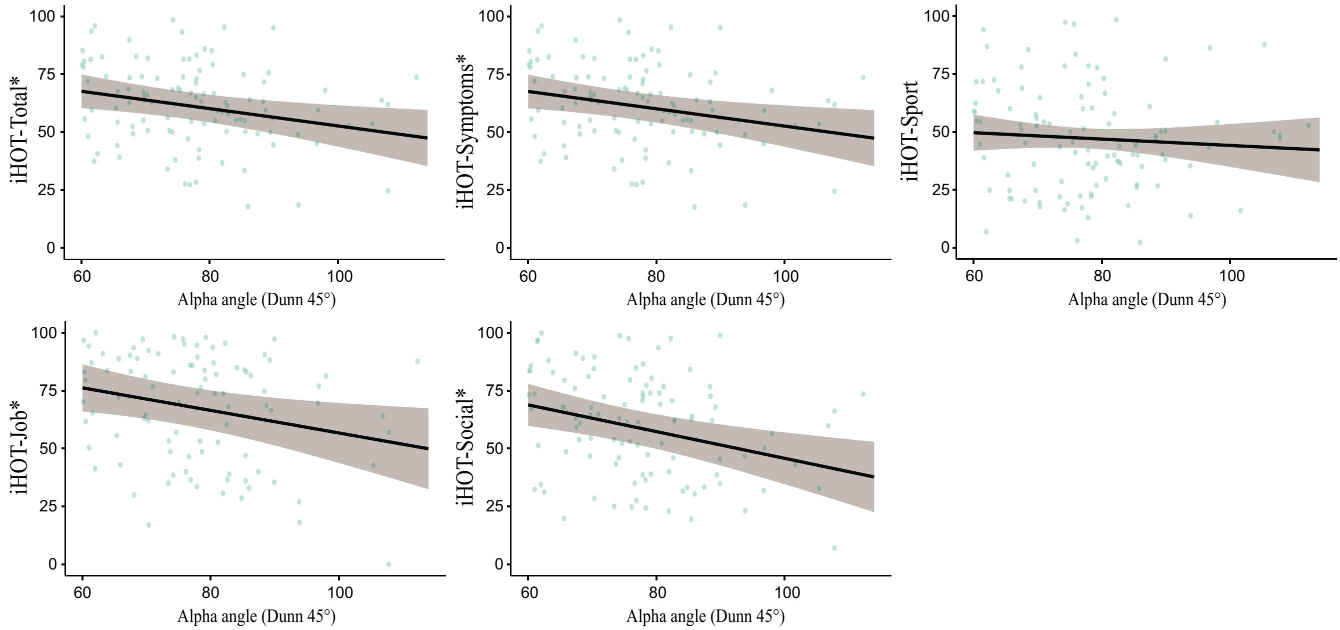

FIGURE 2 Adjusted relationships between alpha angle (degrees) measured using the Dunn 45° radiograph and International Hip Outcome Tool-33 (iHOT-33) subscale scores in football players with femoroacetabular impingement syndrome. *indicates significant relationships ($p < 0.05$)

vs continuous and per-person vs per-hip) and/or unique questions within the iHOT-33 may have influenced the scores and hence the relationships with cam morphology size. Although relationships existed for most iHOT-33 scores, model estimates determined that alpha angle differences of more than 20° would be required to manifest as clinically important score differences between our football players,[22] and smaller alpha angle differences were less likely to be meaningful. Furthermore, small pseudo R^2 values for univariable models found that only 4.6% to 8.7% of the variance in iHOT-33 scores was explained by alpha angle, indicating that the severity of pain, symptoms, and functional impairment reported by our football players was mostly impacted by factors other than anterosuperior cam morphology size. These coexisting factors may be distinct from the sequalae of cam morphology and could include, for example, physical impairments such as strength deficits[10] or altered biomechanics.[34] Other bony morphological features (e.g., acetabular, femoral, and spinopelvic morphologies) have partially explained the presence of hip/groin pain in those undergoing surgery when compared to pain-free people,[17] and greater understanding of the relationships between these imaging findings and the presence of pain and the severity of reported burden are needed in high-impact athletes. Nonphysical (e.g., psychosocial and contextual) factors[35] can moderate relationships between physical findings and reported burden. For example, preoperative mental health status, but not the severity of intraoperative findings, was related to reported burden in people undergoing hip arthroscopy.[31,36] Self-reported treatment outcomes may too be influenced by other physical and nonphysical factors, with postoperative alpha angles or the magnitude of bony resection rarely related to PROM scores following femoral head-neck osteochondroplasty[37]. Our findings suggest that football players with larger anterosuperior cam morphology may be at risk of worse hip/groin pain and symptoms; however, they do not imply that surgical treatment to address bony morphology will improve reported burden. Larger cam morphology might moderate the effectiveness of exercise-based rehabilitation,[38] but full-scale studies are needed to understand this potential relationship. To improve treatment selection and outcomes for football players with FAI syndrome, improved knowledge of the natural history of reported hip/groin burden and the mechanisms of nonsurgical and surgical treatments are needed.

There are limitations that should be considered when interpreting our results. First, AP and Dunn 45° radiographs do not provide three-dimensional visualization of the femoral head-neck junction, potentially leading to under- or over-reporting of cam morphology size (misclassification bias). However, alpha angles recorded using AP and Dunn 45° radiographs have previously demonstrated adequate correlation with computed tomography[39] and magnetic resonance imaging.[15,16] Second, impingement between the femoral head-neck junction and the acetabulum may be more likely in individuals with smaller femoral antetorsion angles,[4] potentially altering the relationship between cam morphology size and self-reported

TABLE 3 Relationship between alpha angle and (A) iHOT-33 and (B) HAGOS scores using anteroposterior pelvis (AP) radiograph

(A)											
$N = 77^a$		iHOT-Total		iHOT-Symptoms		iHOT-Sport		iHOT-Job[b]		iHOT-Social[c]	
Model		Unadjusted $R^2 = 0.004$	Adjusted $R^2 = 0.007$ ($p = 0.974$)	Unadjusted $R^2 = 0.003$	Adjusted $R^2 = 0.016$ ($p = 0.891$)	Unadjusted $R^2 = 0.002$	Adjusted $R^2 = 0.024$ ($p = 0.787$)	Unadjusted $R^2 = 0.027$	Adjusted $R^2 = 0.028$ ($p = 0.768$)	Unadjusted $R^2 = 0.024$	Adjusted $R^2 = 0.038$ ($p = 0.594$)
Cam size	*b*-value	−0.103	−0.100	−0.100	−0.084	0.096	0.067	−0.370	−0.383	−0.327	−0.293
	95%CI	(−0.499, 0.293)	(−0.509, 0.310)	(−0.501, 0.302)	(−0.497, 0.329)	(−0.450, 0.642)	(−0.492, 0.626)	(−0.917, 0.177)	(−0.953, 0.188)	(−0.817, 0.164)	(−0.798, 0.213)
	p value	$p = 0.606$	$p = 0.629$	$p = 0.623$	$p = 0.687$	$p = 0.727$	$p = 0.813$	$p = 0.181$	$p = 0.185$	$p = 0.189$	$p = 0.252$

(B)													
$N = 77^d$		HAGOS-Symptoms		HAGOS-Pain		HAGOS-ADL		HAGOS-Sport		HAGOS-PA[e]		HAGOS-QOL	
Model		Unadjusted $R^2 < 0.001$	Adjusted $R^2 = 0.027$ ($p = 0.753$)	Unadjusted $R^2 = 0.003$	Adjusted $R^2 = 0.074$ ($p = 0.260$)	Unadjusted $R^2 < 0.001$	Adjusted $R^2 = 0.018$ ($p = 0.869$)	Unadjusted $R^2 < 0.001$	Adjusted $R^2 = 0.006$ ($p = 0.981$)	Unadjusted $R^2 = 0.003$	Adjusted $R^2 = 0.027$ ($p = 0.764$)	Unadjusted $R^2 = 0.007$	Adjusted $R^2 = 0.018$ ($p = 0.869$)
Cam size	*b*-value	−0.041	−0.013	−0.073	−0.074	0.007	0.008	0.007	0.006	0.155	0.151	0.152	0.176
	95%CI	(−0.360, 0.279)	(−0.339, 0.313)	(0.374, 0.228)	(−0.374, 0.226)	(−0.389, 0.403)	(−0.398, 0.414)	(−0.432, 0.446)	(−0.446, 0.458)	(−0.514, 0.825)	(−0.539, 0.841)	(−0.282, 0.586)	(−0.270, 0.622)
	p value	$p = 0.801$	$p = 0.938$	$p = 0.629$	$p = 0.622$	$p = 0.973$	$p = 0.968$	$p = 0.975$	$p = 0.979$	$p = 0.645$	$p = 0.663$	$p = 0.486$	$p = 0.434$

Note: R^2 indicates pseudo R^2 values. Sample size variations: $n^a = 74$ (unless otherwise indicated); $n^b = 68$; $n^c = 75$; $n^d = 73$ (unless otherwise indicated); $n^e = 72$.

Abbreviations: 95%CI, 95% confidence interval; ADL, activities of daily living; HAGOS, Copenhagen Hip and Groin Outcome Score; iHOT-33, International Hip Outcome Tool-33; PA, participation in physical activity; QOL, quality of life.

burden in our football players with FAI syndrome. Third, global pincer morphology was defined using the LCEA; however, other pincer morphologies (e.g., global or focal retroversion) may have existed[4] and affected investigated relationships. Fourth, the low specificity of the FADIR test to detect hip-related pain[40] means that hip/groin pain in some of our football players may not have been due to FAI syndrome, despite the presence of cam morphology. Extra-articular groin pain entities[41] and lumbar conditions may have contributed to hip/groin pain in our football players and affected modeled relationships. Fifth, the small number of women we investigated means that we were likely underpowered to determine whether relationships between alpha angle and reported burden were dependent on sex. While sensitivity analyses confirmed our findings in men, studies with more women are needed to confirm or refute a potential sex-specific negative relationship between superior cam morphology and reported burden. Sixth, our findings may be specific to football players, and further investigation of other patient populations with FAI syndrome (e.g., nonathletes and athletes from other sports) is needed to identify whether similar location-specific relationships exist.

5 | CONCLUSIONS

Alpha angle measured using the Dunn 45° radiograph, but not the AP, was modestly related to worse iHOT-33 scores in football players with FAI syndrome with cam morphology. Larger anterosuperior (Dunn 45°) cam morphology may be more relevant to pain and symptoms in football players with FAI syndrome than superior (AP) cam morphology. Further prospective studies are needed to examine the effect of larger anterosuperior cam morphology on reported burden and structural hip disease over time.

6 | PERSPECTIVE

We found that larger anterosuperior, but not superior, cam morphology was modestly associated with worse self-reported pain and symptoms in football players with FAI syndrome. Cam morphology presence, defined by an alpha angle threshold value of 60°, has previously been unrelated to reported burden in people with hip/groin pain;[13,14] however, our findings indicate that larger cam morphology may be more relevant. Our findings are consistent with previous reports of a dose-response relationship between cam morphology and physical findings, where those with larger cam morphology had worse chondrolabral pathology[8,9] and restricted ROM.[11] It is unclear why football players with larger cam morphology reported worse perceived impairment to physical function than those with smaller cam morphology, warranting future investigation of the relationship between cam morphology size and hip joint biomechanics during sporting tasks. The modest strength of our modeled relationships indicated that the severity of reported burden in football players with FAI syndrome was mostly impacted by factors other than anterosuperior cam morphology size; thus, clinicians might consider the relevance of cam morphology size in relation to other physical and nonphysical factors when planning treatment for football players with FAI syndrome. Our location-specific findings support calls for prospective studies that investigate the effect of anterosuperior cam morphology on hip disease in people with FAI syndrome.[5,12] Furthermore, knowledge of the mechanisms of nonsurgical and surgical treatments is needed to improve treatment selection and outcomes for football players with FAI syndrome.

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CONFLICT OF INTEREST

The authors declare that they have no financial involvement or affiliations with any organizations or bodies with direct financial interest in the content discussed in this article.

AUTHOR CONTRIBUTIONS

All authors have made substantial contributions to study design, interpretation of data, and preparation of the manuscript. All authors have read and approved the final manuscript.

Section specialty area

IV – Sports medicine and orthopedics.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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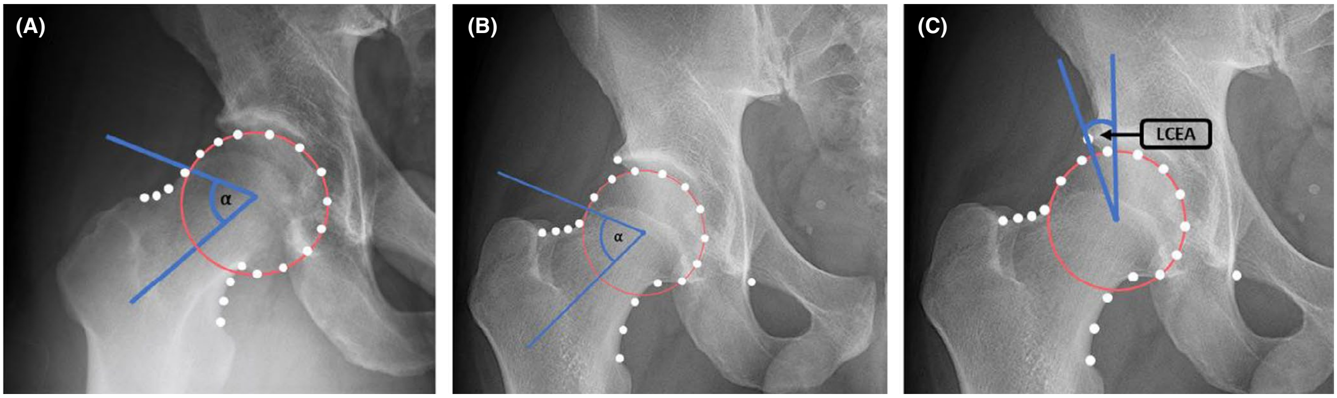
APPENDIX A

Quantitative measures of bony hip morphology



Abbreviations: α, alpha angle. LCEA, lateral center-edge angle.

The white points on the image are representative of the manual point set that was placed on predetermined locations on the surface of the femur and acetabulum.

Alpha angle

Cam morphology presence and size were determined by measuring the alpha angle on the Dunn 45° radiograph (Image A) and anteroposterior pelvis (AP) radiograph (Image B). The points placed on the femoral head and neck determined the circle of best fit around the femoral head and center of femoral neck, respectively. The alpha angle was calculated by the line from the center of the femoral neck to the center of the femoral head and the line from the center of the femoral head to the location where the bone first leaves the circle of best fit.

Lateral center-edge angle

Using the AP radiograph, the LCEA was determined by a vertical line originating from the center of the femoral head and a corresponding line from the center of the femoral head to the most lateral weight-bearing portion of the acetabular sulcus. The vertical line was drawn perpendicular to a horizontal line connecting the two superolateral points of both obturator foramen, to correct for potential pelvic malposition.

APPENDIX B

Arcsine-transformed dependent variables

As the data were bound by scores of 0 and 100, arcsine transformation of patient reported outcome measure (PROM) scores (dependent variables) was completed using formula $Y'' = 2\sin^{-1}\sqrt{Y'}$ (where, y' = PROM observation, y" = transformed PROM score).

B1. Relationship between cam morphology size (Dunn 45° radiograph) and arcsine-transformed iHOT-33 and HAGOS scores

A) iHOT−33

N=110[a]		iHOT-Total		iHOT-Symptoms		iHOT-Sport		iHOT-Job[b]		iHOT-Social	
Model		**Unadjusted** $R^2 = 0.055$	**Adjusted** $R^2 = 0.121$ ($p = 0.010$)	**Unadjusted** $R^2 = 0.046$	**Adjusted** $R^2 = 0.123$ ($p = 0.009$)	**Unadjusted** $R^2 = 0.004$	**Adjusted** $R^2 = 0.089$ ($p = 0.047$)	**Unadjusted** $R^2 = 0.071$	**Adjusted** $R^2 = 0.100$ ($p = 0.044$)	**Unadjusted** $R^2 = 0.089$	**Adjusted** $R^2 = 0.134$ ($p = 0.005$)
Cam size	b-value	−0.226	−0.243	−0.210	−0.230	−0.082	−0.090	−0.358	−0.371	−0.372	−0.391
	95%CI	(−0.407, −0.045)	(−0.422, −0.064)	(−0.395, −0.024)	(−0.412, −0.048)	(−0.321, 0.158)	(−0.324, 0.145)	(−0.621, −0.094)	(−0.640, −0.101)	(−0.603, −0.141)	(−0.621, −0.160)
	P value	$p = 0.015$	$p = 0.008$	$p = 0.027$	$p = 0.014$	$p = 0.500$	$p = 0.449$	$p = 0.008$	$p = 0.008$	$p = 0.002$	$p = 0.001$

B) HAGOS

N=110[a]		HAGOS-Symptoms		HAGOS-Pain		HAGOS-ADL		HAGOS-Sport		HAGOS-PA[c]		HAGOS-QOL	
Model		**Unadjusted** $R^2 = 0.022$	**Adjusted** $R^2 = 0.095$ ($p = 0.036$)	**Unadjusted** $R^2 = 0.002$	**Adjusted** $R^2 = 0.124$ ($p = 0.009$)	**Unadjusted** $R^2 = 0.007$	**Adjusted** $R^2 = 0.053$ ($p = 0.232$)	**Unadjusted** $R^2 = 0.014$	**Adjusted** $R^2 = 0.035$ ($p = 0.455$)	**Unadjusted** $R^2 = 0.002$	**Adjusted** $R^2 = 0.022$ ($p = 0.684$)	**Unadjusted** $R^2 = 0.021$	**Adjusted** $R^2 = 0.059$ ($p = 0.183$)
Cam size	b-value	−0.101	−0.113	−0.030	−0.045	−0.092	−0.109	−0.124	−0.136	−0.076	−0.093	−0.134	−0.145
	95%CI	(−0.233, 0.031)	(−0.243, 0.017)	(−0.171, 0.111)	(−0.180, 0.091)	(−0.306, 0.122)	(−0.323, 0.105)	(−0.324, 0.076)	(−0.339, 0.066)	(−0.421, 0.269)	(−0.443, 0.258)	(−0.311, 0.042)	(−0.322, 0.033)
	P value	$p = 0.131$	$p = 0.087$	$p = 0.677$	$p = 0.514$	$p = 0.397$	$p = 0.315$	$p = 0.221$	$p = 0.185$	$p = 0.664$	$p = 0.601$	$p = 0.134$	$p = 0.109$

Note: R^2 indicates pseudo R^2 values.Abbreviations: HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool 33; ADL = activities of daily living; PA = participation in physical activity; and QOL = quality of life. Sample size variations: $n^a = 107$ (unless otherwise indicated), $n^b = 97$, and $n^c = 106$.

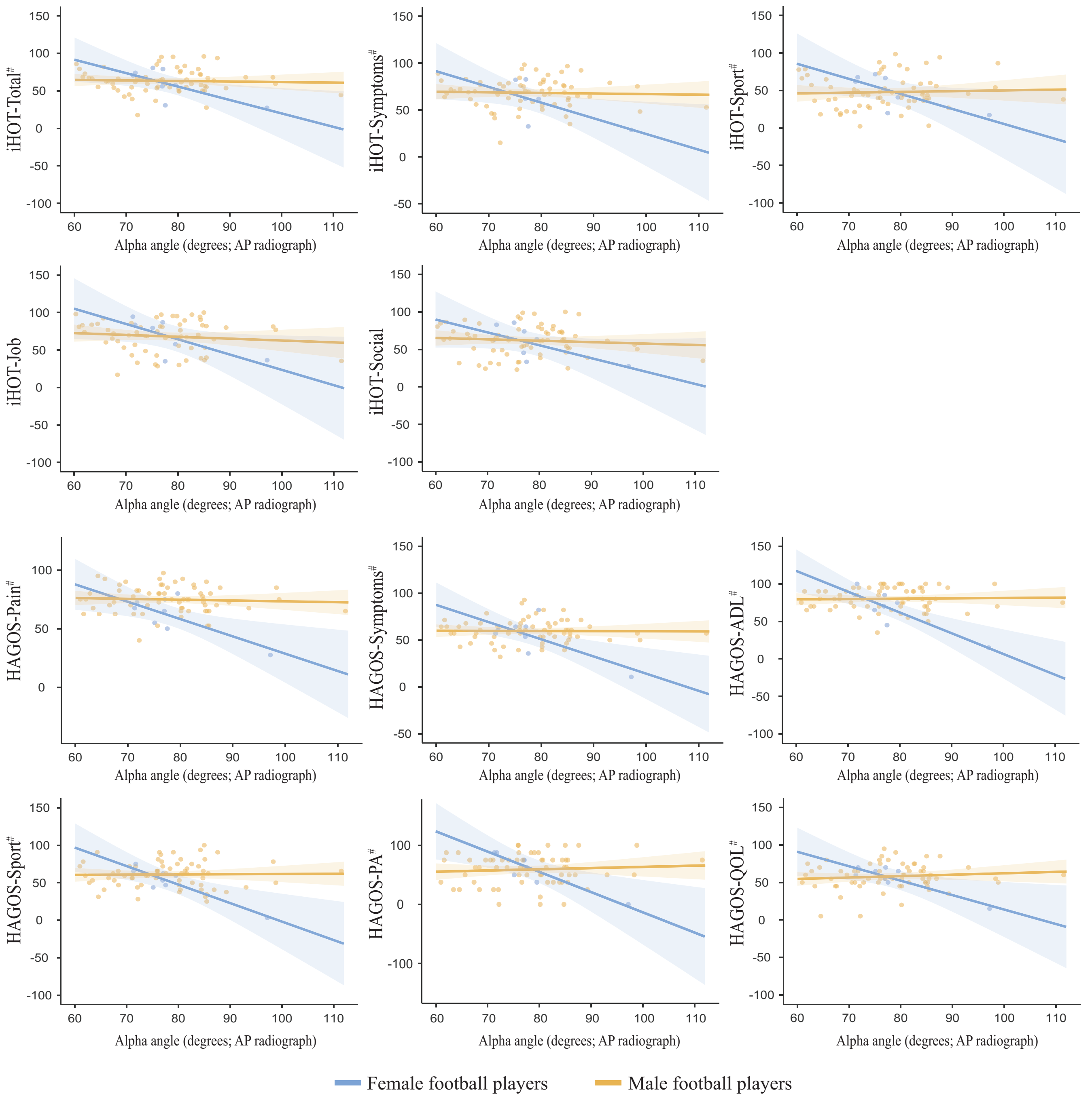
B2. Relationship between cam morphology size (anteroposterior pelvis radiograph) and iHOT-33 and HAGOS scores

A) iHOT−33											
N=77[a]		iHOT-Total		iHOT-Symptoms		iHOT-Sport		iHOT-Job[b]		iHOT-Social[c]	
Model		**Unadjusted** $R^2 = 0.002$	**Adjusted** $R^2 = 0.007$ ($p = 0.974$)	**Unadjusted** $R^2 = 0.002$	**Adjusted** $R^2 = 0.015$ ($p = 0.898$)	**Unadjusted** $R^2 = 0.003$	**Adjusted** $R^2 = 0.023$ ($p = 0.803$)	**Unadjusted** $R^2 = 0.020$	**Adjusted** $R^2 = 0.023$ ($p = 0.830$)	**Unadjusted** $R^2 = 0.016$	**Adjusted** $R^2 = 0.035$ ($p = 0.635$)
Cam size	b-value 95%CI P value	−0.050 (−0.309, 0.208) $p = 0.698$	−0.049 (−0.316, 0.218) $p = 0.714$	−0.048 (−0.314, 0.218) $p = 0.721$	−0.038 (−0.312, 0.235) $p = 0.781$	0.078 (−0.277, 0.434) $p = 0.662$	0.058 (−0.306, 0.422) $p = 0.752$	−0.219 (−0.590, 0.153) $p = 0.244$	−0.227 (−0.615, 0.160) $p = 0.245$	−0.182 (−0.511, 0.148) $p = 0.275$	−0.159 (−0.498, 0.180) $p = 0.352$

B) HAGOS													
N=77[d]		HAGOS-Symptoms		HAGOS-Pain		HAGOS-ADL		HAGOS-Sport		HAGOS-PA[e]		HAGOS-QOL	
Model		**Unadjusted** $R^2 < 0.001$	**Adjusted** $R^2 = 0.027$ ($p = 0.753$)	**Unadjusted** $R^2 = 0.005$	**Adjusted** $R^2 = 0.078$ ($p = 0.231$)	**Unadjusted** $R^2 = 0.003$	**Adjusted** $R^2 = 0.019$ ($p = 0.856$)	**Unadjusted** $R^2 < 0.001$	**Adjusted** $R^2 = 0.006$ ($p = 0.982$)	**Unadjusted** $R^2 = 0.006$	**Adjusted** $R^2 = 0.022$ ($p = 0.818$)	**Unadjusted** $R^2 = 0.008$	**Adjusted** $R^2 = 0.020$ ($p = 0.848$)
Cam size	b-value 95%CI P value	−0.024 (−0.221, 0.174) $p = 0.812$	−0.006 (−0.208, 0.195) $p = 0.950$	−0.061 (−0.269, 0.147) $p = 0.558$	−0.061 (−0.268, 0.145) $p = 0.555$	0.084 (−0.261, 0.430) $p = 0.628$	0.083 (−0.271, 0.438) $p = 0.640$	0.028 (−0.261, 0.318) $p = 0.845$	0.025 (−0.273, 0.324) $p = 0.866$	0.170 (−0.340, 0.679) $p = 0.509$	0.169 (−0.357, 0.696) $p = 0.523$	0.108 (−0.172, 0.388) $p = 0.443$	0.124 (−0.163, 0.412) $p = 0.391$

Note: R^2 indicates pseudo R^2 values. Abbreviations: HAGOS =Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool 33; ADL = activities of daily living; PA = participation in physical activity; QOL = quality of life; and 95%CI = 95% confidence interval. Sample size variations: $n^a = 74$ (unless otherwise indicated); $n^b = 68$; $n^c = 75$; $n^d = 73$ (unless otherwise indicated); and $n^e = 72$.

APPENDIX C



Sex-by-alpha angle (sex*alpha angle) interaction effects for linear models when alpha angle was measured using the anteroposterior pelvis (AP) radiograph. #denotes linear models with significant sex*alpha angle interaction term ($p < 0.05$).

APPENDIX D

D1. Relationship between cam morphology size (Dunn 45° radiograph) and iHOT-33 and HAGOS scores in men only

A) iHOT−33											
N=101[a]		iHOT-Total		iHOT-Symptoms		iHOT-Sport		iHOT-Job[b]		iHOT-Social	
Model		Unadjusted $R^2 = 0.045$	Adjusted $R^2 = 0.114$ ($p = 0.010$)	Unadjusted $R^2 = 0.042$	Adjusted $R^2 = 0.114$ ($p = 0.010$)	Unadjusted $R^2 = 0.002$	Adjusted $R^2 = 0.101$ ($p = 0.018$)	Unadjusted $R^2 = 0.047$	Adjusted $R^2 = 0.084$ ($p = 0.057$)	Unadjusted $R^2 = 0.071$	Adjusted $R^2 = 0.116$ ($p = 0.007$)
Cam size	b-value 95%CI P value	−0.317 (−0.612, −0.023) $p = 0.035$	−0.339 (−0.627, −0.052) $p = 0.021$	−0.305 (−0.601, −0.009) $p = 0.044$	−0.325 (−0.614, −0.037) $p = 0.027$	−0.090 (−0.478, 0.298) $p = 0.647$	−0.121 (−0.493, 0.252) $p = 0.523$	−0.424 (−0.829, −0.018) $p = 0.041$	−0.448 (−0.852, −0.044) $p = 0.030$	−0.500 (−0.867, −0.133) $p = 0.008$	−0.518 (−0.880, −0.155) $p = 0.006$

B) HAGOS													
N=101[a]		HAGOS-Symptoms		HAGOS-Pain		HAGOS-ADL		HAGOS-Sport		HAGOS-PA[c]		HAGOS-QOL	
Model		Unadjusted $R^2 = 0.022$	Adjusted $R^2 = 0.064$ ($p = 0.098$)	Unadjusted $R^2 = 0.004$	Adjusted $R^2 = 0.118$ ($p = 0.008$)	Unadjusted $R^2 = 0.005$	Adjusted $R^2 = 0.046$ ($p = 0.213$)	Unadjusted $R^2 = 0.010$	Adjusted $R^2 = 0.030$ ($p = 0.409$)	Unadjusted $R^2 < 0.001$	Adjusted $R^2 = 0.020$ ($p = 0.594$)	Unadjusted $R^2 = 0.018$	Adjusted $R^2 = 0.054$ ($p = 0.153$)
Cam size	b-value 95%CI P value	−0.155 (−0.366, 0.056) $p = 0.148$	−0.155 (−0.364, 0.054) $p = 0.144$	−0.069 (−0.283, 0.144) $p = 0.521$	0.069 (−0.272, 0.135) $p = 0.503$	−0.092 (−0.354, 0.169) $p = 0.485$	−0.095 (−0.355, 0.164) $p = 0.468$	−0.151 (−0.459, 0.156) $p = 0.331$	−0.154 (−0.462, 0.155) $p = 0.325$	−0.049 (−0.512, 0.414) $p = 0.834$	−0.075 (−0.540, 0.390) $p = 0.750$	−0.193 (−0.485, 0.099) $p = 0.192$	−0.202 (−0.492, 0.088) $p = 0.169$

Note: R^2 indicates pseudo R^2 values. Abbreviations: HAGOS =Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool 33; ADL = activities of daily living; PA = participation in physical activity; and QOL = quality of life. Sample size variations: $n^a = 98$ (unless otherwise indicated), $n^b = 89$, and $n^c = 97$.

D2. Relationship between cam morphology size (AP radiograph) and iHOT-33 and HAGOS scores in men only

A) iHOT−33

N=69[a]		iHOT-Total		iHOT-Symptoms		iHOT-Sport		iHOT-Job[b]		iHOT-Social	
Model		**Unadjusted** $R^2 = 0.002$	**Adjusted** $R^2 = 0.007$ ($p = 0.924$)	**Unadjusted** $R^2 = 0.003$	**Adjusted** $R^2 = 0.010$ ($p = 0.889$)	**Unadjusted** $R^2 = 0.004$	**Adjusted** $R^2 = 0.028$ ($p = 0.609$)	**Unadjusted** $R^2 = 0.011$	**Adjusted** $R^2 = 0.015$ ($p = 0.840$)	**Unadjusted** $R^2 = 0.010$	**Adjusted** $R^2 = 0.021$ ($p = 0.715$)
Cam size	b-value	−0.078	−0.084	−0.088	−0.074	0.142	0.083	−0.232	−0.225	−0.212	−0.198
	95%CI	(−0.476, 0.320)	(−0.493, 0.325)	(−0.493, 0.317)	(−0.490, 0.342)	(−0.416, 0.700)	(−0.486, 0.651)	(−0.804, −0.340)	(−0.846, 0.335)	(−0.725, 0.300)	(−0.723, 0.328)
	P value	$p = 0.697$	$p = 0.683$	$p = 0.667$	$p = 0.723$	$p = 0.613$	$p = 0.772$	$p = 0.420$	$p = 0.390$	$p = 0.411$	$p = 0.455$

B) HAGOS

N=69[c]		HAGOS-Symptoms		HAGOS-Pain		HAGOS-ADL		HAGOS-Sport		HAGOS-PA[d]		HAGOS-QOL	
Model		**Unadjusted** $R^2 = 0.001$	**Adjusted** $R^2 = 0.018$ ($p = 0.765$)	**Unadjusted** $R^2 = 0.006$	**Adjusted** $R^2 = 0.033$ ($p = 0.555$)	**Unadjusted** $R^2 < 0.001$	**Adjusted** $R^2 = 0.015$ ($p = 0.815$)	**Unadjusted** $R^2 < 0.001$	**Adjusted** $R^2 = 0.007$ ($p = 0.936$)	**Unadjusted** $R^2 = 0.007$	**Adjusted** $R^2 = 0.016$ ($p = 0.810$)	**Unadjusted** $R^2 = 0.009$	Adjusted $R^2 = 0.014$ ($p = 0.831$)
Cam size	b-value	−0.049	−0.027	−0.096	−0.071	0.026	0.049	0.018	0.035	0.228	0.220	0.170	0.186
	95%CI	(−0.370, 0.272)	(−0.354, 0.301)	(−0.396, 0.204)	(−0.375, 0.234)	(−0.369, 0.421)	(−0.354, 0.452)	(−0.440, 0.475)	(−0.434, 0.503)	(0.464, 0.919)	(−0.494, 0.934)	(−0.286, 0.626)	(−0.282, 0.653)
	P value	$p = 0.762$	$p = 0.871$	$p = 0.524$	$p = 0.645$	$p = 0.896$	$p = 0.809$	$p = 0.938$	$p = 0.883$	$p = 0.513$	$p = 0.540$	$p = 0.458$	$p = 0.430$

Note: R^2 indicates pseudo R^2 values. Abbreviations: HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool 33; ADL = activities of daily living; PA = participation in physical activity; QOL = quality of life; and 95%CI = 95% confidence interval. Sample size variations: $n^a = 67$ (unless otherwise indicated); $n^b = 61$; $n^c = 66$ (unless otherwise indicated); and $n^d = 65$.