Hip Joint Kinetics and Kinematics are Altered in Symptomatic Femoroacetabular Impingement

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INTRODUCTION: Cam femoroacetabular impingement syndrome (FAIS) is a recognized cause of hip osteoarthritis and hip pain, particularly during activities involving large degrees of hip flexion and internal rotation [1]. Cam FAIS is characterized by femoral head asphericity and reduced femoral head and acetabulum clearance. Research suggests that cam morphology alone may not be the cause of pain, with an estimated ~35% of the population exhibiting asymptomatic cam morphology (ACM) [2]. To date, the pathophysiology of cam FAIS remains unclear. Quantification of hip biomechanical differences, including hip joint contact forces (HCFs), muscle forces, and kinematics between individuals with FAIS and ACM, may clarify the etiology of FAIS, inform diagnostics, and improve treatment. Previous research demonstrated decreased HCFs during squatting in individuals with FAIS compared to individuals with ACM [3]. Our study aims to expand upon these findings by utilizing musculoskeletal modeling to evaluate these two groups during level and inclined walking in addition to squatting. We hypothesized that individuals with FAIS would exhibit reduced HCFs and altered muscle forces and kinematics during inclined walking and squatting, which require greater hip flexion and/or internal rotation—motions often painful in FAIS [4]. In contrast, we expected no significant differences during level walking, where hip demands are lower.

METHODS: Seventeen pre-operative individuals with cam FAIS (8M/9F, age: 27.4±7.1 years, BMI: 24.8±3.1 kg/m^2) and thirteen controls with ACM having similar demographics (7M/6F, age: 26.5±4.9 years, BMI: 23.3±2.1 kg/m^2) participated in this IRB-approved study. Patients with cam FAIS were diagnosed by board-certified orthopaedic surgeons from the University of Utah Orthopaedic Center. In the ACM group, cam deformity was assessed by measuring the alpha angle using anterior-posterior (AP), 45° Dunn lateral, and modified false-profile radiographic views. A cam deformity was considered present if the alpha angle exceeded 55.5° [5] on any radiographic view. Each participant performed three activities at self-selected speeds on a force-instrumented treadmill with marker-based motion capture: level walking, inclined walking (5° incline), and bilateral squats. Kinematics, muscle forces, and HCFs were estimated using OpenSim [6] with a musculoskeletal model having 23 degrees of freedom and 98 musculotendon actuators [7]. Muscle forces were estimated using a custom static optimization implementation [8]. HCFs, muscle forces, and kinematics during early- and late-stance phases of walking and at maximal squat depth were compared using two-sample t-tests. Differences across the entire activity were evaluated with statistical parametric mapping (SPM). Significance level α=0.05 was used for all tests.

RESULTS: No significant kinetic or kinematic differences were observed in the level walk trial. During late-stance of inclined walking, the superiorly directed HCF for the FAIS group was 20.2% lower than the ACM group (p=0.01, **Figure 1**). Posterior gluteus minimus, psoas, iliacus, and rectus femoris muscle forces were also smaller in the FAIS group, compared to ACM, during the late-stance phase of the inclined walk trial (p<0.05). Decreased superiorly directed HCFs were observed during 18–31% of squat descent (p<0.05, **Figure 2**). At peak squat depth, individuals with cam FAIS had decreased gluteus medius, superior gluteus maximus, and piriformis muscle forces (p<0.05), but increased force in the obturator externus (64.3% vs. 39.8% BW; p = 0.025). The FAIS group also showed increased ankle dorsiflexion (p=0.013), knee flexion (p=0.027), and subtalar inversion angles (p=0.019) at maximal squat depth. SPM detected differences between groups in hip internal/external rotation, knee flexion, and ankle flexion angles throughout the squat trial (p<0.05).

DISCUSSION: The current study evaluated the kinetics and kinematics of multiple functional tasks in the FAIS and ACM groups. Despite both cohorts displaying cam morphology, individuals with symptoms (FAIS) displayed reduced HCFs in the late-stance of inclined walking and throughout the squat trial compared to those without symptoms (ACM). Since impingement commonly occurs at the anterior-superior acetabulum [1], individuals with FAIS may lower the iliopsoas muscle forces during the late-stance phase to decrease force on the acetabulum [9] and therefore reduce pain. The increased obturator externus muscle force in the FAIS group during squatting may reflect a compensatory strategy to provide external rotation in the absence of sufficient gluteal contribution to stabilize the hip and prevent excessive internal rotation and impingement during squatting. Overall, differences observed in our study could be the result of pain avoidance and/or a compensatory mechanism to offload the affected hip. Future work will include asymptomatic controls without cam morphology to differentiate the roles of cam, FAIS symptoms, and compensatory movement.

SIGNIFICANCE/CLINICAL RELEVANCE: It is unclear if individuals with ACM will progress to develop FAIS; a longitudinal study would be needed to better understand this or determine the mechanisms responsible for avoiding impingement-related symptoms. Still, the results of the current study could inform physical therapy protocols. Notably, assuming there are no morphological differences in hip anatomy between these groups, we envision patients with FAIS could be taught to mimic the lower extremity biomechanics of their ACM counterparts. We theorize this could reduce clinical symptoms and perhaps improve hip biomechanics in a way that prevents or delays progression to hip osteoarthritis.

REFERENCES: [1] M. Beck et al. (2005). *JBJS Br*, **87(7)**. [2] J. Frank et al. (2015). *Arthroscopy*. **31(6)**. [3] D. Catelli et al. (2021). *Front. Sports Act. Living*, **3**. [4] M. Freke at al. (2016). *Br. J. Sports Med*. **50**. [5] D. Allen et al. (2009). *J. Bone Joint Surg. Br.*, **91**. [6] A. Seth et al. (2018). *PLoS Comput. Biol*. **14(7)**. [7] M. Harris et al. (2017). *J. Biomech.*, **54**. [8] S. Uhlrich et al. (2022). *Sci. Rep.*, **12**. [9] C.L. Lewis et al. (2007). *J. Biomech.*, **40**.

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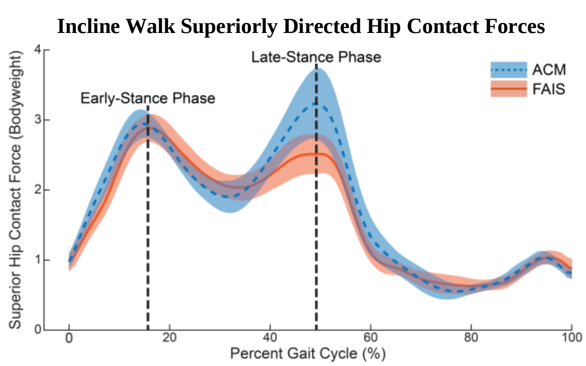

Figure 1: Superiorly directed HCFs for incline walk trial. While SPM did not detect differences, a t-test at the late-stance phase of the gait cycle found a significant difference between groups.

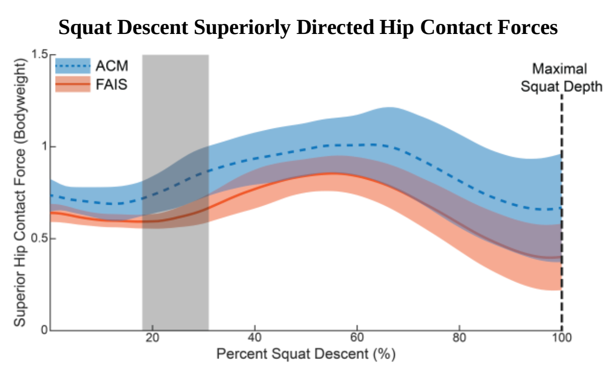

Figure 2: Superiorly directed HCFs for bilateral squat trial. The region of statistically significant differences detected via SPM (α=0.05) is shaded in grey.