

Foot Progression Angle Walking Test

A Dynamic Diagnostic Assessment for Femoroacetabular Impingement and Hip Instability

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Background: Determining an accurate clinical diagnosis for nonarthritic hip pain may be challenging, as symptoms related to femoroacetabular impingement (FAI) or hip instability can be difficult to elucidate with current testing methods. In addition, commonly utilized physical examination maneuvers are static and do not include a dynamic or weightbearing assessment to reproduce activity-related symptoms. Therefore, implementing a dynamic assessment for FAI and hip instability could help to improve diagnostic accuracy for routine clinical examinations of patients with nonarthritic hip pain.

Purpose: To assess the efficacy of a novel diagnostic foot progression angle walking (FPAW) test for identifying hip pathology related to FAI or hip instability.

Study Design: Prospective cohort study; Level of evidence, 3.

Methods: This prospective study included 199 consecutive patients who were evaluated for unilateral hip pain and who underwent FPAW testing along with standard physical examination testing. Demographic data, including age, sex and hip laterality, were collected from each patient. FPAW testing was performed with directed internal and external foot progression angles from their baseline measurements, with a positive test reproducing pain and/or discomfort. Comparisons were then made with flexion adduction internal rotation (FADIR) and flexion abduction external rotation (FABER) tests as the designated diagnostic standard examinations for FAI and hip instability, respectively. Sensitivity and specificity, along with the McNemar chi-square test for group comparison, were used to generate summary statistics. In addition, areas under the combined receiver operating characteristic curves (AUC) of test performance were calculated for both FPAW and the designated standard examination tests (FADIR, FABER). Radiographic imaging was used subsequently to confirm the diagnosis.

Results: The average age of the study cohort was 35.4 ± 11.8 years, with 114 patients being female (57%). Positive internal FPAW testing demonstrated 61% sensitivity and 56% specificity for an FAI diagnosis, compared with the 96% sensitivity and 11% specificity seen with FADIR testing. Internal FPAW was less sensitive, yet more specific compared with FADIR ($P < .001$). Combined testing had improved accuracy (AUC = 0.58; $P < .05$) compared with FADIR (AUC = 0.52; $P = .21$) or FPAW (AUC = 0.57; $P = .057$) alone. Positive external FPAW revealed 67% sensitivity and 70% specificity for hip instability, while FABER testing was 54% sensitive and 90% specific. External FPAW was significantly more specific but had similar sensitivity to FABER. Combined testing had greater accuracy (AUC = 0.77) compared with FABER (AUC = 0.70) or FPAW (AUC = 0.67) alone ($P < .001$).

Conclusion: The FPAW examination can be used as an adjunct examination to assist and improve the accuracy of the clinical diagnosis for FAI and hip instability.

Keywords: femoroacetabular impingement; hip instability; hip dysplasia; clinical diagnosis

Increased awareness of structural hip disease and expanding indications have led to an over 365% increase in hip arthroscopy rates in the past decade.¹¹ This has been coupled with improved consideration of both static and dynamic factors in the determination of mechanical hip pain etiology,²⁴ with the most common morphologic

abnormalities being either femoroacetabular impingement (FAI) or hip dysplasia/instability.⁶ Despite a variety of current diagnostic methods available, identification of nonarthritic hip pathologies such as FAI and hip instability remains a persistent challenge.¹⁶

A recent systematic review and meta-analysis by Reiman et al¹⁵ determined only 2 physical examination maneuvers, flexion adduction internal rotation (FADIR) and flexion internal rotation tests, demonstrated significant value as screening tests for FAI. Similarly, Tijssen et al²⁵ found that

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only 3 of 14 diagnostic accuracy studies for FAI and labral pathology were of good study quality, yet none were appropriate to reliably confirm or negate a diagnosis. Likewise, comparable diagnostic difficulties exist for those with symptomatic hip instability. Nunley et al¹³ revealed that the mean onset of symptoms related to hip dysplasia was over 5 years, with an average of 3.3 health care providers being seen before a definitive diagnosis was made. Consequently, these findings suggest a continuing need for more reliable hip-specific examination testing.

Numerous studies have suggested that the adaptive changes in gait are strategies to avoid pain or recurrent symptoms.^{8,14,17} Current hip-specific examination maneuvers require passive manipulation by the examiner and do not reproduce activity-related symptoms by dynamic means. Therefore, in this prospective study, we evaluate the foot progression angle walking (FPAW) test as a novel diagnostic tool for the detection of FAI and hip instability. This dynamic assessment aims to reproduce or exacerbate symptoms by gait manipulation. Using FPAW, foot progression is modified by internal or external rotation, which translates to directed forces across the hip that modify or exacerbate symptoms. We hypothesized that FPAW testing will provide reliably accurate testing for FAI and hip instability, as compared with standard FADIR testing and flexion abduction external rotation (FABER), respectively.

METHODS

After institutional review board approval, a single-blinded prospective study was performed of patients who had unilateral groin or hip pain between January 2014 and November 2015. Before study commencement, a power analysis was performed to determine a sample size of at least 165 patients with a 95% confidence level.

Study inclusion was composed of consecutive patients between the ages of 18 and 65 years who came to the senior author's (A.S.R.) clinic with hip pain whom consented to the study. Exclusion criteria included patients with concomitant back or knee pain, neurologic disorder, previous hip surgery, baseline ambulation with the use of an assistive device, or having a gross lower extremity torsional deformity. Those who had osteoarthritic changes of the hip greater than a Tönnis grade 1 were excluded as well.

Baseline demographic characteristics were recorded including age, sex, symptomatic hip laterality, and foot progression of the ipsilateral extremity. Patients were then administered the FPAW test by a research associate. The senior author was blinded to the results of the FPAW test and used his history and physical examination findings in conjunction with radiographs to make a diagnosis and classify the

patient as having FAI, hip instability, or neither. Hip examination consisted of range of motion assessment, including provocative maneuvers FADIR and FABER, as previously described.^{2,10} Plain film radiographs with anteroposterior and elongated neck lateral views were used to confirm FAI, with present cam, pincer, or mixed-type morphology. In determination of cam or mixed-type FAI, an alpha angle of $\geq 60^\circ$ was used, with pincer morphology confirmed with a center-edge angle of $>30^\circ$.^{12,20} Diagnosis of hip dysplasia was determined by a lateral center-edge angle of $<25^\circ$.^{7,12,18}

FPAW testing was conducted on every patient who met the inclusion criteria (Figure 1). The patient was first instructed to ambulate at their baseline functional pattern for approximately 20 feet. During this baseline gait assessment, categorization of their ipsilateral foot progression angle was characterized as neutral, out-toeing, or in-toeing. The patient was then directed by measurement to internally rotate their foot by 15° from their baseline pattern. The repeated gait assessment, depicted as internal FPAW, was then performed in the internally rotated position. Direction was also given to maintain the equivalent abduction/adduction of the lower extremity with the assigned rotation. Conversely, external FPAW testing was performed with external rotation of the foot progression angle by 15° from their baseline gait. Measurements were standardized by having patients stand on a blank sheet of paper, measuring 15° with a goniometer (either internal or external), and marking the location for their reference. A positive FPAW test was the presence of hip pain during testing or exacerbation of symptoms if pain was present at their baseline gait assessment. As noted by Sierra et al,²² young patients with hip pathology will modify their foot progression angle to adapt a gait pattern that limits symptoms.

Overall summary statistics were calculated in terms of means and standard deviations for continuous variables and frequencies and percentages for categorical variables. Internal FPAW and FADIR tests were compared for their accuracy in FAI, while external FPAW and FABER tests were compared for the diagnosis of hip instability. Hip instability was defined as discomfort associated with terminal range of motion, as a result of capsular laxity, structural bony abnormality related to dysplasia, or posttraumatic sequelae leading to subluxation or dislocation.^{3,21,26} Differences for discrete variables were evaluated using the McNemar chi-square test for sensitivity and specificity between FPAW testing and FADIR or FABER, depending on the present diagnosis of FAI or hip instability. In addition, sensitivity and specificity were also estimated separately for each test (FADIR, FABER, internal FPAW, and external FPAW), with calculated positive and negative predictive values and positive and negative likelihood ratios. Area under the curve (AUC) was calculated by combined receiver operating characteristic (ROC) to determine diagnostic test accuracy.

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Ethics approval for this study was obtained from the Hospital for Special Surgery Institutional Review Board (study number 2015-126).

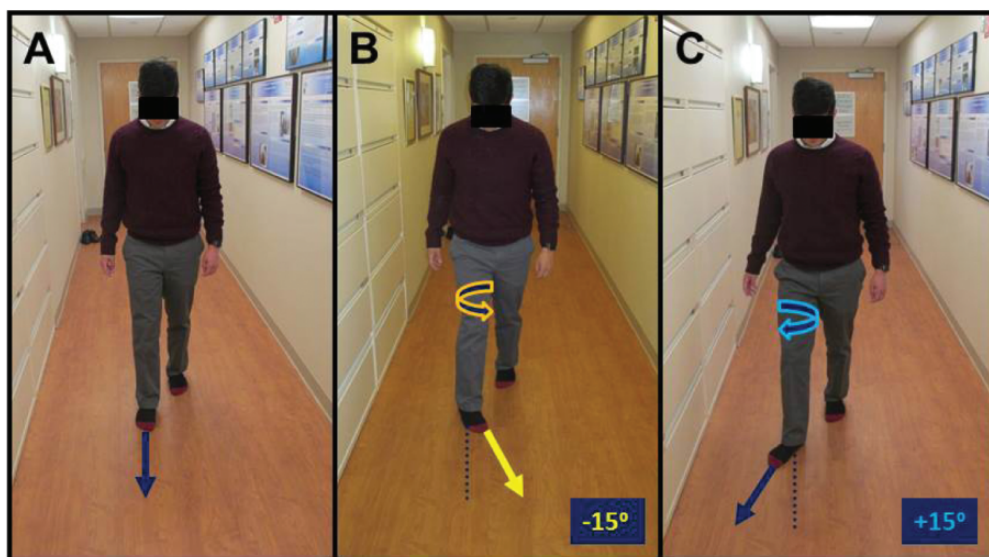


Figure 1. Gait assessment by foot progression angle walking (FPAW) testing. Images show a patient with (A) a baseline neutral foot progression. (B) The patient was then instructed to perform an internal FPAW, followed by a subsequent (C) external FPAW. The solid arrows represent depicted foot progression; dotted lines represent reference of baseline foot progression; curved arrows indicate visual representation of the rotated lower extremity.

TABLE 1
Patient Demographics and Baseline Examination^a

Sex, female/male, n	114/85
Age, y, mean ± SD	35.4 ± 11.8
Affected hip, n	
Left	77
Right	114
Bilateral	8
Baseline gait, n	
Neutral	117
In-toeing	7
Out-toeing	75
Diagnosis, n	
FAI	111
Hip instability	54
Other	34

^aFAI, femoroacetabular impingement.

Statistical significance was set at alpha equal to 0.05. All analyses were done using SAS 9.2 for Windows (SAS Institute Inc). Power and sample size calculations were performed using PASS 2008 software for Windows.

RESULTS

A total of 226 patients were evaluated for hip pain (Table 1). After exclusion of 27 patients who did not meet inclusion criteria, 199 patients were evaluated using FPAW testing. This group was composed of 114 females (57%) with an average age of 35.4 ± 11.8 years. A clinical and radiographic diagnosis of FAI was found in 111 patients, while hip instability was found in 54 patients and 34 patients did not exhibit either diagnosis (Table 2). Laterality of symptoms was isolated to the left hip in 77 patients, the right hip in 114 patients, and 8 patients had bilateral complaints. Baseline gait assessment

TABLE 2
Excluded Patients (n = 34)

Reason for exclusion	n
Previous hip surgery	18
Osteoarthritis	6
Back pain	5
Sports hernia/core muscle injury	3
Neurologic disorder	2

showed that 116 patients had a neutral foot progression angle (<15° external or internal foot progression angle), while 75 patients demonstrated an out-toeing gait pattern and 7 patients showed in-toeing of the affected extremity.

There were 7 patients who reported pain with baseline ambulation, 106 patients who reported pain with internal FPAW, and 80 patients who reported pain with external FPAW testing. The assessment of FAI depicted FPAW testing to have greater overall specificity by group comparison to FADIR testing (Table 3). The sensitivity was improved for FADIR testing as compared with FPAW alone, yet FABER testing proved to be more specific for hip instability. However, overall diagnostic testing performance was improved by the combination of both FPAW and FADIR for FAI (Table 4).

In contrast, FPAW testing was slightly more sensitive than FABER testing for hip instability; however, a group comparison showed no difference. In addition, the combined testing approach showed the highest diagnostic utility with FABER and FPAW testing.

DISCUSSION

The use of static hip-specific physical examination tests for nonarthritic hip pain has shown variable clinical utility¹⁶

TABLE 3
Examination Testing for FAI and Hip Instability^a

Diagnostic Examination	Sensitivity	Specificity	Positive Predictive Value	Negative Predictive Value	Positive Likelihood Ratio	Negative Likelihood Ratio
FAI (n = 110)						
FPAW	61	56 ^b	63	54	1.4	0.7
FADIR	96 ^b	11	57	71	1.1	0.4
Hip instability (n = 54)						
FPAW	67	70	45	85	2.2	0.5
FABER	54	90 ^b	67	84	5.4	0.5

^aData are reported as percentages. FABER, flexion abduction external rotation; FADIR, flexion adduction internal rotation; FAI, femoroacetabular impingement; FPAW, foot progression angle walking.

^bGroup comparison using McNemar chi-square test showed statistical significance ($P < .05$).

TABLE 4
Accuracy of Diagnostic Testing for FAI and Hip Instability^a

Diagnostic Examination	AUC (95% CI)	Standard Error	P Value
FAI (n = 110)			
FPAW	0.57 (0.50-0.65)	0.04	.06
FADIR	0.52 (0.49-0.56)	0.02	.21
FPAW + FADIR	0.58 (0.51-0.66)	0.04	.03
Hip instability (n = 54)			
FPAW	0.67 (0.59-0.75)	0.04	<.001
FABER	0.7 (0.62-0.77)	0.04	<.001
FPAW + FABER	0.77 (0.69-0.85)	0.04	<.001

^aBoldfaced P values indicate statistical significance. AUC, area under the curve, as calculated by receiver operating characteristic; FABER, flexion abduction external rotation; FADIR, flexion adduction internal rotation; FAI, femoroacetabular impingement; FPAW, foot progression angle walking.

and may be further limited by operator-dependent ability to reproduce symptoms with static testing. In our prospective study, we found that the FPAW test, a dynamic gait assessment, provided greater clinical accuracy for FAI and hip instability when combined with current standard testing. In addition, the utility of an internal FPAW test demonstrated greater specificity for FAI than the commonly used FADIR maneuver in our study group.

Disturbances in gait and mobility have been frequently documented in patients with FAI and hip dysplasia.^{1,5,19,23} Kennedy et al⁹ had previously linked gait abnormalities to the presence of FAI, showing that compensatory motion revealed decreased hip abduction and range of motion. Farkas et al⁵ had also recently shown the correlation of FAI with increased alpha- and center-edge angles in patients to have greater disruption of kinematic and kinetic gait variables. Linked to possible soft tissue or mobility constraints, patients may adapt the most efficacious gait while minimizing the recurrence of activity-related symptoms.

The FPAW test aims to reproduce symptoms by incurring a maladaptive gait pattern. The abutment of the head-neck junction with internal rotation would presumably be linked to symptomatic gait in patients with FAI, which coincides with our finding of a positive internal FPAW in

the study group. In contrast, patients with symptomatic hip instability exhibited a positive test with external FPAW, which may reproduce instability or symptoms of under-coverage. Using FPAW gait assessment, we were able to accurately reproduce symptoms through dynamic testing, which proved to be most useful for diagnosis when combined with current standard examination. However, while our observations were limited to foot progression, we did not account for the kinematic changes at the hip or knee. Another consideration would be the effect of our dynamic test to exacerbate symptoms related to abnormal pelvic morphology or motion, which have been shown to correlate with symptomatic FAI.^{7,18}

Tijssen et al²⁵ pointed out that the clinical diagnosis for FAI and labral pathology has largely shifted toward the use of imaging and away from physical examination due to the poor validity and accuracy. They found that only 3 accuracy studies were determined to be qualified, and found no combination of testing to be consistently reliable. In addition, patients may demonstrate imaging findings of FAI or hip instability yet remain asymptomatic. A systematic review with meta-analysis revealed similar findings, with few tests able to make a significant change in posttest probability of FAI or labral injury.¹⁵ In addition, most available tests rely on a passive approach with the patient in the supine or lateral position. The difficulty is that testing could potentially be applied inconsistently, signifying the value of a dynamic assessment such as the FPAW test. In addition, activity-related symptoms may also be more closely mimicked by the FPAW test than by the standardized directed assessment.

Still, our study using FPAW testing for FAI and hip instability does have limitations. This study focused on symptomatic patients with either FAI or hip instability as confirmed by radiographic findings, which may not always be reliable.⁴ We also recognize that abnormal morphology of the hip represents a 3-dimensional deformity; however, we did not employ computed tomography or magnetic resonance imaging for further analysis unless necessitated for preoperative planning. We acknowledge that we did not apply subjective pain scores to quantify the degree of symptoms but rather employed a scale of either having increased pain or not during FPAW testing. Also, we visually directed foot progression by goniometer measurement before FPAW;

however, variability from the 15° marking could have occurred during dynamic testing. In addition, we did not compare our findings to a control group of patients without a diagnosis of FAI or hip instability, which is limited by the population who present to the office. Similarly, it would be unknown whether FPAW could be positive in asymptomatic control patients. This study also remains limited by including only 1 surgeon, which may implicate diagnostic bias and does not allow for interobserver reliability. We also recognize that a subset of patients may exhibit characteristics of both FAI and hip instability. Patients with hip instability can develop anterosuperior labral tears secondary to labral hypertrophy in an attempt to compensate for the lack of coverage. In this scenario, impingement tests such as FADIR or internal FPAW may also be positive. However, we believe FPAW may still be useful for determining a diagnosis in patients with various causes contributing to their hip pain.

CONCLUSION

This study highlights the utility of a combined approach with FPAW and FADIR testing for FAI, along with FPAW and FABER testing for hip instability. This collective testing approach led to improved accuracy compared with either of the tests alone and incorporates dynamic testing that is not examiner dependent. While further studies are necessary for validation in the clinical setting, including testing in asymptomatic individuals, this approach may provide the clinician with improved reliability for physical examination testing of hip-specific pathology.

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