[Physical Therapy]

Impact of Femoroacetabular Impingement Morphology on Gait Assessment in Symptomatic Patients

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Background: Gait is abnormal in patients with femoroacetabular impingement (FAI). To date, studies have not correlated radiographic FAI morphology with gait abnormalities.

Hypothesis: Gait abnormalities in FAI patients will be associated with radiographic FAI morphology.

Study Design: Cross-sectional study.

Level of Evidence: Level 4.

Methods: Patients with symptomatic FAI (n = 20) underwent radiographic and gait analysis. Exclusion criteria included previous injuries or surgeries to the lower extremities or lumbar spine as well as bilateral symptomatic FAI. The alpha angle (AA) and center-edge angle (CEA) were measured on anteroposterior (AP) pelvis, Dunn lateral, and false-profile radiographs, and inter- and intraobserver variability was determined. Motion analysis techniques were used to obtain gait data including 3-dimensional kinematic and kinetic data. Descriptive analysis was performed using Spearman correlations for morphologic measurements. A stepwise regression model was used to examine the association of gait measures with AA and CEA.

Results: Intraobserver agreement for the AA and CEA was 0.92 (CI, 0.80-0.97) and 0.90 (CI, 0.76-0.96), while interobserver agreement for the angles was 0.96 (CI, 0.89-0.98) and 0.96 (CI, 0.90-0.98), respectively. Descriptive analysis suggested correlations between AA and peak external hip and knee external rotation moments, maximum ankle flexion angle, and ankle range of motion (range, -0.51 to 0.42; $P < 0.0001$). The CEA correlated with stride, peak external ankle eversion and inversion moments, peak external knee extension moment, and peak external hip flexion moment (range, -0.44 to 0.51; $P < 0.0001$). We found that gait variables accounted for a large amount of variation in AA (8 variables accounted for 87% variation) and in CEA (7 variables accounted for 82% variation).

Conclusion: Lower extremity gait parameters correlate highly with radiographic FAI morphology in symptomatic FAI patients.

Clinical Relevance: Gait abnormalities are present in FAI patients and may be a useful measure in outcome studies.

Keywords: femoroacetabular impingement; morphology; gait; alpha angle; center-edge angle

Symptomatic femoroacetabular impingement (FAI) is characterized by pathomorphology of the proximal femur and/or acetabulum, which may lead to chondrolabral injury, mechanical limitations, and pain.⁸ FAI subtypes include cam-type FAI, a bony prominence along the femoral head-neck

junction leading to reduced offset, and pincer-type FAI, marked by acetabular overcoverage of the femoral head. Additionally, there is mixed-type FAI, which is a combination of cam- and pincer-type FAI. The abnormal abutment between the proximal femur and acetabulum is thought to lead to chondrolabral

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Figure 1. Representative measurements of the alpha angle on Dunn view (left) and center-edge angle on anteroposterior (AP) view (right) on a pelvis radiograph of a 25-year-old man.

damage and, if left untreated, the repetitive microtrauma may be a significant risk factor for development of end-stage osteoarthritis (OA) of the hip.^{3,8}

Plain radiographs are the initial imaging modality used to evaluate and define FAI pathomorphology.²⁸ A number of different radiographic parameters have been described to identify cam and pincer deformities.^{13,15,20,23,24} Nötzli et al²³ described the alpha angle (AA) to measure femoral head asphericity, while the lateral center-edge angle (CEA) of Wiberg³⁰ is used to measure acetabular coverage of the femoral head and neck (Figure 1). Previous research has reported an association between the magnitude of the AA and labral or chondral damage as well as the development of osteoarthritis.^{7,10,22} Although these measurements are used to characterize the structural deformities of the proximal femur and acetabulum, they do not provide insight into dynamic impingement and functional deficits.

Motion analysis has been extensively used for dynamic assessment in degenerative musculoskeletal research. Recent literature has examined mechanical variations in functional activities and activities of daily living in FAI cohorts.^{4,9,12,14,16,26,27} Much of the prior research focusing on FAI biomechanics has evaluated pre- and postsurgical outcomes without examining the relationship between the morphology of the hip joint and kinematic and kinetic gait variables.

The purpose of this study was to determine the association of FAI morphology, as assessed by the AA and CEA, with gait patterns in symptomatic FAI patients. We hypothesize that increasing static radiographic parameters of FAI would be associated with preoperative kinematic and kinetic gait variables as reported in previous FAI gait literature.

METHODS

Patients

This study was approved by our institutional review board, and informed consent was obtained prior to patient participation, as

well as parental consent for patients <18 years of age. From 2011 to 2013, all consecutive symptomatic FAI patients of the senior author (S.J.N, a fellowship-trained orthopaedic surgeon) who had failed nonoperative treatment and were scheduled to undergo arthroscopic FAI hip arthroscopy surgery were asked to participate in gait analysis prior to surgery. Inclusion criteria included patients between 13 and 50 years of age; radiographic evidence of FAI (AA $\geq 50^\circ$ and/or CEA $\geq 20^\circ$); pain during flexion, adduction, and internal rotation (FADIR) physical examination maneuver⁸; and the ability to walk a quarter of a mile without discomfort. Exclusion criteria included presence of hip dysplasia (CEA $< 20^\circ$),²¹ prior ipsilateral and/or contralateral hip surgery, Tönnis grade >1 ,²⁹ and spinal or lower extremity pathology.

Twenty patients who met the inclusion and exclusion criteria agreed to enroll and were included in the study. All enrolled patients completed a preoperative questionnaire that included relevant demographic information and the validated hip-specific functional outcome scores of the Hip Outcome Score Activity of Daily Living (HOS-ADL) and Sports-Specific Subscales (HOS-SS).¹⁸

Radiographic Analysis

All patients had a standard series of hip radiographs in the supine position, including an anteroposterior (AP) pelvis view,²⁸ a false profile view,²⁸ and the oblique lateral (Dunn lateral) view.²⁸ All radiographs were performed with the coccyx positioned midline, approximately 1 cm above the pubic symphysis (neutral tilt), and the obturator foramina and the trochanters symmetric (neutral rotation).⁶ The AA and CEA were measured on plain radiographs using a digital picture archiving and communication system. Two fellowship-trained orthopaedic surgeons independently reviewed all patient radiographs and independently measured AA and CEA. Intra- and interobserver reliability were determined through intraclass correlation analysis. The AA is measured as the angle formed by the line from the center of the femoral head that bisects the femoral

Table 1. Patient demographic, radiographic, and questionnaire data

Variable	Mean Value	SD
Patients, n	20	NA
Age, y	31.5	±8.4
Range	17-46	NA
Sex, M:F, n	6:14	NA
Weight, kg	70.6	±18.2
Height, m	1.7	±0.1
BMI, kg/m ²	23.9	±4.8
Gait test time point, days ^a	9.4	±7.6
Range	1-22	NA
Alpha angle, deg	64.8	±9.2
Center-edge angle, deg	30.3	±5.6
HOS-ADL, %	68.0	±13.8
HOS-SS, %	46.0	±21.9

BMI, body mass index; HOS-ADL, Hip Outcome Score Activities of Daily Living subscale; HOS-SS, Hip Outcome Score Sport-Specific subscale; NA, not applicable.

^aNumber of days before surgery when the test was performed.

neck and the line from the center of the femoral head to the point where the femoral head loses sphericity (Figure 1).²³ AA is measured on all 3 radiographic views.²⁸ The CEA is measured as the angle formed by a vertical line through the center of the femoral head perpendicular to the pelvic horizontal reference line and a line from the center of the femoral head to the superolateral aspect of the acetabulum (Figure 1).³⁰ CEA is measured on AP radiographs.²⁸ The largest AA measurement was used given the variability of deformity on varying views depending on the 3-dimensional (3D) location of the cam deformity.

Gait Analysis

Preoperative gait evaluation was performed within 1 month of the patients' scheduled surgical date (Table 1). Data for each patient were collected during a single preoperative gait evaluation. Three-dimensional kinematic and kinetic data were obtained using previously published methods.^{1,2} A 12-optoelectronic camera system (Qualisys) recorded the 3D position of 28 passive retroreflective markers modified from the Helen Hayes marker set (Figure 2).¹¹ Markers were bilaterally placed on lower extremity bony landmarks and included: the

Figure 2. Anterior (left) and lateral (right) view of the modified Helen Hayes¹¹ passive retroreflective marker set. Bilateral marker placement included: most superior point of the iliac crest (1), anterior (2) and posterior (3) superior iliac spines, the greater trochanter (4), anterodistal thigh (5), lateral (6) and medial (7) knee joint line, tibial tuberosity (8), lateral (9) and medial (10) malleoli, lateral-most point on the calcaneus (11), and the second (12) and fifth (13) metatarsal. Markers are also placed on the L5/sacrum and on the right shoulder to denote sides (not pictured).

most superior point of the iliac crest (1); anterior (2) and posterior (3) superior iliac spines; the greater trochanter (4); anterodistal thigh (5); lateral (6) and medial (7) knee joint line; tibial tuberosity (8); lateral (9) and medial (10) malleoli; lateral-most point on the calcaneus (11); and the second (12) and fifth (13) metatarsal (Figure 2). A marker was also placed on the L5/sacrum and unilaterally on the right shoulder to denote sides. Spatiotemporal parameters were calculated at the hip, knee, and ankle. Calculations were based on the 3D positions of the markers. Anthropometric measures were employed to find the joint centers relative to marker placement.^{1,2,25} A multicomponent floor-embedded force plate (Bertec) measured ground reaction force (GRF) and location. External moments,

Table 2. Spearman correlations between alpha angle and kinematic and kinetic gait variables

Variable	Hip		Knee		Ankle		
	R Value	P Value	R Value	P Value	Variable	R Value	P Value
Kinematics, deg							
Minimum flexion	−0.129	0.200	−0.091	0.368	Minimum flexion	−0.140	0.164
Maximum flexion	−0.056	0.577	0.059	0.561	Maximum flexion	−0.413	<0.0001
ROM	−0.118	0.241	0.121	0.232	ROM	−0.512	<0.0001
Moments ^a							
Flexion	0.233	0.020	0.165	0.101	Dorsiflexion	0.245	0.014
Extension	0.147	0.145	−0.127	0.207	Plantar flexion	0.045	0.657
Adduction	0.004	0.965	0.169	0.092	Inversion	0.100	0.322
Abduction	−0.101	0.318	−0.012	0.907	Eversion	0.229	0.022
IR	−0.026	0.797	0.232	0.020	IR	−0.160	0.113
ER	0.371	0.0001	0.418	<0.0001	ER	−0.208	0.038

ER, external rotation; IR, internal rotation; ROM, range of motion. Bold faced *P* values represent statistically significant correlations after Bonferroni correction.

^a%Body weight * height.

calculated by inverse dynamics, were normalized to percent body weight times height (%BWH).¹⁹ Patients completed 15 trials per limb at 5 slow, 5 normal, and 5 fast self-selected speeds while wearing their own shoes. The data collected from the surgical side were averaged for each patients' normal speed. We examined the dynamic hip, knee, and ankle range of motion in the sagittal plane and peak external moments about the lower extremities.

Statistical Analysis

Interpatient comparisons were performed between morphologic measurements and gait variables on the surgical extremity. The intra- and interreliability of the AA and CEA were examined with the intraclass correlation coefficient (ICC). Thresholds according to Landis and Koch¹⁷ were used to interpret the data: <0.20, slight agreement; 0.21 to 0.40, fair agreement; 0.41 to 0.60, moderate agreement; 0.61 to 0.80, substantial agreement; and >0.80, almost perfect agreement.

Descriptive analysis was performed using means and standard deviations. Bivariate correlations were computed using nonparametric rank-based Spearman correlations. In addition to correlations, a multivariable stepwise regression was used to explain variability between both the AA and CEA measurements and gait variables in Statistical Analysis Systems (SAS) software (version 9.3; SAS Institute Inc). Age was centered at 30 years, body mass index (BMI) centered at 30 kg/m², and male sex was also eligible to enter in the stepwise model. The inclusion criterion was based on a *P* value of 0.05.

To estimate the appropriate sample size and power, 30 patients were needed to detect a correlation coefficient of 0.5 between AA and peak external hip with 80% power, assuming a type I error rate of 5%. Currently, we have 20 patients that result in a power of 60% to detect a correlation coefficient of 0.5. Power estimates were computed using nQuery Advisor 7.0 (Statistical Solutions).

We performed a sensitivity analysis to determine whether our findings were different after excluding 3 patients who presented with CEA < 25°.

RESULTS

The radiographic, demographic, and questionnaire summary data for included patients are provided in Table 1.

Intraobserver agreement for the AA and CEA was 0.92 (CI, 0.80-0.97) and 0.90 (CI, 0.76-0.96), while interobserver agreement for the angles was 0.96 (CI, 0.89-0.98) and 0.96 (CI, 0.90-0.98), respectively. All ICC measurements denoted high rater reliability.

Femoroacetabular impingement morphologic measurements exhibited multiple significant correlations with kinematic and kinetic gait variables (Tables 2-4). The AA positively correlated with the peak external hip and knee external rotation moments ($R = 0.37$; $P < 0.0001$ and $R = 0.42$; $P < 0.0001$). Inverse correlations between the AA and maximum ankle flexion angle ($R = -0.41$; $P < 0.0001$) as well as ankle range of motion ($R = -0.51$; $P < 0.0001$) were demonstrated. All ankle kinematic

Table 3. Spearman correlations between center-edge angle and kinematic and kinetic gait variables

Variable	Hip		Knee		Ankle		
	R Value	P Value	R Value	P Value	Variable	R Value	P Value
Kinematics, deg							
Minimum flexion	0.168	0.869	0.342	0.001	Minimum flexion	0.081	0.425
Maximum flexion	−0.145	0.151	−0.253	0.011	Maximum flexion	−0.109	0.279
ROM	−0.027	0.790	−0.010	0.924	ROM	0.067	0.506
Moments ^a							
Flexion	−0.383	<0.0001	0.178	0.077	Dorsiflexion	0.333	0.001
Extension	−0.078	0.440	0.511	<0.0001	Plantar flexion	0.243	0.015
Adduction	0.091	0.370	−0.225	0.024	Inversion	−0.437	<0.0001
Abduction	−0.250	0.012	−0.003	0.978	Eversion	0.380	<0.0001
IR	−0.043	0.669	0.117	0.247	IR	−0.079	0.435
ER	0.228	0.022	−0.054	0.593	ER	0.052	0.603

ER, external rotation; IR, internal rotation; ROM, range of motion. Bold faced *P* values represent statistically significant correlations after Bonferroni correction.
^a%Body weight * height.

Table 4. Spearman correlations of morphologic measurement with spatiotemporal variables

Variable	Alpha Angle, deg		Center-Edge Angle, deg	
	R Value	P Value	R Value	P Value
Speed, m/s	0.180	0.073	0.216	0.030
Stride, m	0.064	0.525	0.415	<0.0001
Cadence, steps/min	0.174	0.084	−0.081	0.423

Bold faced *P* values represent statistically significant correlations after Bonferroni correction.

variables exhibited an inverse trend with regard to an increasing AA. This association was also evident at the hip; however, no correlations were significant (Table 2). These correlations were still significant after Bonferroni correction for multiple comparisons.

The CEA positively correlated with the peak external knee extension and ankle eversion moments ($R = 0.51$; $P < 0.0001$ and $R = 0.38$; $P < 0.0001$). The peak external hip flexion ($R = -0.38$; $P < 0.0001$) and ankle inversion ($R = -0.44$; $P < 0.0001$) moment were negatively associated with the CEA (Table 3). These correlations were also significant after Bonferroni correction for multiple comparisons.

The CEA positively correlated with stride ($R = 0.42$; $P < 0.0001$), while no other morphologic measures were associated

with spatiotemporal parameters (Table 4). This correlation was still significant after Bonferroni correction for multiple comparisons. Correlations between spatiotemporal parameters and morphology are presented in Table 4.

From our stepwise regression models, male sex was associated with greater AA. In male patients, AA was 16.5° greater than in female patients. Increase in %BWH for peak external hip flexion and adduction moments, as well as the peak external knee internal rotation moment, predicted AA measurements. Stride, minimum hip flexion angle, maximum ankle flexion angle, and the peak external hip abduction and internal rotation moments negatively predicted AA. These 9 measures explained 87% of variations in AA. Regression coefficient estimates for significant AA associations are presented in Table 5.

Table 5. Significant findings from multivariate stepwise regression analysis for the alpha angle

Variable	Regression Coefficient Estimate	Standard Error	P Value
Male	16.5	1.1	<0.0001
Kinematics			
Stride	−14.1	4.0	0.0008
Minimum hip flexion, deg	−0.4	0.09	<0.0001
Maximum ankle flexion, deg	−0.7	0.1	<0.0001
Moments ^a			
Hip flexion	1.4	0.4	0.0025
Hip adduction	6.0	0.5	<0.0001
Hip abduction	−3.0	1.1	0.007
Hip internal rotation	−14.4	2.6	<0.0001
Knee internal rotation	10.4	1.3	<0.0001

^a%Body weight * height.

The maximum hip flexion angle and the peak external hip flexion and ankle inversion moments were all negatively associated with greater CEA. Speed and peak external hip internal rotation and external rotation moments, as well as the peak external knee extension moment, were all positively associated with CEA. These measures explained 82% of variations in CEA. Regression coefficient estimates for significant CEA associations are presented in Table 6.

After removing the 3 patients with CEA < 25°, we did not find any noticeable difference in our correlations or regression estimates. This suggests that the 3 patients did not exert any overt influence on our findings.

DISCUSSION

Femoroacetabular impingement is a common cause of pain, chondrolabral injury, and mechanical limitations in young patients.⁸ Although previous studies have demonstrated differences in kinematic and kinetic variables between pre- and postoperative FAI patients as well as healthy controls,^{4,9,12,14,26,27} little is known about the associations between radiographic FAI morphology and gait abnormalities. We hypothesized that with an increasing AA and CEA there would be significant correlations with specific kinematic and kinetic gait variables about the hip, knee, and ankle.

In the present study, AA positively correlated with the peak external hip external rotation moment, while it negatively correlated the peak external hip abduction and internal rotation moments. We propose that a cam deformity may lead to an alteration in the moment arm at the hip resulting in gait

deviations. The increasing AA with an increasing peak external hip external rotation moment, which is counteracted by the net activity of the hip internal rotators, could be associated with altered activity of the hip internal rotators and abductors (gluteus medius and minimus muscles) often reported in FAI.⁵ Moreover, the AA negatively associated with the peak external hip abduction and internal rotation moments. The hip adductors and external rotators counteract these moments, and it is interesting to note these muscles are antagonistic to the gluteus medius and minimus muscles. The present trends and their associated agonistic and antagonistic muscle groups denoted opposite trends in relation to the AA. This may suggest that peak external moments may have a unique relationship with AA, and therefore, may demonstrate unique gait deviations, such as those reported in the FAI gait literature.^{4,9,14} The present findings help explain Hunt et al,⁹ who showed a reduced hip external rotation moment in preoperative FAI patients vs a control group and cited reduced activity of the internal rotators.⁹ Brisson et al⁴ reported reductions in the peak hip abduction and internal rotation moments in pre- and postoperative patients with cam FAI versus controls, while Kumar et al¹⁴ reported reductions in the external rotation moment in patients with cartilage lesions who have FAI. Surgical correction of the deformity may lead to improved gait, as evidenced by postoperative improvements in kinematic and kinetic variables.^{4,26,27} These findings suggest a cam deformity in FAI may lead to alterations in gluteal function and their opposing muscle groups, which may consequently affect the moment arm of the muscle to counteract the peak external moments.

Table 6. Significant findings from multivariate stepwise regression analysis for the center-edge angle

Variable	Regression Coefficients Estimate	Standard Error	P Value
Kinematics			
Speed, m/s	6.9	2.4	0.0053
Maximum hip flexion, deg	−0.3	0.1	<0.0001
Moments ^a			
Hip flexion	−4.9	0.4	<0.0001
Hip internal rotation	3.6	1.1	0.0020
Hip external rotation	12.9	1.4	<0.0001
Knee extension	1.6	0.4	<0.0001
Ankle inversion	−1.3	0.5	0.0082

^a%Body weight * height.

We report an association between the CEA and maximum hip flexion angle, the peak external hip flexion, and the internal and external rotation moments. A similar theory as described above may be present with regard to CEA, where altered gluteal function by greater acetabular overcoverage may alter the moment arm at the hip. These findings support the work of Rylander et al,^{26,27} who reported preoperative reductions in maximum hip flexion. Additionally, following the same line of thought, Kumar et al¹⁴ reported a larger internal rotation moment in relation to a control group. The gluteus maximus and gluteus medius and minimus counteract these moments, and altered function may explain the reported gait deviations as a result of the acetabular overcoverage. Thus, these findings may also suggest that altered gluteal function as a result of FAI pathomorphology may lead to altered gait patterns.

This study is not without limitations. First, this study was cross-sectional by design with no control group, and therefore, causality cannot be determined. Second, the study had a relatively small sample size, but it is not uncommon to see such a sample in FAI gait studies.^{4,9,12,26,27} This is likely because of difficulty in patient recruitment and retention, as well as the length of gait tests. Third, hip morphology is 3-dimensional, whereas radiographic assessment only allows for 2-dimensional measurements. Computed tomography or magnetic resonance imaging would allow for improved visualization of the 3D bony morphology of the hip joint. Thus, enabling 3D interpretation of joint pathoanatomy to further understand morphology's association to gait variables would be vastly beneficial. Last, 75% (15/20) of the FAI morphotypes were of mixed impingement, with the remaining consisting of cam impingement, subsequently limiting a more sophisticated analysis.

CONCLUSION

Gait and lower extremity kinematic parameters correlate with radiographic FAI morphology in symptomatic FAI patients. We found significant associations between both the AA and CEA with gait variables.

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