Comparison Of Proximal Femur Shape in Patients with Cam-type Femoroacetabular Impingement Before and After Hip Arthroscopic Surgery: A Statistical Shape Modeling Study

Catherine Yuh[1], Philip Malloy[1,2], Omair Kazi[1], Jorge Chahla[1], Shane J. Nho[1], Steven Mell[1]

[1]Rush University, Chicago, IL, [2]Arcadia University, Glenside, PA

catherine_yuh@rush.edu

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INTRODUCTION: Femoroacetabular impingement (FAI) is a clinical hip condition that arises from shape deformities of the femur and/or acetabulum. Cam type FAI occurs when the shape deformity is driven by an overgrowth of tissue at the anterosuperior region of the proximal femur, which manifests as a lack of femoral head-neck offset due to an asphericity of the femoral head. In certain positions and motions, this overgrowth of tissue impinges into the acetabulum, leading to abnormal mechanical contact and tissue damage at the hip joint. Hip arthroscopic surgery has emerged as a primary surgical treatment for FAIS with the goal of removing the cam deformity to restore femoral head-neck offset. While great strides in hip arthroscopy for treating FAI have been achieved, isolating the cam deformity from the remaining normal tissue presents a significant challenge to surgeons when determining how much tissue to remove. Previously, our group developed a non-invasive shape-fitting method to virtually predict the cam deformity in FAI patients, for the purposes of aiding surgical planning [1,2]. While this technique can be used to reveal quantitative information of the cam geometry at a patient-specific level pre-operatively, this work could be further enhanced by using population-based statistical shape modeling (SSM), a technique that has increasingly been implemented in studies on FAI [3,4]. Specifically, implementing SSM would allow for robust quantitative comparisons between preoperative and postoperative states for understanding changes in shape as a result of surgery. This information could eventually be used to help guide surgical resection of cam deformities to optimize hip joint function and patient outcomes. Therefore, in this preliminary study, we performed SSM on FAI patients, using magnetic resonance imaging (MRI) scans obtained pre- and post-operatively. Our research question for this study was: can SSM be used to identify where the largest differences in shape occur in pre- versus post-operative states, isolating the region that was removed from arthroscopic surgery?

METHODS: For this institutional review board approved study, 15 patients with FAI were enrolled from a single surgeon's high-volume hip preservation clinical practice (SJN). Inclusion and exclusion criteria are included in Table 1. Both before and after hip arthroscopic surgery to treat FAI, 1.5T MRI scans were obtained using a 3D gradient dual-echo MRI sequence with two echo times, as previously described [5]. Segmentation (Mimics) of the bone was performed on exported DICOMs of the MRI data for the pre- and post-operative proximal femur. Post-processed data were then imported as .stl files into an open-source SSM software (ShapeWorks [6]). A total of 2048 correspondence points (particles) were placed and optimized in ShapeWorks. To remove the effect of femoral size, a Procrustes scaling transformation was also included. The mean shape of the preoperative and postoperative femurs was then calculated based on the mean particle configuration within each group. The output particle model allowed for the statistical comparison of the mean shapes for the pre-operative and post-operative groups, using linear discriminant analysis (LDA). For this study, the significance threshold was set at $\alpha = 0.01$.

RESULTS: The patient cohort enrolled in this study had the following characteristics: age (28.6±7.1 years), BMI (22.6±2.8), male/female (6/9), and time to postop imaging (9.4±2.1 months). As expected, the region that was shown to have the largest and most significant differences between preoperative and postoperative shape was located at the anterosuperior aspect of the proximal femur, where the cam deformity is typically located (Figure 1). The largest change in depth was approximately 2.5 mm, as shown in Figure 1.

DISCUSSION: This preliminary study is the first to implement SSM to quantitively identify differences in proximal femur shape in patients with cam type FAI preoperatively and postoperatively. In addition, this study demonstrates the feasibility of performing SSM for studying FAI using MRI scans, as opposed to CT scans or radiographs. In the future, we will include asymptomatic controls into this work to answer the question: does arthroscopic surgery correct the FAI hip shape, such that postoperative hip shape is representative of the asymptomatic population? This would provide crucial information that could serve as a basis towards improving surgical resection guidelines to avoid negatives outcomes of arthroscopic surgery such as under- or over-resection, both of which can lead to the need for revision surgery or conversion to total hip arthroplasty. Therefore, the findings of this preliminary study serve as an important proof-of-concept for specifically studying surgical outcomes associated with FAIS.

SIGNIFICANCE: By studying the change in proximal femur shape before and after arthroscopic treatment using population-based SSM, the results of this study serve as a first step towards building a platform to study the effect of surgery on femoral shape, which has not been reported on previously using population-based statistical techniques. The expansion of this study can provide crucial data that will be used towards improving guidelines for hip arthroscopic surgery to treat FAI.

REFERENCES: **1** Guidetti, M. *et al. Journal of Orthopaedic Research* **2** Guidetti, M. *et al. Journal Orthopaedic Research* 41, 1256–1265 (2023) **3** Harris, M. D. *et al. J Orthop Res* 31, 1620–1626 (2013) **4** Van Buuren, M. M. A. *et al. Osteoarthritis and Cartilage Open* 4, 100275 (2022) **5** Malloy, P. *et al. J Orthop Res* 38, 2050–2056 (2020) **6** Cates, J. *et al.* in *Statistical Shape and Deformation Analysis* (eds. Zheng, G. et al.) 257–298 (Academic Press, 2017)

Table 1: Inclusion/Exclusion criteria for the 15 cam-type FAIS subjects

Inclusion
Diagnosis of cam-type FAIS
α angle > 50°
Undergo elective hip arthroscopic surgery
Exclusion
Tönnis Grade > 1
Prior surgery to the index or contralateral hip
History of developmental hip disorder
Developmental hip dysplasia

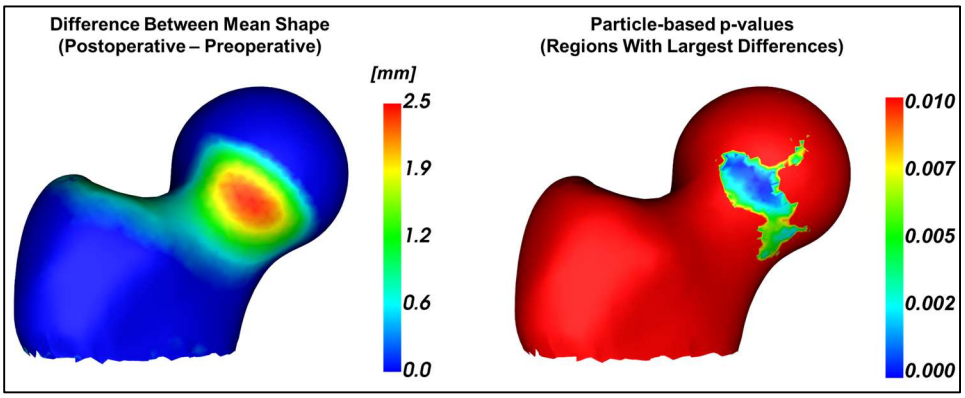

Figure 1: SSM results. Left: Heat map demonstrating depth differences in mean shape before and after hip arthroscopic surgery. Right: Corresponding p-values of the depth differences on the left.