

# Patients with Femoroacetabular Impingement Syndrome Demonstrate Altered Double-Leg Squat Movement Strategies at the Hip, Knee, and Ankle

Mell SP<sup>1</sup>, Yuh C<sup>1</sup>, Wright-Chisem J,<sup>1</sup> Alvero A<sup>1</sup>, Nho SJ<sup>1</sup>, Malloy P<sup>1,2</sup>  
<sup>1</sup>Rush University, Chicago, IL, <sup>2</sup>Arcadia University, Glenside, PA  
 Steven\_P\_Mell@rush.edu

**Disclosures:** Mell (N), Yuh (N), Wright-Chisem (N), Alvero (N), Nho (Allosource, American Orthopaedic Society for Sports Medicine, Arthrex Inc., Arthroscopy Association of North America, Athletico, DJ Orthopaedics, Linvatec, OSSUR, Smith & Nephew, Springer, Stryker Stryker), Malloy (N)

**INTRODUCTION:** Femoroacetabular impingement syndrome (FAIS) is a motion-related hip condition that presents with symptoms such as hip pain and impaired range of motion (ROM). Clinical imaging findings often include abnormal asphericity of the femoral head (also known as cam morphology). This abnormal morphology impinges into the acetabulum, causing injuries including cartilage damage and labral tears<sup>1</sup>. This impingement often occurs during athletic activities, where the joint is placed in extreme ROMs, such as during a double leg squat (DLS)<sup>1,2</sup>. Since a DLS commonly reproduces symptoms and can be easily assessed in the clinical setting, it has potential as a ‘biomechanical marker’ for predicting the presence of FAIS. A systematic review found that differences exist during DLSs between patients with FAIS and controls<sup>2</sup>. However, the contributing literature presents conflicting results, most likely due to small sample sizes<sup>2</sup>. Furthermore, several recent studies utilize data from the same cohort of subjects<sup>3,4,5</sup>. Thus, larger studies that expand on and validate previous findings are needed to better understand DLS biomechanics within the context of FAIS. A larger sample size also provides the statistical power to simultaneously evaluate mechanical variables of the knee and ankle, in addition to the hip. As the lower extremity joints are kinematically linked, other joints may demonstrate equal or greater magnitude of change than the hip alone. The purpose of this study is, therefore, to compare DLS lower extremity joint kinematics and squat performance in patients with FAIS versus healthy controls. We hypothesize that compared to healthy controls, patients with FAIS will squat to a lesser depth at a lower velocity, and demonstrate decreased hip, ankle, and knee joint sagittal plane motion.

**METHODS:** 60 participants, including 30 patients with FAIS and 30 healthy controls were enrolled in this institutional review board approved study. Participants underwent marker based three-dimensional motion capture while performing three trials of a DLS (Figure 1) with a twenty-camera system and force plates, where kinematic data was sampled at 100 Hz and kinetic data at 1000 Hz. The participants were instructed to “squat as low as possible”. All data were processed using Visual3D software, and a custom MATLAB script was used to define the squat cycle, calculate squat depth, maximum descent and ascent velocities, and joint ROM at the hip, knee, and ankle. Squat depth was calculated as the change in vertical position of the center of mass (COM) marker from full standing to the lowest vertical position during the squat cycle. Squat velocity during the descent (start to minimum vertical COM position) and ascent (minimum COM position to standing) phases were calculated as the first derivative of the COM marker position and were normalized to height. Joint ROM at the hip, knee, and ankle were defined as the difference of the maximum and minimum angles during the squat cycle. Independent sample t-tests ( $\alpha = 0.05$ ) were performed in SPSS to compare means in patients with FAIS and healthy controls and Bonferroni adjustments for multiple comparisons were applied to all comparisons. Cohen’s d (effect sizes) were also calculated for all variables.

**RESULTS:** Patients with FAIS and controls were matched with no between group differences in age, sex, height, and weight ( $p > 0.05$ ). Patients with FAIS demonstrate significantly less squat depth ( $p=0.0002$ ), and both slower ascent ( $p=0.0022$ ) and descent ( $p=0.0015$ ) velocity, when compared to healthy controls ( $n=30$ , Figure 2). Total sagittal plane hip, knee, and ankle ROM were also significantly less in patients with FAIS than controls (Hip  $p=0.0059$ ; Knee  $p=0.0001$ ; Ankle  $p=0.0029$ ). Interestingly, the largest effect size for total joint ROM was observed at the knee ( $d=-1.0936$ ), followed by the ankle ( $d=-0.7882$ ), and then the hip, which showed the lowest effect size ( $d=-0.7295$ ). All effect sizes and p-values are also listed in Table 1.

**DISCUSSION:** Our findings demonstrate key differences in DLS biomechanics between patients with FAIS and healthy controls for all variables studied, confirming our hypotheses that FAIS patients would squat lower and slower than healthy controls, and that the differences in squat depth would be reflected across the entirety of the lower extremity in the sagittal plane. Our results also further support and validate the findings of several studies that show decreased DLS performance in FAIS patients<sup>2-5</sup>. However, the existing literature on DLS biomechanics in the FAIS population is inconsistent, with studies often limited by low sample sizes and underpowered comparisons. Our study is unique in that our large FAIS and healthy control cohorts enabled highly powered comparisons, allowing a large number of biomechanical variables to be assessed. Our findings indicate that FAIS patients demonstrate altered squat movement strategies in several ways: 1) FAIS patients perform DLSs more slowly during both the ascent and descent phases, 2) FAIS patients squat to a lower depth, and 3) this lower squat depth is reflected in a lower total ROM at all joints of the lower extremity in the sagittal plane. This last point is critical, as it indicates that squat modification strategies in FAIS patients are not limited to the hip alone. In fact, the largest effect size was observed at the knee, while the hip had the smallest effect size. Similarly, Lamontagne et al. showed, that knee and ankle joint ROM changed significantly after hip arthroscopic surgery for FAIS, whereas hip joint ROM did not<sup>5</sup>. Together, these findings suggest that motion at the knee and ankle may be equally as important to study as motion at the hip in patients with FAIS. This study had several limitations, namely 1) we did not include asymptomatic individuals with cam morphology, which might reveal that these individuals have adopted compensatory movement strategies compared to patients with FAIS, and 2) we only reported on sagittal plane ROM. Reducing our data to only the sagittal plane kept the number of comparisons lower to maintain high statistical power. However, differences may exist in the other anatomical planes, which we will investigate in future work.

**SIGNIFICANCE/CLINICAL RELEVANCE:** DLS biomechanics clearly differ between FAIS patients and matched controls, both in magnitude and significance. We demonstrate DLS movement alterations across the lower extremity kinematic chain, indicating the need to understand the contributions of other joints above and below the hip to compensatory movement strategies in these patients. Since the DLS is easy to assess in a clinical setting, this task is therefore an exciting potential biomechanical marker of FAIS, that could have implications on clinical diagnosis, athletic performance, and return to sport.

**REFERENCES:** 1) Griffin, D. R., et al. *BJSM* 2016 2). King, M. G., et al. *BJSM* 2018 3). Catelli, D. S., et al. *OJSM* 2018 4) Catelli, D. S., et al. *JBJS* 2020 5) Lamontagne, M., et al. *JBJS* 2011

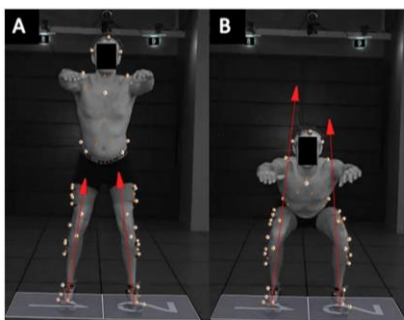


Figure 1: Motion analysis marker set up for a double leg squat task. Each subject was instructed to “squat as low as possible”.

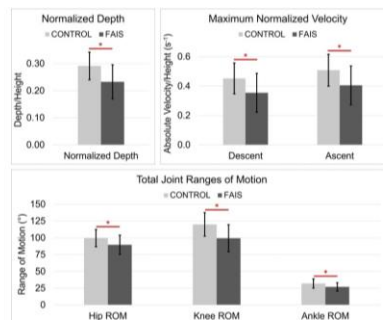


Figure 2: Average ± Standard Deviations for each variable were compared between patients with FAIS versus healthy controls. (\* $p < 0.05$ , Bonferroni corrected)

Table 1: Bonferroni corrected p-values and effect sizes are presented for each variable.

	n=30 FAIS n=30 Controls	p-value (Bonferroni Corrected)	Effect Size (Cohen’s d)
Normalized Depth		0.0002	-1.0273
Normalized Max Descent Velocity		0.0022	-0.8213
Normalized Max Ascent Velocity		0.0015	-0.8530
Total Hip Sagittal ROM		0.0059	-0.7295
Total Knee Sagittal ROM		0.0001	-1.0936
Total Ankle Sagittal ROM		0.0029	-0.7882