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Sex-specific sagittal and frontal plane gait mechanics in persons post-hip arthroscopy for femoroacetabular impingement syndrome.

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Abstract

Post-operative gait mechanics in persons with femoroacetabular impingement syndrome (FAIS) remain understudied as a treatment outcome despite observed, yet inconclusive, pre-operative gait abnormalities. Females with FAIS demonstrate worse pre-operative patient-reported hip function and altered hip mechanics when compared to males; it is unknown whether these sex differences persist post-arthroscopy. The purpose of this study was to compare sex-specific gait kinematics between persons at least one year post-arthroscopy for FAIS and healthy comparisons (HC). General linear models with estimating equations were used to evaluate the effect of (1) limb and sex within each group, and (2) limb and group within each sex for peak sagittal and frontal plane trunk, pelvis, and hip kinematics during stance phase of gait. Analyses were covaried by gait speed. Seventeen females and eight males an average 2.5 years post-arthroscopy (1.1–7.2y) for FAIS were compared to healthy females (n=7) and males (n=5). Females in the FAIS group presented with an average of 4.6° more anterior pelvic tilt, and 4.8° less hip extension compared to healthy females (P 0.03) and 8.6° less trunk flexion, 4.8° more anterior pelvic tilt, 3.1° more pelvic drop, and 7.5° more hip flexion than males with FAIS (P 0.03). Males in the FAIS group

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Conceptualization (LBT, TEH, JR, SD, CLL); data collection (LBT, SD); data analysis (LBT, SD, CLL, BS, JP); funding acquisition (TEH, SD); project administration (SD); patient acquisition (JR); writing (LBT, BS, CLL, TEH, JR, SD, JP). All authors have read and approved the submitted version.

presented with 2.9° less pelvic drop, and 3.2° less hip adduction than healthy males. Pre-operative gait mechanics were not collected and thus changes in mechanics could not be evaluated. This study is significant to clinicians who treat patients post-arthroscopy to consider sex-specific gait impairments.

Keywords

FAI; walking; gender; kinematics

Introduction:

Cam and pincer morphology of the hip can result in aberrant contact between the femur and acetabulum,¹ but does not always manifest as painful or limited movement.^{2,3} Only those with pain and symptoms are diagnosed with the clinical condition femoroacetabular impingement syndrome (FAIS). Surgical intervention to address anatomical morphology may improve patient-reported function; however, as little as 1 in 4 patients reported satisfaction with their outcome two years post-operatively.⁴ These data indicate there may be other factors of this multi-faceted clinical syndrome, not addressed by surgery, which could contribute to suboptimal function.

Individuals with FAIS exhibit unique mechanics during functional movements, such as squatting, rising from seated, climbing stairs, and walking.⁵ A recent systematic review and meta-analysis of 14 biomechanical investigations of movement patterns associated with FAIS included six studies reporting reduced hip extension and internal rotation compared to controls.⁵ More recent biomechanical studies with larger participant samples indicate truncated hip kinematics may be a hallmark of individuals with FAIS.⁶⁻⁸ It is unclear from the limited available evidence whether movement impairments persist post-operatively,^{9,10} and help explain the variation in patient-reported outcomes.^{4,11-13}

The majority of studies that have examined gait mechanics of individuals with FAIS included primarily male participants,⁵ despite epidemiological reports that indicate females represent over half of the FAIS population.¹⁴ Sex-specific differences for patient-reported outcomes have been identified,¹⁵⁻¹⁷ but the effect of sex on movement impairments has only recently been examined. While sex differences are apparent in gait mechanics of healthy populations,¹⁸⁻²¹ these may be exacerbated in patients with FAIS.^{6,8} A cross-sectional study of 21 participants with FAIS compared to 41 healthy comparisons found distinct pelvic-femoral kinematics of participants with FAIS that were also sex-dependent.⁶ In another cross-sectional study specific to competitive soccer players with FAIS, males demonstrated less hip flexion, adduction, and internal rotation during the stance phase of gait than females.⁸ Considering the evidence that gait mechanics in FAIS may be sex-specific and that females may be more susceptible to inferior treatment outcomes,^{16,17,22} an understanding of sex-specific mechanics following hip arthroscopy could enhance current peri-operative rehabilitation.¹¹⁻¹³

The purpose of this study was to compare sex-specific gait kinematics between persons after hip arthroscopy for FAIS and healthy comparisons. Based on the findings of Lewis and

colleagues (2018), we tested the primary hypotheses that (1) males in the FAIS group would demonstrate more anterior pelvic tilt and decreased hip extension and abduction, regardless of limb, when compared to healthy males; and (2) females in the FAIS group would exhibit hip extension asymmetry that was not observed in healthy comparisons. Healthy females demonstrate more pelvic motion^{18–20} and less trunk flexion²³ than healthy males; and thus, a secondary hypothesis tested was that females in the FAIS group would demonstrate less trunk flexion and more anterior pelvic tilt and pelvic drop than males in the FAIS group. We hypothesized that these sex differences would be greater than those identified in the healthy cohort. While hip arthroscopy may reduce symptoms through improved local joint biomechanics (i.e. bony resection), movement impairments during functional tasks can persist.^{10,24} We anticipated that similar movement impairments previously identified in pre-operative cohorts would also be identified in this post-operative cohort.

Methods

The institutional review board at The Ohio State University approved this cross-sectional, case-control laboratory study (Level III evidence). All participants completed and signed an informed consent.

Participants

Persons with FAIS who underwent unilateral hip arthroscopy and healthy comparison participants were recruited for this study. Participants with FAIS were recruited over 21 months from a prospective registry of patients who underwent elective hip surgery. Included FAIS participants were between the ages of 18 and 50 years at time of surgery with an intra-operative diagnosis of cam and/or pincer morphology treated via unilateral hip arthroscopy at least one year prior to enrollment in this study. Participants with a history of serious injury or surgery to spine or other lower extremity joints were excluded; serious injury was defined as injury requiring assistive device or medical attention beyond 3 days.

Healthy comparison (HC) participants were recruited over three months via convenience sampling. Participants in the HC group were invited to participate if they denied hip pain over the prior month and denied history of serious injury or surgery to the spine or lower extremity joints.

Sample Size

This study is a secondary analysis from a longitudinal study designed to evaluate changes in patient-reported hip function and movement mechanics. An *a priori* power analysis for the variable of interest (i.e. peak hip extension) of this specific study was not performed.

Data collection

Motion Capture—Retroreflective markers including four lower extremity clusters, cluster backpack, and custom shoes were placed on anatomical landmarks by lab personnel with verified reliability to the gold standard (Principal Investigator). Standard error of the measurement (SEM) for single-session intra-limb variability of sagittal and frontal plane hip angles were 0.2° and 2.3° respectively. Sagittal plane SEM for trunk, pelvis, and hip angles

were calculated from intra- and inter-rater reliability data (2.9°, 2.1°, 3.6° and 3.9°, 0.6°, 1.1° respectively). Frontal plane SEM values were also calculated for the trunk, pelvis, and hip from intra- and inter-rater reliability data (0.4°, 2.2°, 2.5° and 0.3°, 1.0°, 1.5° respectively). A 12-camera motion analysis system (240Hz; Motion Analysis Co., Santa Rosa, CA) was used to record kinematic gait data from the trunk, pelvis, and lower extremities. Participants performed a static calibration to define segment positions and joint centers. Dynamic hip joint movements with flexion, abduction, extension, and circumduction were used to locate the hip joint center using established methods.²⁵ Five unilateral foot strikes on a single force plate were obtained for each leg at a self-selected walking speed using the cue to “walk at your comfortable pace, as if you have somewhere to be, but are not running late.” Participants were asked to report their pain during walking using the Numeric Pain Rating Scale.

Participant-Reported Function—All participants completed the 33-item International Hip Outcome Tool (iHOT33) to capture self-reported hip function.²⁶ This tool has previously been demonstrated to be valid, reliable, and responsive for active persons with symptomatic hip conditions.^{26,27} An iHOT33 score of 91 out of 100 has previously been proposed as optimal function.²⁸

Data processing

Motion capture trials for the last 3 of 5 gait trials were labeled using Cortex software (Motion Analysis, Santa Rosa, CA) and gaps <100ms were spline filled. Marker data were filtered in Visual3D software (C-Motion Inc. Rockville, MD) using a 4th order low-pass Butterworth 20hz filter. Participant-specific models were created to identify segment poses of the trunk, pelvis, and lower extremity, as well as joint centers of the hip, knee, and ankle. Dynamic hip joint movement trials were used to define the hip joint center.²⁵ Knee and ankle joint centers were defined as the midpoint between medial and lateral joint lines and malleoli, respectively. Models were generated using a modified Helen Hayes markerset with cluster tracking for the shanks, thighs, and sacrum. Segment inertial parameters were sex-specific and defined using adjusted parameters described by de Leva.²⁹ Euler joint angles were calculated with an X-Y-Z rotation sequence (flexion/extension, abduction/adduction, internal/external rotation) throughout stance of gait trials for each limb. The joints were not assumed to be in neutral position during static standing calibration.

Vertical trunk axis was defined as the line between C7 and T12 markers. Anterior-posterior axis was defined as the line between C7 and suprasternal notch markers. Medial-lateral axis was defined as the cross product of vertical and anterior-posterior axes following the right-hand rule. The pelvis was defined using anterior, superior iliac spine and sacral markers. Thigh segments were defined using greater trochanter and knee joint line markers. Shank segments were defined using knee joint line and ankle malleoli markers. Thigh and shank segments were tracked using posterolateral clusters. The foot was defined using ankle malleoli and shoe markers.

Trunk and pelvis angles were defined with respect to the global lab coordinate system. Lateral flexion of the trunk during stance was described as towards or away from the stance

limb. Frontal plane pelvic motion was described as drop or hike of the non-stance side of the pelvis (Figure 1). Hip, knee, and ankle angles were defined as the distal relative to the proximal segment. Peak sagittal and frontal plane angles during stance at the trunk, pelvis, and hip were identified in each trial for each limb, then averaged for statistical analysis. Stance was defined when the vertical ground reaction force surpassed 20N (initial contact) to the point when it dropped below 20N (toe off).

Statistical analysis

Assumptions of statistical tests were assessed; non-parametric equivalents were performed in the event of violated assumptions. All *a priori* significance levels were set to $P = 0.05$. Analyses were performed using IBM SPSS Statistics Version 24 (IBM Corporation, Armonk, NY). For the biomechanical variables of interest, gait speed was used as a covariate in each general estimating equations model and the dominant limb of the HC group was operationally defined as the involved limb. Significant differences were only reported if they exceeded the calculated SEM.

Demographics and patient-reported hip function—The interaction of sex and group (HC vs. FAIS) was evaluated for age and body mass index with two-way analyses of variance. If significant interactions were found, *post hoc* independent sample t-tests were used to identify (1) sex differences within groups and (2) group differences within sexes. Significant main effects were reported if no significant interactions were found. A Kruskal Wallis test was used to compare gait speed and iHOT33 scores across FAIS females, FAIS males, HC females, and HC males. If a significant effect was observed, Mann Whitney U tests were used to (1) identify sex differences within groups and (2) group differences within sexes. A Mann Whitney U test was used to compare time post-arthroscopy between FAIS males and females.

Effect of limb and group within sexes—General linear models with estimating equations were used to detect interactions of limb and group within each sex for peak sagittal and frontal plane kinematics at the trunk, pelvis, and hip throughout stance. If significant interactions were found, planned *post-hoc* t-tests with least significant difference adjustment for multiple comparisons were performed to compare (1) involved limb mechanics between groups, and (2) limbs within each group. Significant main effects of limb and group were reported when significant interactions were not identified.

Effect of limb and sex within groups—General linear models with estimating equations were used to detect interactions of limb and sex within each group for peak sagittal and frontal plane kinematics at the trunk, pelvis, and hip throughout stance. If significant interactions were found, planned *post-hoc* t-tests with least significant difference adjustment for multiple comparisons were performed to compare (1) involved limb mechanics between sexes, and (2) limbs within each sex. Significant main effects of limb and sex were reported when significant interactions were not identified.

Results

This study included 25 participants at least one-year post-arthroscopy for FAIS and 12 HC participants (Table 1). There was no interaction or main effect of sex or group for age ($P = 0.21$; Table 1). There was no interaction of sex and group for BMI ($P=0.23$); however, females presented with lower BMI [$24.09(2.94) \text{ kg/m}^2$] than males [$25.76(2.29) \text{ kg/m}^2$; $P=0.05$], regardless of group. The FAIS group reported worse iHOT33 scores than the HC group ($P = 0.004$; Table 1); however, iHOT33 scores and time from surgery did not differ between FAIS males and females ($P = 0.44$; Table 1). Gait speed was not significantly different between FAIS females, FAIS males, HC females, and HC males ($P=0.15$; Table 1). All participants denied pain (i.e. reported 0/10 pain via numeric pain rating, 0–10) during walking gait trials. Trunk, pelvis, and hip kinematics are reported based on sex and group. Knee and ankle kinematics are provided as supplemental data (Supplemental File 1).

Males: FAIS vs. HC

Trunk—There were no interactions or main effects for peak trunk flexion ($P = 0.13$), extension ($P = 0.09$), or lateral flexion towards ($P = 0.72$) or away ($P = 0.82$) from the stance limb (Table 2).

Pelvis—There were no interactions or main effects for peak anterior ($P = 0.27$) or posterior ($P = 0.06$; Table 3) pelvic tilt or pelvic hike ($P = 0.10$); however, there was an interaction of limb and group for pelvic drop ($P=0.04$). Males in the FAIS group demonstrated less pelvic drop during testing of the involved limb [$3.4(2.2^\circ)$] compared to healthy males [$6.3(2.6^\circ)$; $P=0.02$].

Hip—There was an interaction of limb and group for peak hip flexion ($P=0.02$). Healthy males demonstrated limb asymmetry that did not exceed the SEM for intra-limb variability. There was no interaction or main effects for peak hip extension ($P = 0.22$; Table 4). There was an interaction of limb and group for peak hip adduction ($P=0.01$), such that FAIS males demonstrated less hip adduction on the involved limb [$5.9 (1.9^\circ)$] than healthy males [$9.1 (2.6^\circ)$; $P=0.01$]. There was a main effect of group for peak hip abduction ($P=0.05$); however, group differences did not exceed the SEM.

Females: FAIS vs HC

Trunk—There were no interactions or main effects for peak trunk flexion ($P = 0.22$) or extension ($P = 0.28$; Table 2). There was a main effect of limb for peak lateral flexion toward the stance ($P=0.02$) and non-stance ($P=0.02$) limbs. Females, regardless of group, demonstrated 1.3° less lateral trunk flexion toward the stance limb and 1.4° more lateral trunk flexion away from the stance limb during involved stance compared to uninvolved stance.

Pelvis—There were no interactions for peak anterior or posterior pelvic tilt ($P = 0.12$); however, there were significant main effects of group. The FAIS females presented with more anterior pelvic tilt [$10.3(5.5^\circ)$] than healthy females [$5.7(4.6^\circ)$; $P=0.03$]. At peak posterior pelvic tilt, both groups demonstrated an anterior pelvic tilt, but the FAIS females

were more anteriorly tilted [6.4(5.4°)] than healthy females [1.2(4.8°); $P=0.01$]. There was an interaction of limb and group for peak pelvic hike ($P=0.006$). Healthy females presented with more pelvic hike during stance on the non-dominant limb [6.1 (1.8°)] compared to the dominant limb [3.7 (2.5°); $P=0.02$]. There was a main effect of limb for peak pelvic drop ($P=0.02$), but limb differences did not exceed the SEM.

Hip—There was no interaction or main effects for peak hip flexion ($P=0.07$); however, there was an interaction of limb and group for peak hip extension ($P=0.01$). The FAIS females presented with less hip extension on the involved limb [10.5(6.4°)] compared to the dominant limb of healthy females [15.3(5.4°); $P=0.04$]. Healthy females demonstrated limb asymmetry that did not exceed the SEM for intra-limb variability. There was no interaction or main effects for peak hip adduction ($P=0.13$). There was an interaction of limb and group for peak hip abduction, but no significant pairwise comparisons were identified between limbs within groups or between groups for the involved limb ($P=0.13$).

FAIS: Males vs Females

Trunk—There were interactions of limb and sex for peak trunk flexion and extension ($P<0.001$). Males in the FAIS group demonstrated more trunk flexion [20.9(5.9°)] during a step with their involved limb compared to FAIS females [12.3(3.4°); $P<0.001$; Figures 2 and 4]. Both FAIS females and males were flexed at peak trunk extension during stance of the involved limb [females: 8.8(3.6°) flexed; males: 17.8(5.9°) flexed; $P<0.001$]. There were no interactions or main effects for peak lateral trunk flexion towards or away from the stance limb ($P=0.13$).

Pelvis—There was an interaction of limb and sex for peak anterior pelvic tilt ($P=0.04$). Females in the FAIS group presented with more anterior tilt during stance on the involved limb [10.3(5.4°)] than males [5.5(5.4°); $P=0.03$]. There was no interaction nor main effects of limb or sex for peak posterior tilt ($P=0.08$) or pelvic hike ($P=0.26$). There was an interaction of limb and sex for peak pelvic drop ($P=0.001$). During stance on the involved limb, FAIS females demonstrated more pelvic drop [6.5 (1.7°)] than FAIS males group [3.4 (2.2°); $P<0.001$].

Hip—There was an interaction of limb and sex for peak hip flexion ($P=0.02$). Females in the FAIS group demonstrated more hip flexion [34.1(7.4°)] on their involved limb compared to FAIS males [26.6(7.2°); $P=0.01$; Figure 2]. No interaction or main effects of limb or sex were identified for peak hip extension ($P=0.46$). There were interactions of limb and sex for both peak hip adduction and abduction ($P<0.001$). Females in the FAIS group presented with more hip adduction [11.3 (2.2°)] and less hip abduction on the involved limb [2.9 (2.4°)] than FAIS males [adduction: 5.9 (1.9°), $P<0.001$; abduction: 6.5 (1.6°), $P<0.001$; Figures 3 and 5].

HC: Males vs Females

Trunk—There was no interaction nor main effects of limb or sex for peak trunk flexion, extension, or lateral flexion to either side ($P=0.09$).

Pelvis—There was no interaction nor main effects of limb or sex for peak anterior pelvic tilt ($P = 0.45$). There was an interaction of limb and sex for peak posterior tilt ($P=0.04$). Healthy males presented with asymmetry; however, this did not exceed the SEM for tester reliability. There was no interaction nor main effects of limb or sex for peak pelvic hike ($P = 0.11$); however, there was an interaction for peak pelvic drop ($P=0.05$). Healthy females group presented with more pelvic drop during stance on the dominant limb, compared to stance on the non-dominant limb, but these differences did not exceed the SEM.

Hip—There was an interaction of limb and sex for peak hip flexion ($P=0.03$). Healthy males presented with asymmetry that did not exceed the SEM for tester reliability. There was no interaction of limb and sex for peak hip extension ($P=0.10$); however, there was a main effect of limb that did not exceed the SEM for tester reliability. There was an interaction of limb and sex for peak hip adduction ($P=0.01$). During stance on the involved limb, healthy females displayed more hip adduction [$13.5 (4.6^\circ)$] than healthy males [$9.1 (2.6^\circ)$; $P=0.02$]. There was also a main effect of sex for peak hip abduction ($P=0.008$). Healthy females presented with less peak hip abduction [$4.4 (4.9^\circ)$] than healthy males [$8.0 (2.3^\circ)$], regardless of limb.

Discussion

This study aimed to compare sex-specific gait kinematics between persons after surgery for FAIS and healthy comparisons. Contrary to our hypotheses, we did not observe any sagittal plane differences between post-arthroscopy and healthy males; however, frontal plane differences at the pelvis and hip were observed. Furthermore, sagittal plane differences were identified between post-arthroscopy and healthy females and also between FAIS males and females. As expected, frontal plane sex differences existed in both FAIS and HC groups for the pelvis and hip, but were greater in the FAIS group.

These findings contrast previous work in a younger cohort that identified six degrees reduced peak hip extension and five degrees more anterior pelvic tilt in FAIS males compared to healthy males.⁶ This same cohort included FAIS females who presented with two degrees reduced hip extension on their painful compared to non-painful limb.⁶ Participants in this present study were an average 2.5 years post-arthroscopy, whereas Lewis and colleagues (2018) recruited participants with FAIS who had not received any surgical treatment.⁶ These separate cohorts were evaluated at different points of their treatment course, which may contribute to the different observed biomechanical adaptations. Furthermore, Lewis and colleagues (2016) had more even distribution of sex across the FAIS and control samples. The small male sample in the present study may limit our identification of potential group differences for males.

Interestingly, this study identified differences between healthy and post-arthroscopy participants, specific to females. Females in the FAIS group presented with more anterior pelvic tilt and reduced hip extension than healthy females. These group-specific movement impairments were not observed in sampled males. In combination, an anteriorly tilted pelvis and reduced hip extension may indicate an unconscious attempt to maintain a more flexed hip to avoid excessive hip extension, which can increase anteriorly directed forces within the

hip.³⁰ Importantly, all participants in this study reported no pain during walking trials, suggesting that this adaptation exists after surgery, in spite of reduced pain and improved function.

Average peak hip extension was similar across sexes in both groups. These data highlight the group difference in females, but may lack statistical power to detect sex differences in participants with FAIS. Females in the FAIS group also presented with more anterior pelvic tilt and peak hip flexion than FAIS males; whereas FAIS males presented with more trunk flexion. These sex-specific adaptations were not observed in HCs. The trunk flexion observed in FAIS males and the anterior pelvic tilt observed in females are both movement compensations that have been postulated to reduce loads about the hip^{30,31}; however, kinetics were not included in this analysis and thus this is only a hypothesis for these observations. The sex difference may be the result of a learned post-operative strategy to protect the anterior joint capsule or specific to intra-articular pathology, such as articular cartilage damage, or labral degeneration, that produced abnormal movement strategies prior to surgery which persisted post-operatively. Males with FAIS have previously been shown to have larger cam morphology than females,^{32,33} which may have prevented excessive pelvic motion and thus encouraged a trunk strategy to offload the hip. Unfortunately, the present sample is cross-sectional and any speculations related to pre-operative gait mechanics cannot be confirmed or denied.

Frontal plane abnormalities have been identified during gait^{5,7,8} and more dynamic activities^{34–36} for persons with FAIS. The present study identified sex-specific differences in the frontal plane that were unique to the FAIS group. Females in the FAIS displayed approximately 3° more pelvic drop than FAIS males. This sex-specific pelvic motion was not identified in the HC group. The syndrome-specific sex differences for pelvic drop complement the sagittal plane findings that males and females display different pelvic strategies during gait after hip arthroscopy compared to healthy counterparts.

The results of this study indicated statistically significant limb asymmetries within the HC group; however, each limb difference fell below the SEM for sagittal plane kinematics. Surprisingly, no sagittal plane sex differences were identified within this small HC group. Pelvic and lower extremity alignment differ between healthy males and females in static positions,³⁷ and sex differences have been reported during gait for healthy individuals.^{6,18–21,38} All participants in the present study demonstrated faster walking speeds than previously published cohorts,³⁹ which may contribute to the lack of sex-dependent sagittal plane gait mechanics in our healthy cohort.

Study limitations

Healthy comparisons were not recruited as exact sex-matches to FAIS participants and may have been limited by a small sample size. While healthy comparisons denied hip pain during the month prior to testing, some may have experienced hip pain before. The significantly better hip function reported by the healthy comparisons reaffirms their distinct difference from the post-arthroscopy group. Cam and pincer morphology have previously been identified in asymptomatic cohorts^{2,3} and may have been present in the healthy cohort. To our knowledge, no studies have been published to identify abnormal gait mechanics in

asymptomatic individuals with morphological features of FAI, although asymptomatic morphology may be associated with impaired squat mechanics.⁴⁰ The purpose of this study was to evaluate sex differences in persons after hip arthroscopy compared to a pain-free sample without history of hip arthroscopy for symptomatic FAI. Radiographic evaluation of the comparison group was not required since this study did not aim to evaluate the effect of cam or pincer morphology on gait.

Imaging was not included in this study. Anatomical variances, including across sexes, may have contributed to group differences in gait mechanics. The presence of sex-specific differences in the FAIS group, but not the HC group, suggests that sex-specific anatomical differences are not the sole contributor to sex-specific gait mechanics observed post-arthroscopy. While standing posture was not the focus of this study, the authors recognize that sex- and syndrome-specific gait abnormalities may be related to differences in preferred postures. Future investigations should consider the potential effect of posture on mechanics during dynamic tasks.

Participants post-arthroscopy were recruited at a variety of years after surgery (1.1 – 7.2 years) at a time when self-reported hip function during daily activities begins to plateau.^{12,22} The time from surgery in this sample was not related to worse patient-reported hip function or pain levels in the week preceding testing. Its relationship to gait mechanics was not assessed in this study, but it is possible that the gait mechanics of these patients may continue to change in the years following surgery; thus, serial, longitudinal gait assessments will be important for future studies. Pre-operative gait mechanics were not collected and thus changes in mechanics could not be evaluated.

Participants post-arthroscopy were older than other cohorts with FAIS.⁴¹ The sex differences observed for gait mechanics in this cohort may not be generalizable to younger patients. Furthermore, the sex distribution was skewed toward females, but this is representative of the larger population of persons with FAIS.^{41,42}

Preferred versus prescribed gait speed has previously not elucidated additional gait alterations in those with FAIS⁶; however, cueing to produce slower speeds may have altered study findings. Three-dimensional motion capture with skin-mounted markers can result in error from soft tissue artifact and marker misplacement which may impact kinematic calculations.^{43,44} Five separate healthy participants were used to calculate SEM values for each variable of interest in this study. The SEMs were likely influenced by the small sample, but were still valuable to compare any significant group or sex differences to potential error. Previous SEM values have not been reported in many biomechanical investigations of FAIS, as identified by King and colleagues.⁵ The results of the present study were reported only if they exceeded SEM values.⁴⁵

Conclusion

Females post-arthroscopy for FAIS presented with increased anterior pelvic tilt during walking compared to males, who presented with increased trunk flexion. Females in the FAIS group also presented with more pelvic drop than the FAIS males. These sex

differences were not observed in the HC group. Despite previous work that has identified a relationship between movement and hip function for persons with chronic hip joint pain,³⁴ the movement impairments observed post-arthroscopy in this study were not reflected in patient-reported hip outcomes which were similar, and suboptimal, across both males and females post-arthroscopy.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure1.
Frontal plane pelvic position was described as hike or drop relative to the stance limb.

Figure2. Schematic sagittal plane representation of relative joint positions of the trunk, pelvis, and lower extremity at peak hip extension for healthy cohort (A) and femoroacetabular impingement syndrome (FAIS) cohort (B). Group means for each joint position (trunk, pelvis, hip, knee, ankle) were obtained based on time-normalized data.

Figure3.

Schematic frontal plane representation of relative joint positions of the trunk, pelvis, and lower extremity at peak hip extension for healthy cohort (A) and femoroacetabular impingement syndrome (FAIS) cohort (B). Group means for each joint position (trunk, pelvis, hip, knee, ankle) were obtained based on time-normalized data.

Figure4. Sagittal plane time series curves representing averages and standard error for females (red) and males (black) in the healthy and femoroacetabular impingement syndrome (FAIS) groups. Flex=Flexion, Ext=Extension, Post=Posterior, Ant=Anterior.

Figure5.

Frontal plane time series curves representing averages and standard error for females (red) and males (black) in the healthy and femoroacetabular impingement syndrome (FAIS) groups. Lateral trunk flexion is in relation to the ipsilateral or contralateral side of the stance limb. Ipsi=Ipsilateral, Contra=Contralateral, Add=Adduction, Abd=Abduction.

Table 1.**Participant Demographics**

	Healthy Sample		FAIS Sample	
	Females	Males	Females	Males
N	7	5	17	8
Age (y)	30(9)	38(9)	36(11)	36(8)
Height (m)	1.63(0.05)	1.72(0.07)	1.64(0.03)	1.79(0.06)
Weight (kg)	64.67(13.39)	82.36(13.79)	65.04(5.35)	79.91(7.67)
BMI (kg/m ²)	24.23(4.78)	27.36(2.15)	24.03(1.96)	24.77(1.85)
Gait speed (m/s)	1.64(0.12)	1.67(0.35)	1.60(0.13)	1.48(0.12)
iHOT33	98(5)	99(1)	77(18)	75(17)
Time post-operative (y)			2.63(1.50)	2.16(1.10)

Means(standard deviation) are presented

FAIS: Femoroacetabular impingement syndrome; BMI: Body mass index; iHOT33: 33-item international hip outcome tool

Table 2.**Peak Trunk Position during Stance Phase of Walking Gait**

	FAIS				HC				
	Surgical		Non-surgical		Dominant		Non-dominant		
Female									
Max Trunk Flexion [†]	12.3	(3.4)	11.9	(3.5)	14.0	(4.1)	14.0	(3.6)	
Min Trunk Flexion [†]	8.8	(3.6)	8.3	(3.7)	10.2	(4.1)	10.4	(3.9)	
Max Lateral Trunk Flexion towards stance limb [‡]	2.7	(2.7)	3.4	(2.6)	1.8	(2.8)	4.9	(2.6)	
Max Lateral Trunk Flexion away from stance limb [‡]	3.2	(2.4)	2.4	(2.7)	4.7	(3.0)	1.5	(2.2)	
Male									
Max Trunk Flexion [†]	20.9	(5.9)	20.4	(6.0)	15.9	(6.2)	16.0	(5.9)	
Min Trunk Flexion [†]	17.8	(5.9)	17.5	(6.0)	12.5	(5.9)	12.7	(5.4)	
Max Lateral Trunk Flexion towards stance limb	5.0	(2.3)	3.5	(3.4)	3.7	(5.3)	4.8	(6.1)	
Max Lateral Trunk Flexion away from stance limb	3.1	(3.1)	4.2	(2.2)	4.2	(5.2)	3.4	(5.3)	

Data are represented as mean(standard deviation) during stance phase of each limb; FAIS=femoroacetabular impingement syndrome; HC=healthy comparison; Max=maximum; Min=minimum

[†] significant difference between sexes for involved limb of FAIS group (P 0.05)

[‡] significant main effect of limb (P 0.05).

Table 3.**Peak Pelvic Position during Stance Phase of Walking Gait**

	FAIS				HC				
	Surgical		Non-surgical		Dominant		Non-dominant		
Female									
Max Anterior Pelvic Tilt ^{*†}	10.3	(5.4)	10.4	(5.8)	5.6	(4.7)	5.7	(5.0)	
Min Anterior Pelvic Tilt [*]	6.3	(5.4)	6.5	(5.7)	1.1	(5.2)	1.4	(4.8)	
Max Pelvic Hike [‡]	3.6	(1.5)	4.2	(1.8)	3.7	(2.5)	6.1	(1.8)	
Max Pelvic Drop ^{§†‡}	6.5	(1.7)	6.2	(1.5)	7.9	(1.7)	5.4	(2.6)	
Male									
Max Anterior Pelvic Tilt [‡]	5.5	(5.4)	5.9	(5.7)	7.8	(4.9)	7.3	(4.4)	
Min Anterior Pelvic Tilt [‡]	2.7	(5.2)	2.7	(5.0)	2.5	(4.2)	2.9	(4.1)	
Max Pelvic Hike	3.9	(1.4)	2.7	(2.1)	4.6	(1.2)	4.7	(5.8)	
Max Pelvic Drop ^{◇†}	3.4	(2.2)	4.8	(2.1)	6.3	(2.6)	3.3	(1.4)	

Data are represented as mean(standard deviation) during stance phase of each limb; FAIS=femoroacetabular impingement syndrome; HC=healthy comparison Max=maximum; Min=minimum

^{*} significant main effect of group (P<0.05)

[†] significant difference between sexes for involved limb of FAIS group (P<0.05)

[‡] significant asymmetry within HC group (P<0.05)

[§] significant main effect of limb (P<0.05)

[◇] significant difference between groups for involved/dominant limb (P<0.05).

Table 4.**Peak Hip Position during Stance Phase of Walking Gait**

	FAIS				HC			
	Surgical		Non-surgical		Dominant		Non-dominant	
Female								
Hip Flexion [‡]	34.1	(7.4)	34.9	(6.8)	28.3	(7.7)	30.0	(8.2)
Hip Extension ^{‡*§}	10.5	(6.4)	10.4	(6.0)	15.3	(5.4)	14.1	(6.0)
Hip Adduction ^{‡Φ}	11.3	(2.2)	10.0	(4.0)	13.5	(4.6)	11.3	(3.5)
Hip Abduction ^{‡/}	2.9	(2.4)	4.5	(3.7)	2.6	(6.0)	6.1	(2.9)
Male								
Hip Flexion ^{*‡}	26.6	(7.2)	26.0	(8.6)	30.7	(2.6)	31.8	(2.4)
Hip Extension [§]	12.8	(7.7)	12.6	(8.4)	15.2	(7.8)	14.0	(9.0)
Hip Adduction ^{‡/★Φ}	5.9	(1.9)	7.0	(4.0)	9.1	(2.6)	8.5	(1.6)
Hip Abduction ^{‡★/}	6.5	(1.6)	5.8	(3.5)	8.0	(2.5)	8.0	(2.4)

Data are represented as mean(standard deviation) during stance phase of each limb; FAIS=femoroacetabular impingement syndrome; HC=healthy comparison

* significant asymmetry within HC group (P 0.05)

‡ significant group difference for involved limb (P 0.05)

‡ significant difference between sexes for involved limb of FAIS group (P 0.05)

§ significant main effect of limb for HC group (P 0.05)

★ significant main effect of group (P 0.05)

Φ significant difference between sexes for involved limb of HC group (P 0.05)

/ significant main effect of sex for the HC group (P 0.05).