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Preoperative and Postoperative Walking Gait in Women With Acetabular Labral Tears and Femoroacetabular Impingement Syndrome

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Context: Symptomatic femoroacetabular impingement syndrome (FAIS) is a painful condition that leads to decreased function. How walking gait changes over time within the first year after surgery for FAIS and how these changes present in women are currently unknown.

Objective: To determine biomechanical gait differences between women with FAIS or labral tears and control individuals preoperatively and at 3 and 6 months postoperatively.

Design: Case-control study.

Setting: Laboratory.

Patients or Other Participants: A total of 18 female participants comprising 9 women in the FAIS group (age = 31.44 ± 7.47 years, height = 1.73 ± 0.08 m, mass = 73.61 ± 14.44 kg) and 9 women in the control group (age = 31.44 ± 6.65 years, height = 1.69 ± 0.06 m, mass = 60.93 ± 5.58 kg).

Main Outcome Measure(s): Between-groups comparisons of the Hip Outcome Score Activities of Daily Living subscale (HOS_{ADL}) and gait biomechanics were conducted preoperatively and at the 3- and 6-month postoperative sessions. Statistical parametric mapping was performed on normalized time-series data.

Results: Preoperatively, the FAIS group had poor HOS_{ADL} scores (FAIS group = 64.1 ± 15.4 versus control group = 100.0 ± 0, $P < .001$), walked 15% slower, and exhibited several gait differences compared with the control group. Three months postoperatively, the FAIS group displayed greater vertical ground reaction force ($P = .01$), ankle-dorsiflexion angle ($P = .02$), and external dorsiflexion moment ($P = .01$) in midstance, as well as a greater knee-flexion angle through the second half of stance ($P < .001$). The FAIS group also demonstrated less hip-extension angle ($P = .02$) and hip-abduction angle ($P = .01$) through the second half of stance, which transitioned into less hip extension ($P = .040$) and hip abduction ($P = .03$) during the subsequent swing phase. The FAIS group improved their HOS_{ADL} to 87.6 ± 7.6 by 6 months postoperatively and had a greater dorsiflexion moment ($P = .003$) and ankle external rotation during stance ($P = .03$). In addition, the FAIS group showed a greater external hip external-rotation moment in late stance ($P < .001$).

Conclusions: The biomechanical differences between groups were most evident at 3 months postoperatively, suggesting that women with FAIS had more postoperative gait compensations in the short term after surgery. By 6 months postoperatively, patient-reported outcomes had markedly improved, and the FAIS group displayed few gait differences compared with the control group.

Key Words: hip arthroscopy, females

Key Points

- Women with femoroacetabular impingement syndrome (FAIS) walked more slowly and had abnormal patient-reported outcome measures before hip arthroscopy.
- Ankle-, knee-, and hip-joint kinematic and kinetic gait changes in the FAIS group were most pronounced at 3 months postoperatively.
- By 6 months postoperatively, women with FAIS achieved a similar gait to that of control participants, and their patient-reported outcome measures increased to near-normal levels.

Femoroacetabular impingement syndrome (FAIS) results from femoral or acetabular bony morphology and has been recognized as a primary hip condition that may lead to mechanical damage and premature development of osteoarthritis or osteoarthrosis.[1–3] The femur contacts the acetabulum during motion, leading to labral and cartilage lesions and contributing to early degenerative joint changes.[1] Osseous impact of the proximal femur and acetabular rim typically occurs with greater hip flexion (>100°) and in combination with internal rotation and adduction.[4,5]

Authors of systematic reviews have described resultant physical impairments and decreased function[6] as well as altered lower extremity walking, squatting, and stair-climbing biomechanics.[7] However, previous postoperative gait studies[8–11] were limited by mixed-sex samples, various surgical procedures, or inconsistent postoperative follow-up times. For a more thorough understanding of FAIS recovery, sex-specific studies that feature earlier followups at discrete times postoperatively are still needed. Understanding how gait changes in the short term (eg, <1 year postoperatively) may provide important clinical information for surgeons and clinicians throughout the recovery process and could allow for enhanced interventions during rehabilitation. Additionally, earlier researchers studying FAIS gait examined only stance-phase biomechanics. Given that people with FAIS have painful hip conditions, swing-phase mechanics could also be affected.

In addition to these methodologic limitations of previous postoperative FAIS research, analysis of biomechanical data has recently been aided by statistical parametric mapping (SPM) techniques.[12,13] The SPM analysis is possible via open-source code for drawing inferences from sets of time-normalized data (https://spm1d.org/index.html). In short, groups of participants can be analyzed over ensemble waveforms (eg, comparing the entire sagittal-plane knee angle during stance) rather than using the traditional method of comparing maximum or minimum values (eg, peak knee-flexion angle during stance).

Therefore, the aims of our study were to examine female-specific triplanar ankle, knee, hip, pelvis, and thorax gait biomechanics during stance between a group with FAIS or acetabular labral tears and an age-matched control group preoperatively and at 3 and 6 months postoperatively. The swing-phase kinematics of the hip joint were also analyzed to further explore possible differences between these groups. We hypothesized that the FAIS group would demonstrate an abnormal gait and poor patient-reported outcomes compared with the control group preoperatively. Specifically, if the hip was painful, we would expect decreased range of motion and altered forces at the hip, as well as increases in the adjacent joints. We also hypothesized that as patient-reported outcome measures improved, gait would be similar to that of controls by 6 months postoperatively.

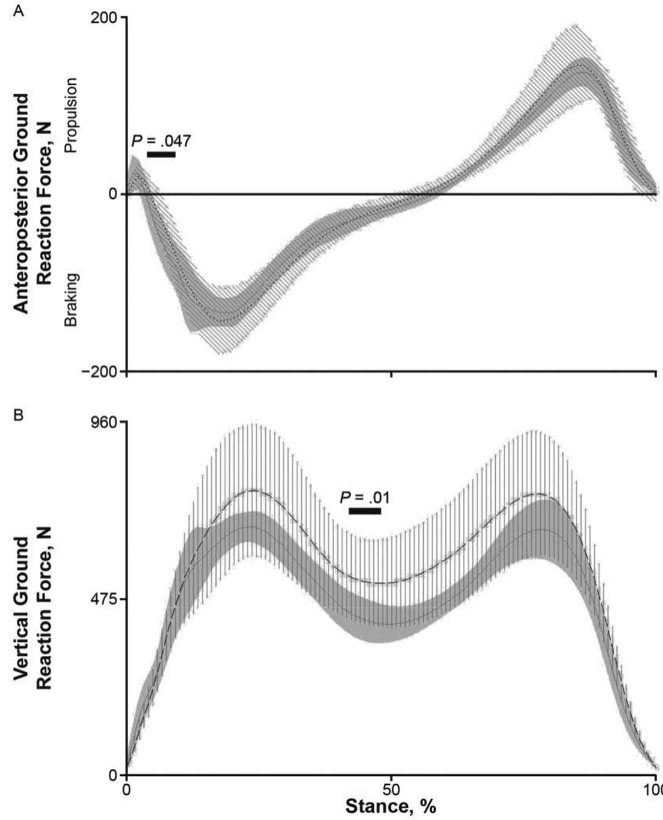

Figure 1. Differences between control and femoroacetabular impingement syndrome (FAIS) groups for A, anteroposterior ground reaction force preoperatively and B, vertical ground reaction force 3 months postoperatively. Black bars with *P* values indicate regions of significant statistical parametric mapping analyses. Normalized mean (line) and SDs (shading) represent control (solid line indicates mean; diagonal shading indicates SD) and FAIS (dashed line indicates mean; vertical shading indicates SD) groups.

METHODS

Research Design

We compared the walking biomechanics of patients with unilateral FAIS and those of control participants of similar age and sex. The FAIS group was analyzed at 3 data-collection points (preoperatively and 3 and 6 months postoperatively) and compared with the control group, who attended a single data-collection session. The Hip Outcome Score Activities of Daily Living (ADL) subscale (HOS_{ADL}) was calculated at the aforementioned time points.[14,15] A perfect HOS score is 100, which indicates *normal function* during ADLs due to hip injury. A score of 64 indicates *abnormal function*, and 89 is considered *nearly normal function*.[15]

Participants

We recruited participants from the orthopaedic practices of 2 board-certified surgeons (R.D. and S.C.). The study enrollment period was 2 years and yielded 43 eligible candidates for recruitment. Thirty-three people declined to participate, resulting in the final FAIS group of 10 (n = 5 per surgeon). One participant with FAIS moved out of state before the 6-month session, resulting in 9 patients. All patients with FAIS had undergone unsuccessful conservative treatment that included at least 1 of the following: activity modification, physical therapy, nonsteroidal anti-inflammatory drugs, or intra-articular injections. The FAIS group inclusion criteria were (1) a positive physical examination for signs and symptoms of labral injury (eg, positive anterior impingement sign); (2) failure of conservative measures; (3) radiographic evidence of cam morphology (n = 3; α angle >50° on frog lateral radiograph or magnetic resonance imaging scan), pincer morphology (n = 5; lateral center edge >35°, acetabular inclination <10°, or positive signs of retroversion [crossover sign, ischial spine sign, posterior wall sign]), or both cam and pincer morphologies (n = 2); and (4) acetabular labral tear on magnetic resonance imaging scan that was confirmed during arthroscopy. The exclusion criteria were bilateral symptoms, endocrine system dysfunction, avascular necrosis or chondrolysis, radiographic appearance of osteoarthrosis, or any other medical condition that might adversely affect gait. All patients with FAIS underwent hip arthroscopy using a 2-portal technique (anterolateral and midanterior portals) and partial T capsulotomy. The labrum was repaired via suture anchor and femoroplasty, acetabuloplasty, or both based on individual morphology. All participants completed individualized physical therapy programs of their choosing, which concluded around 6

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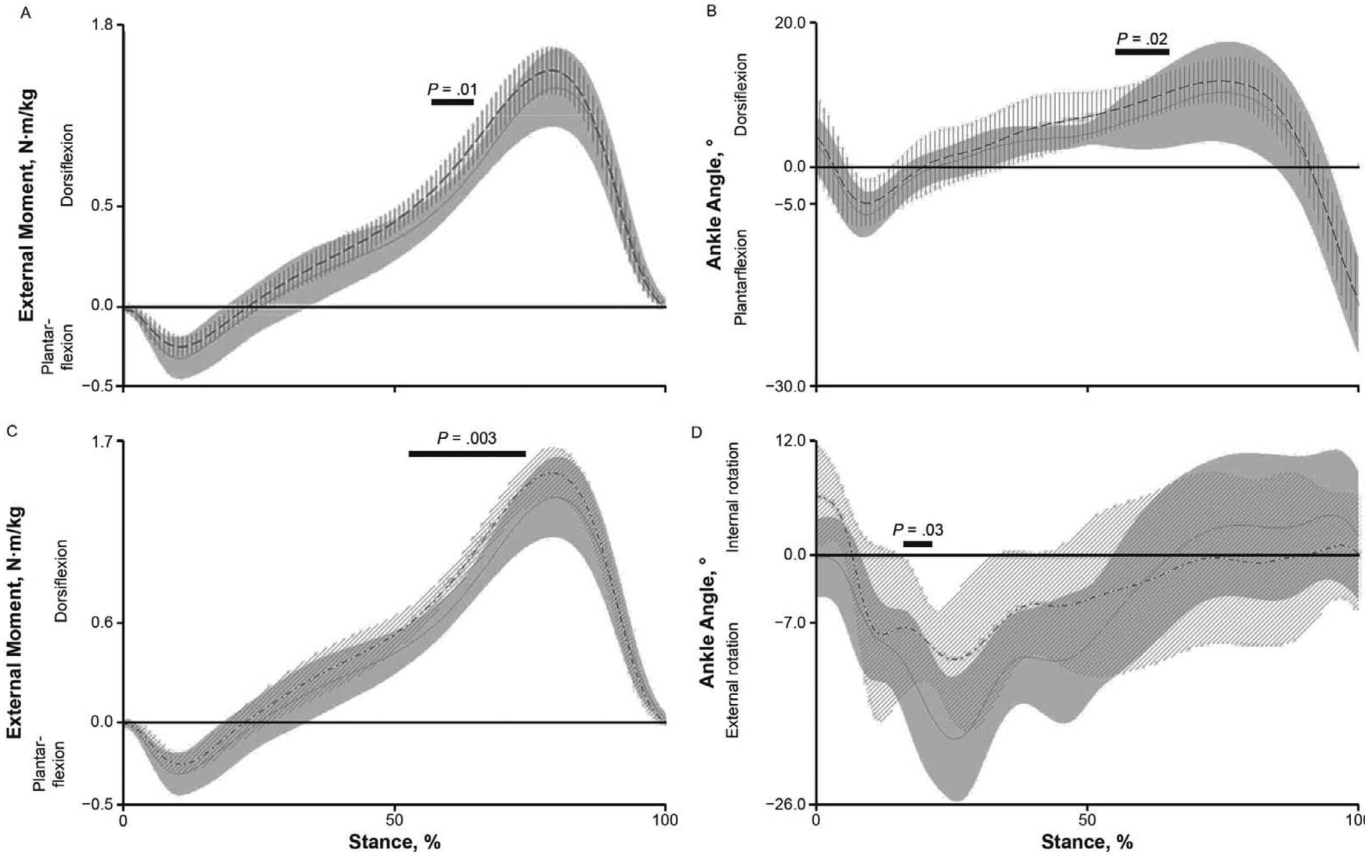

Figure 2. Differences in ankle biomechanics between control and femoroacetabular impingement syndrome (FAIS) groups for, A, sagittal-plane external ankle moment at 3 months postoperatively, B, sagittal-plane ankle angle at 3 months postoperatively, C, sagittal-plane external ankle moment at 6 months postoperatively, and, D, transverse-plane ankle angle at 6 months postoperatively. Black bars with *P* values indicate regions of significant statistical parametric mapping (SPM){t} analyses. Normalized mean (line) and SDs (shading) represent control (solid line indicates mean; diagonal shading indicates SD) and FAIS (dashed line indicates mean; vertical shading indicates SD) groups.

months postoperatively, and then were cleared to begin level-ground jogging. It was not possible to standardize the postoperative physical therapy because of insurance and other logistical barriers. Participants were recruited for the age-matched control group (n = 9) from the local community and denied a history of significant lower extremity injury or surgery. Before the study, all participants provided written informed consent, and the study was approved by the Human Studies Program, Office of Research Compliance, University of Hawai'i at Mānoa.

Procedures

Participants reported to the university's human performance laboratory for all data collection. Data were collected preoperatively (6.4 ± 4.4 days) and at 3 months (3.3 ± 0.6 months) and 6 months (6.2 ± 0.7 months) postoperatively. Anthropometric data included height measured via a wall-mounted stadiometer (model 67032 Seca Telescopic Stadiometer; Country Technology, Inc) and weight measured via a calibrated scale (Detecto Inc). Biomechanics were collected using a set of 27 retroreflective modified plug-in gait markers, with placement at the bilateral acromioclavicular joints, C7, T10, inferior angle of the right scapula, superior notch of the sternum, and xiphoid process (thorax) and bilaterally at the anterior-superior and posterior-superior iliac spines (pelvis), medial and lateral femoral condyles, lateral shanks, and medial and lateral malleoli, calcanei, and second metatarsophalangeal joints. Similar marker sets have shown good levels of reliability between trials.[16] Knee- and ankle-joint center locations were adjusted via custom scripts (Vicon), and an additional tibial rotation correction was applied to help minimize errors. Hip-joint centers were estimated using the equation of Bell et al.[17] Static calibrations were recorded to individualize models, including calculation of body segments and joint centers. Participants then walked shod at a self-selected pace across a 10-m runway for all trials.

Three-Dimensional Gait Analysis

A 20-camera 3-dimensional motion-capture system (Vicon) and software (version 1.7.1; Vicon Nexus) were used to capture kinematics. Force plates (Advanced Mechanical Technology, Inc) embedded flush with the floor surface were used to collect kinetic data during gait trials. Marker trajectories were collected at 240 Hz and smoothed using a Woltring filter (mean square error cutoff = 10) and time synchronized with kinetic data collected at 960 Hz. Gaps were filled with a cubic spline polynomial routine in Vicon Nexus software. Visual 3D (C-Motion, Inc) was used for data processing with inverse dynamics to obtain mass-normalized external hip, knee, and ankle moments. Ground reaction forces (GRFs) and external

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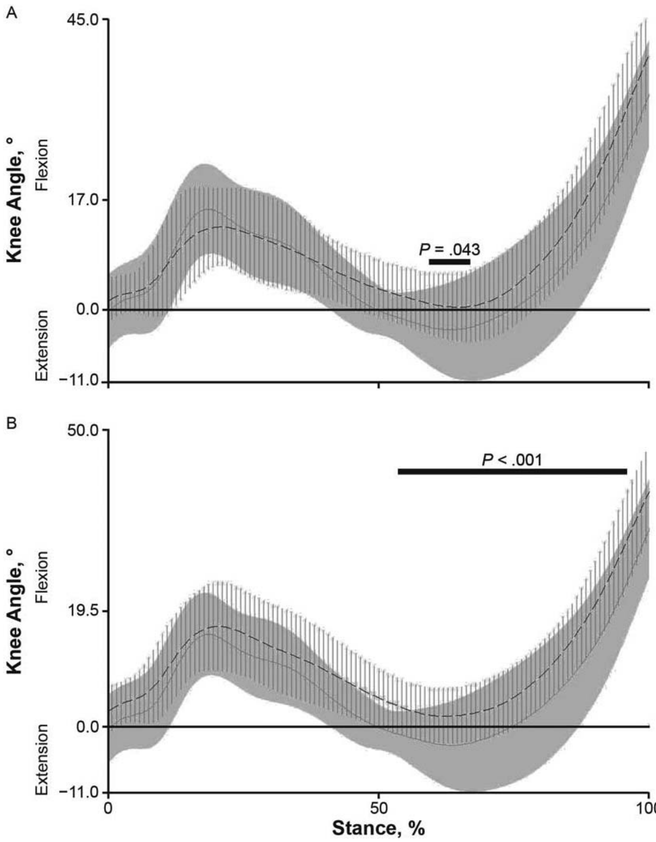

Figure 3. Differences between control and femoroacetabular impingement syndrome (FAIS) groups for sagittal-plane knee angle, A, preoperatively, and B, 3 months postoperatively. Black bars with *P* values indicate regions of significant statistical parametric mapping analyses. Normalized mean (line) and SDs (shading) represent control (solid line indicates mean; diagonal shading indicates SD) and FAIS (dashed line indicates mean; vertical shading indicates SD) groups.

moments were filtered using a fourth-order low-pass Butterworth filter with cutoff frequencies of 50 and 10 Hz, respectively, to reduce the risk of artificial moment impact peaks.[18,19] Ensemble averages of 3 successful trials for each lower extremity were used for subsequent analyses. A *successful trial* was defined as completion of the pass through the data-collection field at a consistent velocity, walking with the head up, and stepping with 1 foot completely on the force plate with no obvious change in stride or targeting of the force plate. All analyzed swing phases were captured immediately after the stance phase that occurred over the force plate through the next initial contact with the ground. Speedtrap-II infrared sensors (Brower Timing Systems) were placed 4 m apart in the middle of the runway to measure walking velocity.

Data Analysis

Descriptive statistics including means and SDs are reported for group characteristics and HOS_{ADL} scores, with differences assessed preoperatively between the FAIS and control groups using independent-samples *t* tests. Statistical parametric mapping was conducted using independent-samples *t* tests for each of the biomechanical variable time-series comparisons. For each SPM *t* test, a parametric map (SPM{t}) was created with calculation of the univariate *t* statistic at each time point of the normalized mean signal during the stance phase (and swing phase for hip kinematics).[12] Random field theory allowed estimation of the critical threshold above which only 5% ($\alpha = .05$) of equally smoothed random data were expected to cross.[20,21] Differences across the normalized time series were observed when the SPM{t} crossed the critical threshold and a suprathreshold cluster was created. A Bonferroni correction was applied for each *t* test, and a *P* value was obtained when a significant cluster was observed across the time series. Given the large number of comparisons in the SPM analysis, the results are summarized in Figures 1 through 5 using black bars to indicate significant SPM{t} regions that were different for the normalized signal mean figures. These regions correspond with differences observed in each parametric map. For SPM results that were not different, refer to Supplemental Figures 1 through 6 (available online at https://doi.org/10.4085/1062-6050-0026.21.S1), which provide comparisons of each variable between the FAIS and control groups. Descriptive statistics and analysis of group characteristics were performed using SPSS (version 25.0; IBM Corp). The α level was set a priori at $\leq .05$. All SPM analyses were conducted using open-source code (version M.0.4.7; www.spm1d.org) in MatLab (MathWorks).

RESULTS

Participant Characteristics and HOS_{ADL}

Descriptive data for participants are summarized in the Table. All characteristics were normally distributed, and equality of error variances was assumed only for height and age. No differences were detected between groups for height or age. Body mass was greater in the FAIS (73.61 ± 14.44 kg) than the control (60.93 ± 5.58 kg; $P = .03$) group. Body mass index was greater in the FAIS (24.61 ± 3.88) than the control (21.35 ± 1.03; $P = .04$) group. The control group reported a perfect score of 100 on the HOS_{ADL} subscale, whereas the FAIS group reported a lower HOS_{ADL} score preoperatively (64.1 ± 15.4; $P < .001$) and at 3 (74.7 ± 14.1; $P < .001$) and 6 (87.6 ± 5.6; $P < .001$) months postoperatively.

Biomechanics

Walking velocity was slower in the FAIS group preoperatively (1.29 ± 0.12 m/s) than in the control group (1.52 ± 0.24 m/s; $P = .02$). However, no differences were found at the 3- (1.40 ± 0.11 m/s; $P = .21$) or 6- (1.43 ± 0.11 m/s; $P = .36$) month sessions postoperatively. Braking GRFs were decreased preoperatively in the FAIS group across 6% to 9% of stance compared with those of the control group ($P = .047$; Figure 1A). Additionally, vertical GRF was greater at 3 months in the FAIS group across 38% to 48% of stance ($P = .01$; Figure 1B).

The FAIS group had a greater dorsiflexion (DF) external moment between 55% and 65% of stance ($P = .01$) and greater DF angle during 55% to 70% of stance ($P = .02$) at 3 months postoperatively (Figure 2A and 2B). The ankle DF moment remained greater at 6 months postoperatively across 55% to 70% of stance ($P = .003$; Figure 2C). Conversely, the FAIS group had less ankle external-rotation

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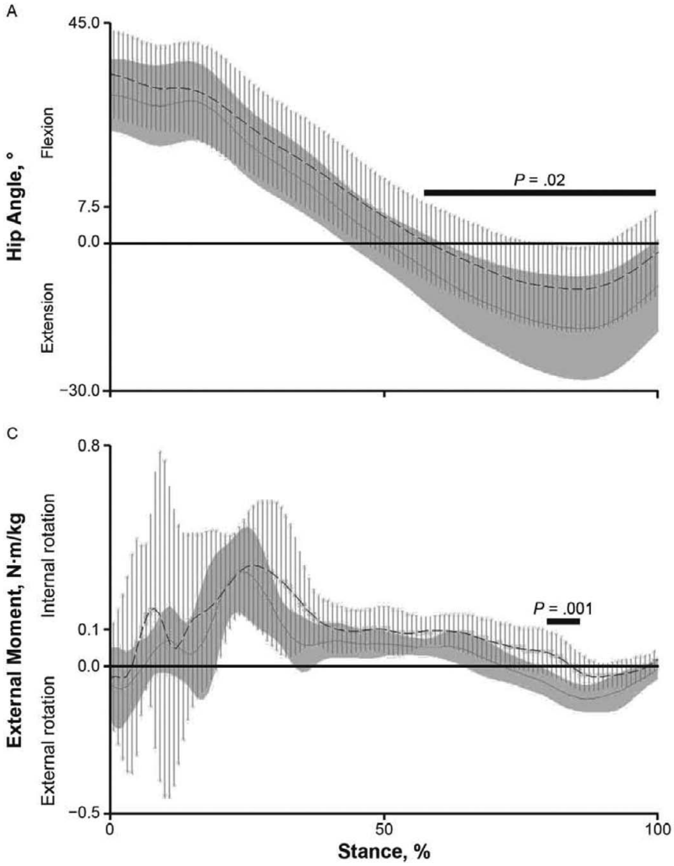

Figure 4. Differences in hip biomechanics during stance between control and femoroacetabular impingement syndrome (FAIS) groups for A, sagittal-plane hip angle at 3 months; B, frontal-plane hip angle at 3 months; C, transverse-plane hip external moment at 3 months; and D, external transverse-plane hip moment at 6 months. Black bars with *P* values indicate regions of significant statistical parametric mapping analyses. Normalized mean (line) and SDs (shading) represent control (solid line indicates mean; diagonal shading indicates SD) and FAIS (dashed line indicates mean; vertical shading indicates SD) groups.

(ER) angle across 18% to 25% of stance at 6 months postoperatively ($P = .03$; Figure 2D).

The FAIS group had a greater knee-flexion angle across 62% to 68% of stance preoperatively ($P = .043$) and 54% to 99% of stance at 3 months postoperatively ($P < .001$) compared with the control group (Figure 3).

The FAIS group had a smaller hip-extension angle across 65% to 99% of stance ($P = .02$) and hip-abduction angle across 55% to 95% of stance ($P = .01$) at 3 months postoperatively (Figure 4A and 4B). The hip ER moment was greater in the FAIS group across 78% to 85% of stance at 3 months postoperatively ($P = .001$) and 79% to 91% of stance at 6 months postoperatively ($P < .001$; Figure 4C and 4D). No differences were found for the pelvis or thorax in any planes at any time point between groups.

Table. Preoperative Patient Characteristics

Characteristic	Group, Mean ± SD		*P* Value
	Control (n = 9)	Femoroacetabular Impingement Syndrome (n = 9)	
Age, y	31.44 ± 6.65	31.44 ± 7.47	>.99
Height, m	1.69 ± 0.06	1.73 ± 0.08	.27
Body mass, kg	60.93 ± 5.58	73.61 ± 14.44	.03[a]
Body mass index	21.35 ± 1.03	24.61 ± 3.88	.04[a]

[a] Indicates difference ($P = .05$).

During the swing phase, the FAIS group had less hip extension preoperatively compared with the control group over the first 2% ($P = .050$; Figure 5A). The FAIS group also had less extension and transitioned into greater flexion over the first 22% of swing at 3 months postoperatively ($P = .040$; Figure 5B). Additionally, at 3 months postoperatively, the FAIS group had less hip abduction over the first 25% of swing ($P = .03$; Figure 5C).

DISCUSSION

We are the first to use the SPM technique to analyze the entire waveform data rather than analyzing only discrete points for an FAIS group. Additionally, we are the first to report on gait changes in female patients with FAIS and the first to examine patients at 3 and 6 months after hip arthroscopy. Given that not all patients will have similar rehabilitation lengths, clinicians should be aware of how patients with FAIS typically recover from surgical procedures. This is particularly relevant when considering the poor patient-reported outcomes for pain, ADLs, and other quality-of-life measures postoperatively.[22] Our main findings were that most biomechanical differences were seen at 3 months postoperatively and fewer differences

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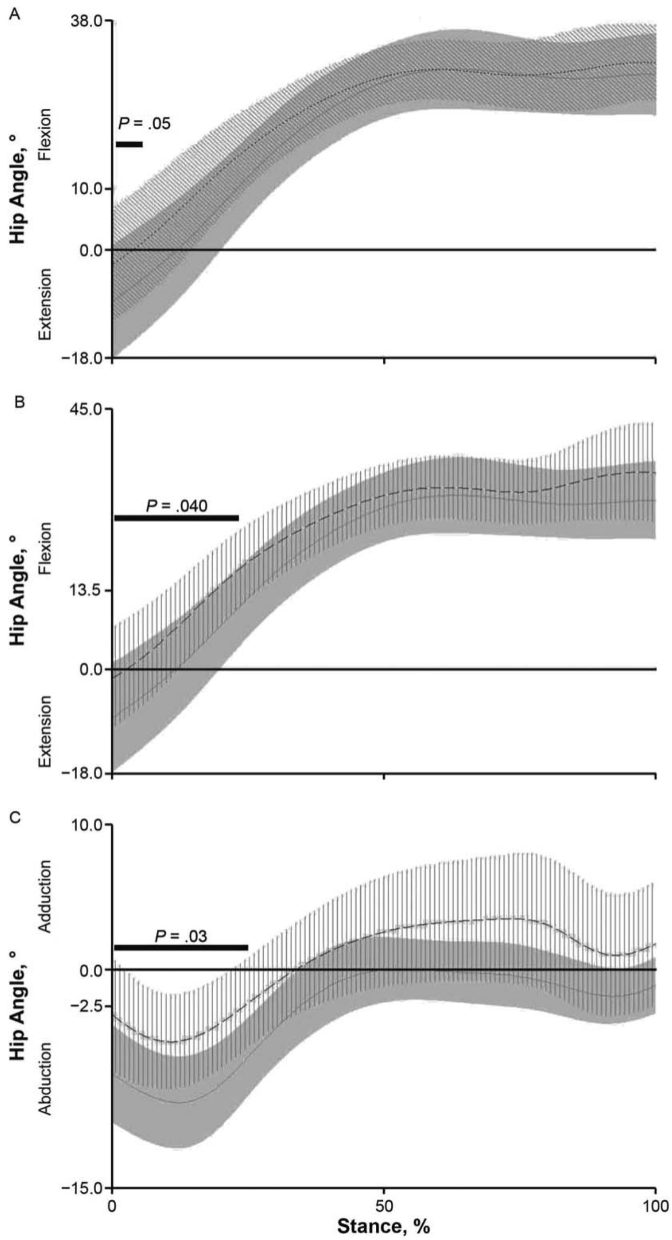

Figure 5. Differences in hip kinematics during swing between control and femoroacetabular impingement syndrome (FAIS) groups for A, sagittal-plane hip angle preoperatively; B, sagittal-plane hip angle 3 months postoperatively; and C, frontal-plane hip angle 3 months postoperatively. Black bars with *P* values indicate regions of significant statistical parametric mapping analyses. Normalized mean (line) and SDs (shading) represent control (solid line indicates mean; diagonal shading indicates SD) and FAIS (dashed line indicates mean; vertical shading indicates SD) groups.

were found at 6 months postoperatively, when the ADLs were also greatly improved.

Preoperatively, the FAIS group had a 15% slower walking velocity and decreased braking forces (posterior GRF) compared with the control group. The average HOS_{ADL} score was 64.1 ± 15.4, indicating considerable pain and dysfunction before surgery. The velocities in this study were similar to those reported in previous preoperative research[23,24] on patients with FAIS. The decreased walking velocity is accompanied by decreases in step length and cadence, which may also lead to reduced kinematics and kinetics.[9,25] However, the SPM analysis revealed no other differences in the stance-phase waveform data preoperatively. We observed only a brief time of decreased hip extension during the initial swing phase.

Most gait differences between the FAIS and control groups were found at 3 months postoperatively. During midstance, participants with FAIS had increased vertical GRF, ankle DF and external DF moments, and knee flexion. This highlights a clear alteration in distal lower extremity function from the ankle to the knee joint rather than the expected differences anticipated at the hip while loading the limb. Because these differences were not found preoperatively, the adaptations may have occurred postoperatively to further unload work and forces at the hip joint. After these midstance events, the hip FAIS group displayed decreased hip extension and abduction during the second half of stance, with decreased hip extension continuing into the swing phase. During this portion of stance, the FAIS group appeared less inclined to drive hip extension via the posterolateral hip muscles or stretch the anterior aspect of the joint. We do not know if this was because of weakness, fear avoidance, or some other compensation patterns, yet researchers[9,25] have established that patients with FAIS experience altered muscle forces around the hip joint that may linger up to 2 years after surgery. This gait pattern likely has multifactorial explanations, as complex relationships exist between neuromuscular strength and recovery from the operations. These adaptations occurred despite a 14% improvement in HOS_{ADL} scores from preoperatively (64.1 ± 15.4) to 3 months postoperatively (74.7 ± 14.1; $P < .001$). Further complicating this was the absence of between-groups thoracic or pelvic differences, which are common with hip injuries.

The HOS_{ADL} scores continued to improve up to an average of 87.6 by 6 months, and minimal differences in gait were observed. This study provides unique insight into both ADLs and gait changes postoperatively for female patients undergoing surgery for labral tears and FAIS. Although most aspects of walking normalized, the few differences warrant further investigation into how more specific rehabilitation protocols could possibly alter walking after hip arthroscopy. Identifying potential sex-specific compensations may provide clinicians with better information regarding patient progress postoperatively. In turn, these findings could be used to address functional deficits that are present after surgery.[22]

Our study had several limitations. The sample was small but similar in size to samples in previous research, and it consisted of only female participants. Direct comparison with male patients with FAIS was not our goal, so this factor may require consideration in future studies. This work highlighted only changes in females with FAIS versus age-matched control individuals, so directly comparing larger groups of sex-specific groups would better elucidate the differences or similarities reported here. No data were collected on hormonal or ovarian cycle changes, which may have influenced the results via increased tissue laxity or gait characteristics. Different results might have been noted if all surgeries had been performed by a single surgeon, despite the similarity of the arthroscopic procedures. All patients had labral tears, but they had various types of hip morphologies, which may have affected the results. The

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primary factor influencing their preoperative gait changes was likely pain and not mechanical impingement; however, we did not directly assess pain. Patients underwent nonstandardized postoperative physical therapy. The exercise selection, length of the programs, and gait training varied because of insurance and logistical barriers and was left to the discretion of the individual therapists. Therefore, nonstandardized rehabilitation programs could have had an effect on the results. Lastly, no diagnostic imaging was conducted on control participants, so it is possible that existing asymptomatic hip morphologies may have influenced gait without our knowledge.

CONCLUSIONS

We presented gait changes in women with FAIS compared with control individuals. Patients in this sample achieved walking gaits that were similar to those of control participants by 6 months postoperatively. Notable gait changes in women were observed at 3 months postoperatively. These may be considered postoperative compensations of which clinicians should be aware. In particular, the increased use of ankle and knee motion and forces during loading and midstance was followed by decreased amounts of hip extension in terminal stance and swing. If these are observed clinically, it is important for clinicians to determine if pain, fear, or neuromuscular causes led to the gait alteration. Six months after their hip arthroscopy, patients with FAIS walked faster, had normalized their gait, and had greatly improved their ADLs.

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SUPPLEMENTAL MATERIAL

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