

Postoperative Alpha Angle and Patient-Reported Outcomes After Hip Arthroscopy for Cam-Type Femoroacetabular Impingement Syndrome: Associations Across Radiographic Views

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Background: Cam-type femoroacetabular impingement syndrome (FAIS) is characterized by a nonspherical femoral head, routinely corrected via arthroscopic cam resection. Although postoperative radiographic measurements are widely used to assess resection quality, whether these objective structural metrics translate into improved patient-reported outcomes (PROs) remains unclear.

Purpose: To determine whether postoperative alpha angle is associated with PROs following arthroscopic surgery for cam-type FAIS.

Methods: This retrospective case series included 95 patients undergoing hip arthroscopy for FAIS. Alpha angles were measured on anteroposterior (AP), 45° Dunn, and frog-leg lateral views. PROs (iHOT-33, NAHS, HOS-SP, HOS-ADL) were collected preoperatively and at two-year follow-up. Postoperative alpha angle was analyzed continuously and categorically (<55° vs ≥55°). Bivariate correlations were adjusted using the Benjamini-Hochberg False Discovery Rate (FDR). Nominally significant associations were evaluated in multivariable linear regression adjusting for baseline PROs, preoperative alpha angle, age, sex, and BMI.

Results: Postoperative alpha angles decreased across all views ($p < 0.001$, <55° achieved in 75-82%). All PROs improved significantly at two-year follow-up ($p < 0.001$). Bivariate analyses showed weak-to-fair correlations between alpha angles on 45° Dunn and frog-leg views and selected PROs, but none on AP views. After adjustment, no bivariate correlations remained statistically significant (45° Dunn - NAHS was borderline, $FDRp = 0.050$). In multivariable analyses, higher 45° Dunn alpha angle remained associated with lower NAHS ($\beta = -0.483$, $p = 0.037$) and HOS-ADL ($\beta = -0.471$, $p = 0.037$). Frog-leg associations did not persist after adjustment, and categorical analyses were not significant.

Conclusion: Postoperative alpha angle showed weak-to-fair, unadjusted associations with selected two-year PROs, with the most consistent findings observed on 45° Dunn radiographs. These findings highlight the importance of radiographic projection when interpreting postoperative alpha-angle measurements and support considering alpha angle alongside clinical and patient-level factors rather than as an isolated indicator of outcome.

What this study adds: This study identified view-specific associations between postoperative alpha angle and selected PROs, with the most consistent associations observed on 45° Dunn radiographs.

How this study might affect research, practice or policy: Postoperative alpha angle should be interpreted in the context of the radiographic projection used and alongside other clinical and patient-level factors when evaluating postoperative outcomes.

Study Design: Retrospective case series

Level of Evidence: Level IV

Keywords: Hip arthroscopy; Alpha angle; Surgical outcomes; Patient-reported outcomes; FAIS; Cam morphology.

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Introduction

Cam-type femoroacetabular impingement syndrome (FAIS) is a common cause of hip pain, particularly in young and middle-aged adults, and is characterized by abnormal bony morphology at the femoral head-neck junction [1][2][3]. This morphology can cause repetitive contact between the femoral head and acetabulum, contributing to cartilage and labral injury, pain, functional limitation, and an increased risk of early osteoarthritis [2][4][5]. When non-surgical management fails to adequately control symptoms, arthroscopic cam resection is a widely used treatment aimed at restoring femoral head-neck morphology, addressing associated intra-articular pathology, and improving clinical outcomes [6][7][8]. Despite generally favorable outcomes following hip arthroscopy [9][10][11], some patients experience persistent symptoms, which may require revision surgery or conversion to total hip arthroplasty [12][13][14]. Therefore, identifying factors associated with postoperative outcomes remains clinically important.

Several preoperative factors have been associated with poorer outcomes following hip arthroscopy, including joint parameters such as larger cam deformity and more extensive cartilage damage [15][16][17][18][19], as well as patient-related factors, including older age, higher body mass index (BMI), and longer symptom duration prior to surgery [16][17][18][19]. Postoperatively, residual cam morphology is commonly assessed on plain radiographs using the alpha angle, which reflects asphericity at the femoral head-neck junction [20][21][22][23]. Alpha angle can be measured on several radiographic views, such as the AP pelvis, frog-leg lateral, 45° Dunn, 90° Dunn, and cross-table lateral views, to provide different profiles of the femoral head-neck junction [8][12][24]. Thresholds used to define cam morphology vary, although alpha angles >50–55° have commonly been used, with higher angles indicating more severe deformity [21][22][23][25]. Postoperative reduction below this threshold or a ≥20° decrease from baseline has been used to define adequate radiographic correction [20][22][26][27]. The alpha angle is a practical, objective measure of residual cam morphology, but its clinical relevance depends on whether postoperative measurements are associated with patient-reported outcomes.

Despite widespread use of radiographic parameters such as the alpha angle, evidence regarding their association with patient outcomes remains inconsistent [10][12][28][29]. A 2014 systematic review reported that restoring the alpha angle to <55° was associated with improved patient-reported outcomes (PROs) [22]; however, several subsequent studies did not demonstrate a consistent association [10][28][30][31][32]. In 2021, a systematic review similarly found no

consistent association between radiographic correction and clinical outcomes [12]. Comparisons across studies are limited by substantial methodological heterogeneity, including variation in radiographic projections, measurement thresholds, and outcome assessment [12]. Whether these associations are consistent across radiographic projections remains incompletely characterized.

Therefore, the purpose of this study was to examine whether postoperative alpha angle, analyzed continuously and using <55° as an operational threshold for cam morphology correction, was associated with PROs following arthroscopic surgery for cam-type FAIS. We hypothesized that lower postoperative alpha angles would be associated with better PROs at approximately two-year follow-up.

Materials and Methods

Patient Selection

This study involved a retrospective analysis of patients who underwent primary hip arthroscopy for FAIS between 2015 and 2019 by the principal investigator (I.W.), an orthopedic surgeon with fellowship training in Sports Medicine and over 10 years of experience, at the Queen Elizabeth II Health Sciences Center in Halifax, Nova Scotia. Ethical approval was obtained from the Nova Scotia Health Institutional Review Board (File #: 1020557). Due to the retrospective nature of the study, the requirement for informed consent to participate was waived by the Ethics Committee.

Inclusion criteria were preoperative radiographic signs of cam-type impingement (alpha angle >55° measured on the weight-bearing AP, frog-leg lateral, or 45° Dunn view) and postoperative plain radiographs in at least one view. Exclusion criteria were radiographic signs of pincer or mixed impingement (a lateral center-edge angle (LCEA) >40° or a positive crossover sign on the AP pelvic radiograph); history of femoral neck or proximal femur fracture; and treatment for concomitant hip pathology, including hip dysplasia (LCEA <20°), avascular necrosis, or severe pre-existing cartilage loss or damage. Additionally, due to the focus on PROs, patients were also excluded if they were receiving workers' compensation or long-term disability benefits, or if PRO data were insufficient (e.g., incomplete surveys or loss to follow-up).

Clinical and Radiographic Data Collection

Demographic and surgical information including age, sex, operative side, weight, height, BMI, date of surgery, and whether the patient underwent subsequent revision surgery were extracted from patient charts. Patients had plain radiographs (weight-bearing AP, frog-leg lateral, and/or 45° Dunn views) performed pre- and postoperatively. The alpha

angle was measured by determining a best-fit circle around the femoral head and measuring the angle between two lines drawn from its center: one to the midpoint of the femoral neck and the other to the point at which the femoral head contour deviates from the best-fit circle (**Figure 1**) [33][34]. For categorical analyses, postoperative alpha angles were

classified as $<55^\circ$ or $\geq 55^\circ$, with $<55^\circ$ used as an operational radiographic threshold for cam morphology correction. Alpha angle was measured on all three views, if available, by a single fellowship-trained orthopaedic sports medicine surgeon and subsequently confirmed by the principal investigator.

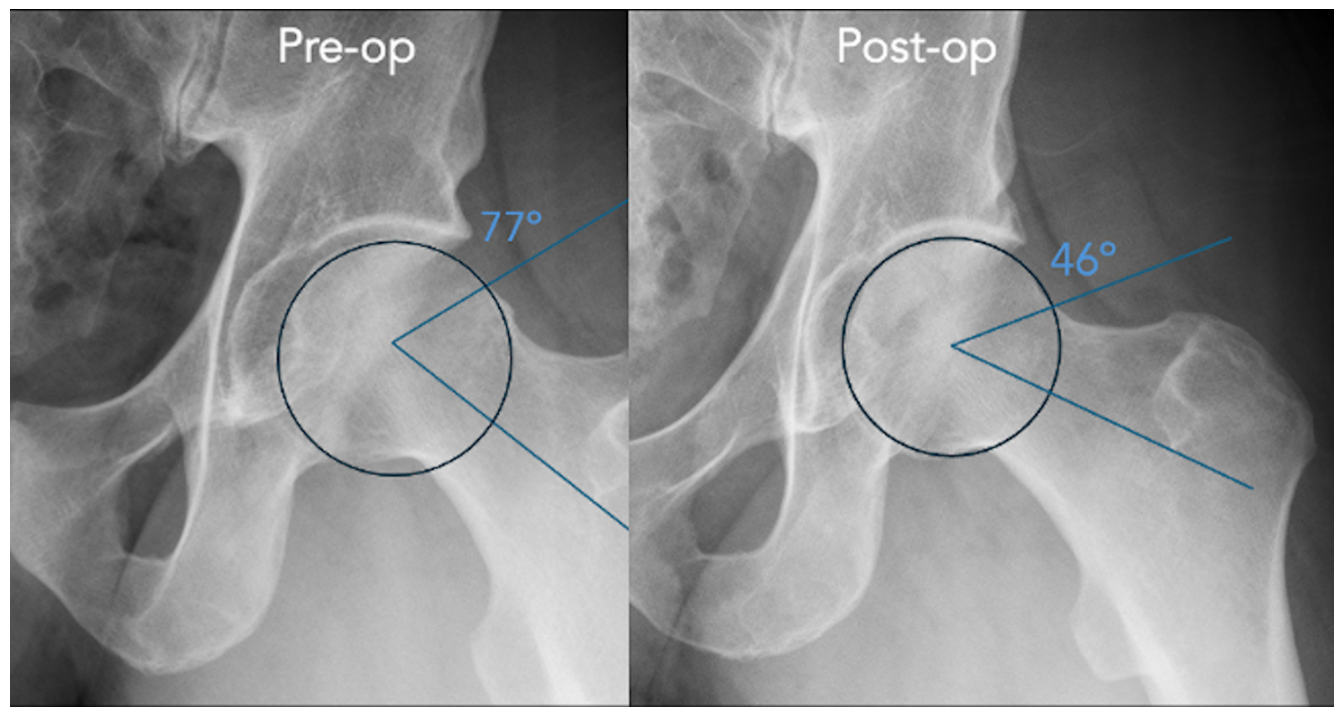


Figure 1. Example measurement of the alpha angle on preoperative and postoperative radiographs in the 45° Dunn view.

Patient-Reported Outcomes

PROs were collected using validated, self-report instruments widely used in hip arthroscopy research: the 33-item International Hip Outcome Tool (iHOT-33), Non-Arthritic Hip Score (NAHS), and Hip Outcome Score Activities of Daily Living (HOS-ADL) or Sport Score (HOS-SP) [8][35][36]. The iHOT-33 consists of 33 items covering symptoms and function, sports and recreation, job-related concerns, and social and emotional well-being [37]. Responses are recorded on a visual analog scale and converted to a scale from 0 to 100, with the total score calculated as the average of all completed items [37]. The NAHS includes 20 questions assessing pain, mechanical symptoms, function, and activity limitations, and uses a scoring system from 0 to 100 [38]. The HOS-ADL and HOS-SP scales contain 17 items and 9 items, respectively. Across all instruments, higher scores indicate better PROs [37]. These instruments were selected based on their established measurement properties following hip arthroscopy [35][38][39][40][41][42]. Patients completed PROs preoperatively and at annual follow-up visits. Two-year follow-up was defined as the primary target time point for PRO assessment. When 2-year data were unavailable, 3-year

follow-up data were used to capture short-term postoperative outcomes.

Statistical Analysis

Statistical analyses were conducted using RStudio (version 2024.12.0+467; Posit PBC, Boston, MA). A two-tailed significance (alpha) level of 0.05 was used for all tests. Descriptive statistics were used to summarize the study population. Continuous variables (age, BMI) were reported as mean $\pm$ standard deviation (SD), and categorical variables (sex, surgical side) as frequencies and percentages.

Pre- and postoperative alpha angles and PROs were compared using either paired t-tests or Wilcoxon signed-rank tests, depending on the results of the Shapiro-Wilk test for normality. Mean follow-up time for each PRO was calculated and reported as mean $\pm$ SD.

Bivariate correlation analyses were performed to assess the direction and strength of associations between postoperative alpha angles and PROs. For continuous postoperative alpha angles and PROs, Pearson's product-moment correlation or Spearman's rank correlation was used, depending on the normality of the data. Associations between continuous

PROs and the postoperative alpha angle category ($<55^\circ$ vs $\geq 55^\circ$) were assessed using point-biserial correlation [43][44]. Correlations were classified by absolute value as weak (<0.3), fair (0.3 - 0.49), moderate (0.5 - 0.69), or strong (>0.7) [45][46][47]. To account for multiple comparisons across radiographic views and outcome measures, p-values were adjusted using the Benjamini-Hochberg False Discovery Rate (FDR) procedure. Adjusted $p < 0.05$ was considered statistically significant. All correlation coefficients are reported with 95% confidence intervals (95% CIs).

To further evaluate associations identified in the bivariate analyses, multivariable linear regression models were performed with postoperative PRO scores as the dependent variables and postoperative alpha angle as the primary independent variable. Regression analyses were restricted to radiographic-PRO associations that demonstrated nominal statistical significance in the bivariate analyses ($p < 0.05$). Each multivariable linear regression model was adjusted for the corresponding preoperative PRO score, preoperative

alpha angle measured on the same radiographic view, age, sex, and BMI. These covariates were selected to account for baseline outcome status, preoperative radiographic morphology, and relevant patient characteristics. Multicollinearity among predictors was assessed using variance inflation factors (VIFs), with VIF values <2.5 considered acceptable. Unstandardized regression coefficients (β), 95% confidence intervals (95% CIs), and p-values were reported.

Results

Patient Selection and Baseline Characteristics

Of 695 patients who underwent hip arthroscopy for FAIS between 2015 and 2019, 95 participants were included in the study (Figure 2).

Participant demographic and baseline characteristics are summarized in Table 1.

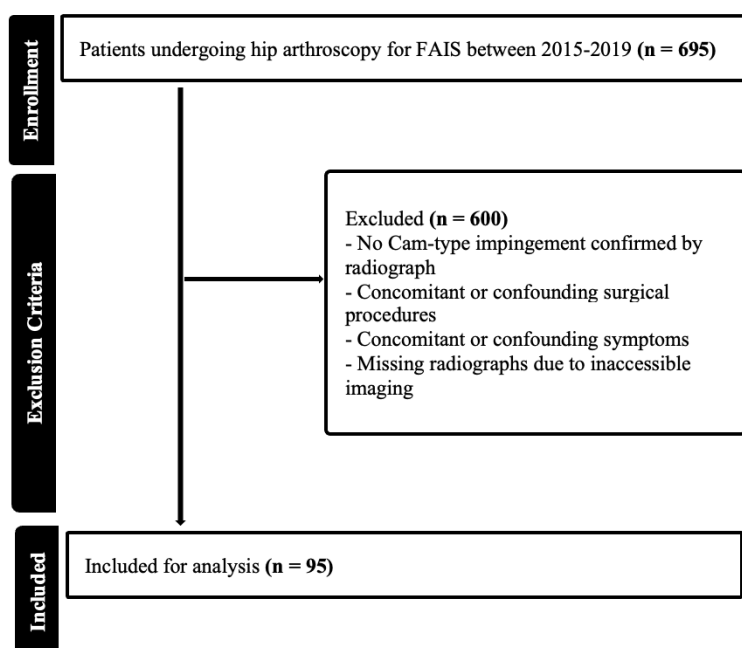


Figure 2. Participant Flow Diagram.

Table 1. Patient demographics and baseline characteristics (n=95).

		Baseline Value
Age, years; mean (SD)		34.45 (11.46)
Body Mass Index, kg/m ² ; mean (SD)		25.27 (4.88)
Sex		
	Female, n (%)	58 (61%)
	Male, n (%)	37 (39%)
Operative Side		
	Left, n (%)	39 (41%)
	Right, n (%)	56 (59%)

SD = standard deviation.

Pre- to Postoperative Changes

Postoperative radiographs were available for 95 (100%) patients in the AP view, 89 (93.7%) in the frog-leg lateral view, and 54 (56.8%) in the 45° Dunn view. Paired preoperative and postoperative radiographs were available for 95 (100%), 86 (90.5%), and 47 (49.5%) patients, respectively, and were used for the pre- to postoperative comparisons in Table 2. Alpha

angles decreased significantly from preoperative to postoperative assessment across all three radiographic views ($p < 0.001$). Mean decreases in alpha angle were 13.7° in the AP view, 10.4° in the frog-leg lateral view, and 19.2° in the 45° Dunn view (**Table 2**). Mean PRO follow-up time was 2.08 ± 0.27 years. All PROs improved significantly from pre- to postoperative assessment ($p < 0.001$; **Table 2**).

Table 2. Pre- to postoperative changes in radiographic and patient-reported outcomes.

		n	Preoperative	Postoperative	p-value
Radiographic Outcomes					
	AP view alpha angle	95	64.93 $\pm$ 18.99	51.28 $\pm$ 13.73	<0.001*
	Frog-leg Lateral view alpha angle	86	57.09 $\pm$ 12.76	46.67 $\pm$ 8.76	<0.001*
	45° Dunn view alpha angle	47	68.15 $\pm$ 7.90	48.98 $\pm$ 9.34	<0.001*
Patient-Reported Outcomes					
	iHOT-33 score	75	42.74 $\pm$ 19.08	79.27 $\pm$ 21.51	<0.001*
	NAHS score	47	51.40 $\pm$ 15.25	70.85 $\pm$ 10.59	<0.001*
	HOS-ADL score	52	70.62 $\pm$ 16.60	92.45 $\pm$ 10.87	<0.001*
	HOS-SP score	52	48.72 $\pm$ 21.44	86.93 $\pm$ 19.26	<0.001*

Note: Asterisks (*) indicate statistical analysis using Wilcoxon signed-rank tests. P-values represent pre- to postoperative differences, and bolded p-values indicate statistical significance ($p < 0.05$). Abbreviations: AP = anteroposterior. iHOT-33 = 33-item International Hip Outcome Tool. HOS-ADL = Hip Outcome Score, Activities of Daily Living. HOS-SP = Hip Outcome Score, Sports. NAHS = Non-Arthritic Hip Score. n = number of patients with paired preoperative and postoperative data available for each outcome.

Postoperative Alpha Angle and Revision Surgery

Postoperative alpha angles $< 55^\circ$ were observed in 75% (n=71/95) of patients on AP views, 82% (73/89) on frog-leg

lateral views, and 76% (41/54) on 45° Dunn views. One patient (1.1%, 1/95) underwent revision surgery and had a postoperative alpha angle $\geq 55^\circ$ on all three radiographic views.

Correlation Analysis

Continuous postoperative alpha angles and PROs violated the assumption of normality; therefore, Spearman's rank correlations were used to assess associations between continuous alpha angles and PROs. Associations between PROs and the postoperative alpha angle category (<55° vs ≥55°) were assessed using point-biserial correlations.

In bivariate analyses, postoperative iHOT-33 scores were not significantly associated with postoperative alpha angle, analyzed either continuously or postoperative alpha angle category on any radiographic view (**Table 3**). Higher postoperative NAHS scores showed a weak correlation with lower postoperative frog-leg lateral alpha angle ($r=-0.236$, $p=0.029$) and a fair correlation with lower postoperative 45° Dunn alpha angle ($r=-0.454$, $p=0.001$). The postoperative 45°

Dunn alpha angle category also showed a fair correlation with NAHS ($r=0.412$, $p=0.003$). Higher postoperative HOS-ADL scores showed a fair correlation with lower postoperative 45° Dunn alpha angle ($r=-0.387$, $p=0.006$) and with the postoperative 45° Dunn alpha angle category ($r=0.371$, $p=0.009$). Higher postoperative HOS-SP scores showed a weak correlation with lower postoperative frog-leg lateral alpha angle ($r=-0.265$, $p=0.016$) and with the postoperative frog-leg lateral alpha angle category ($r=0.240$, $p=0.029$). After adjustment for multiple comparisons using the Benjamini-Hochberg false discovery rate, none of the associations clearly remained statistically significant at an FDR-adjusted p -value <0.05. The strongest association was between the 45° Dunn alpha angle and NAHS (FDR $p = 0.050$), while the corresponding categorical analysis was not significant after FDR adjustment (FDR $p = 0.078$) (**Table 3**).

Table 3. Correlation coefficients between radiographic and patient-reported outcomes.

Postoperative Patient-Reported Outcome	Postoperative Radiographic Outcome	Correlation Coefficient r (95% CI)	p -value	FDR p -value
iHOT-33 score	AP alpha angle	0.057(-0.17 to 0.27)	0.595	0.713
	Frog-leg alpha angle	-0.118(-0.34 to 0.12)	0.277	0.504
	45° Dunn alpha angle	-0.262(-0.52 to 0.02)	0.066	0.287
	AP alpha angle <55° vs ≥55°	-0.080(-0.28 to 0.13)	0.453	0.572
	Frog-leg alpha angle <55° vs ≥55°	0.145(-0.06 to 0.37)	0.182	0.437
	45° Dunn alpha angle <55° vs ≥55°	0.270(-0.07 to 0.56)	0.058	0.287
NAHS score	AP alpha angle	0.095(-0.11 to 0.29)	0.371	0.539
	Frog-leg alpha angle	-0.236(-0.45 to -0.01)	0.029	0.198
	45° Dunn alpha angle	-0.454(-0.65 to -0.20)	0.001	0.050
	AP alpha angle <55° vs ≥55°	-0.104(-0.26 to 0.08)	0.329	0.535
	Frog-leg alpha angle <55° vs ≥55°	0.180(-0.05 to 0.41)	0.097	0.360
	45° Dunn alpha angle <55° vs ≥55°	0.412(0.12 to 0.66)	0.003	0.078
HOS-ADL score	AP alpha angle	0.045(-0.16 to 0.25)	0.675	0.748
	Frog-leg alpha angle	-0.171(-0.37 to 0.05)	0.116	0.371
	45° Dunn alpha angle	-0.387(-0.59 to -0.14)	0.006	0.097
	AP alpha angle <55° vs ≥55°	-0.118(-0.25 to 0.04)	0.266	0.504
	Frog-leg alpha angle <55° vs ≥55°	0.146(-0.09 to 0.41)	0.180	0.437
	45° Dunn alpha angle <55° vs ≥55°	0.371(0.03 to 0.63)	0.009	0.104

Postoperative Patient-Reported Outcome	Postoperative Radiographic Outcome	Correlation Coefficient r(95% CI)	p-value	FDR p-value
HOS-SP score	AP alpha angle	0.092(-0.12 to 0.30)	0.395	0.542
	Frog-leg alpha angle	-0.265(-0.46 to -0.05)	0.016	0.150
	45° Dunn alpha angle	-0.271(-0.53 to 0.01)	0.063	0.287
	AP alpha angle <55° vs ≥55°	-0.117(-0.27 to 0.07)	0.281	0.504
	Frog-leg alpha angle <55° vs ≥55°	0.240(-0.02 to 0.47)	0.029	0.198
	45° Dunn alpha angle <55° vs ≥55°	0.235(-0.11 to 0.51)	0.107	0.368

Abbreviations: AP = anteroposterior. iHOT-33 = 33-item International Hip Outcome Tool. HOS-ADL = Hip Outcome Score, Activities of Daily Living. HOS-SP = Hip Outcome Score, Sports. NAHS = Non-Arthritic Hip Score. FDR = False Discovery Rate. Categorical analyses used a postoperative alpha angle threshold of <55° versus ≥55°. Bolded p-values indicate statistical significance (p<0.05).

Multivariable Regression Analysis

In multivariable linear regression analyses, higher postoperative alpha angle on the 45° Dunn view was associated with lower postoperative NAHS after adjustment for preoperative NAHS, preoperative alpha angle, age, sex, and BMI ($\beta = -0.483$, 95% CI -0.934 to -0.032; $p = 0.037$). Similarly, higher postoperative 45° Dunn alpha angle was

associated with lower postoperative HOS-ADL ($\beta = -0.471$, 95% CI -0.910 to -0.033; $p = 0.037$) after adjustment for the same covariates. In contrast, postoperative alpha angle measured on the frog-leg view was not associated with postoperative NAHS or HOS-SP after adjustment. Categorical analyses using the 55° threshold also demonstrated no significant adjusted associations for 45° Dunn alpha angle and NAHS or frog-leg alpha angle and HOS-SP (**Table 4**).

Table 4. Multivariable associations between postoperative alpha angle and patient-reported outcomes.

Postoperative PRO	Radiographic View	Predictor	Beta (β)	95% CI Lower	95% CI Upper	p-value
NAHS	45° Dunn	Continuous	-0.483	-0.934	-0.032	0.037
NAHS	Frog-leg	Continuous	-0.007	-0.327	0.313	0.964
HOS-ADL	45° Dunn	Continuous	-0.471	-0.910	-0.033	0.037
HOS-SP	Frog-leg	Continuous	-0.154	-0.885	0.577	0.672
NAHS	45° Dunn	<55° vs ≥55°	4.830	-8.040	17.699	0.438
HOS-SP	Frog-leg	<55° vs ≥55°	-2.793	-19.283	13.698	0.734

Abbreviations: NAHS = Non-Arthritic Hip Score. HOS-ADL = Hip Outcome Score, Activities of Daily Living. HOS-SP = Hip Outcome Score, Sports. CI: Confidence Interval. Categorical analyses used a postoperative alpha angle threshold of <55° versus ≥55°. Bolded p-values indicate statistical significance (p<0.05).

Discussion

The principal finding of this study was that postoperative alpha angle was associated with selected PROs, although the observed associations were weak to fair and differed across radiographic projections. On 45° Dunn radiographs, higher postoperative alpha angles were associated with lower postoperative NAHS and HOS-ADL scores after adjustment for preoperative PRO score, preoperative alpha angle, age, sex, and BMI. In contrast, the nominal associations observed

on frog-leg lateral radiographs in the unadjusted analyses did not persist after adjustment, and no significant associations were observed on AP radiographs. Analyses using <55° as an operational threshold for cam morphology correction also did not demonstrate significant adjusted associations. Overall, these findings suggest that the relationship between postoperative alpha angle and patient-reported outcomes was modest and varied according to radiographic projection and analytic approach, with the most consistent evidence observed for continuous alpha angle measured on the 45° Dunn view.

This projection-specific pattern may reflect differences in the regions of the femoral head-neck junction visualized by each radiographic view [8][12][24]. Although there is no standardized imaging protocol for assessing cam morphology [12][20][35][48], lateral and oblique projections are often preferred because they best profile the regions where cam deformity most often occurs [6][49][50][51][52][53]. Specifically, the 45° Dunn view profiles the anterosuperior head-neck junction [6][33][51][52], and the frog-leg lateral view profiles the anterolateral region [49][51][53], providing complementary visualization of the femoral head-neck junction. Anatomical overlap on AP radiographs may obscure portions of the femoral head-neck contour [51][53]. These findings highlight the importance of radiographic projection when interpreting postoperative alpha-angle measurements.

Previous studies investigating postoperative radiographic morphology and PROs have reported inconsistent findings, with some reporting significant associations [22][23][54][55][56] and others reporting none [30][31][32][57][58]. Differences in radiographic technique [12] and measurement thresholds [12] may contribute to this variability. Postoperative outcomes may also reflect factors beyond cam morphology correction, including age [11][15][17][16][18][54], BMI [17][54][59], sex [16][17], preoperative symptom duration [18][19], preoperative PROs [18][59], coexisting musculoskeletal diagnoses [16], and joint characteristics, including decreased joint space and osteoarthritis [11][16][17][18], hip morphology and cartilage defects [15][16][17][59][61]. These factors reinforce the importance of interpreting radiographic findings within the broader clinical context.

Postoperative alpha angle provides a radiographic measure of cam morphology correction, but it should not be interpreted as a direct measure of clinical outcome. Its limited and projection-specific associations with PROs support its interpretation as one component of the postoperative assessment alongside clinical and patient-level factors.

Strengths and Limitations

The main strengths of this study include consistency in surgical expertise and technique, as all surgeries were performed by a single, fellowship trained, orthopaedic surgeon with over a decade of experience in hip arthroscopy. Additionally, multiple PRO instruments specifically validated for measuring outcomes after hip arthroscopy for FAIS were used [38][39][40][41].

This study also has several limitations. Its retrospective case-series design and relatively small sample size limit generalizability. Although multivariable analyses were performed to account for several measured baseline

characteristics, potentially relevant factors such as cartilage status, labral pathology, symptom duration, and other clinical characteristics were not included in the models; therefore, residual confounding cannot be excluded. In addition, the multivariable analyses were restricted to associations that demonstrated nominal statistical significance in the bivariate analyses and should therefore be interpreted as adjusted analyses of selected associations rather than confirmatory hypothesis tests. Imaging availability differed across radiographic projections, with frog-leg lateral and 45° Dunn imaging unavailable in a subset of patients. This is particularly relevant to the 45° Dunn analyses, where the largest observed associations were derived from a smaller subset of patients, potentially introducing bias and limiting precision and generalizability. Furthermore, formal inter- and intraobserver reliability testing was not conducted for the radiographic measurements in this study cohort. Although all measurements were performed by a single experienced investigator using a standardized protocol, the lack of cohort-specific reliability metrics remains a potential source of observer variability.

Finally, two-dimensional radiographs incompletely characterize the complex three-dimensional morphology of the femoral head-neck junction. Although advanced imaging modalities such as Magnetic Resonance Imaging (MRI) provide more comprehensive morphological assessment, they are resource intensive and are not routinely used for postoperative assessment in most clinical settings [52][62].

Conclusion

Postoperative alpha angle showed weak-to-fair, unadjusted associations with selected two-year PROs, with the most consistent findings observed on 45° Dunn radiographs. These findings highlight the importance of radiographic projection when interpreting postoperative alpha-angle measurements and support considering alpha angle alongside clinical and patient-level factors rather than as an isolated indicator of outcome. Further prospective studies using standardized multi-view imaging and appropriately adjusted multivariable analyses are needed to better define the relationship between postoperative radiographic morphology and patient-reported outcomes.

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Authors' Contributions

C.L. contributed to data curation and writing the original draft. *A.B.* led the writing—review and editing and contributed to methodology and project administration. *J.H.* contributed to formal analysis, visualization, and writing—review and editing. *F.L.* and *J.M.* contributed to project administration and writing—review and editing. *I.W.* contributed to conceptualization, methodology, resources, supervision, and writing—review and editing. All authors reviewed and approved the final manuscript.

Conflict of Interest

CL, AB, JH, FL and *JM* declare no conflicts of interest. *IW* reports relationships with Arthrex Inc, CONMED Corporation, DePuy Mitek, Smith & Nephew, and VALD, including consulting/advisory roles and speaking or lecture fees. *IW* reports a relationship with Bioventus LLC limited to speaking and lecture fees. *IW* also serves on the editorial boards of the American Journal of Sports Medicine, Arthroscopy, and The HIVE Musculoskeletal Journal, and is an associate editor for the Orthopaedic Journal of Sports Medicine. *IW* is a board or committee member for AANA, ISAKOS, and AAC.

Ethical Consideration and Consent to Participate

This study was conducted in accordance with the principles of Helsinki. Ethical approval was obtained from the Nova Scotia Health Institutional Review Board (File #: 1020557). Due to the retrospective nature of the study, the requirement for informed consent to participate was waived by the Ethics Committee.

Data Availability Statement

Restricted Due to Privacy/Ethics - The data supporting this study are not publicly available due to privacy and ethical restrictions but can be obtained from the corresponding author upon reasonable request, subject to institutional approval.

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