Early and Persistent Meniscal Changes Following ACL Surgery

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INTRODUCTION: Anterior cruciate ligament (ACL) injuries commonly occur with a concurrent injury of the meniscus [1]. To supplement existing clinical assessments of evaluating graft maturity and estimating the structural properties of the healing ACL, quantitative magnetic resonance imaging (qMRI) has been used as a non-invasive method to measure cross-sectional area (CSA) and signal intensity (SI) [2]. qMRI-based predicted failure load of the ACL utilizes a combination of CSA and SI and has been found to be predictive of risk of revision within 2 years after ACL surgery [2]; however, the application and predictive power of these metrics as they relate to the menisci are largely unexplored. Early morphologic cartilage changes have also been detected with the use of MRI, with studies showing thickening of the central medial aspect of the femoral cartilage over the first two years post ACL reconstruction (ACLR) [3]. This evidence, and the growing acceptance that ACL injury, initiates a whole-joint response that provides additional motivation to investigate longitudinal changes in menisci after ACL surgery. The purpose of the study was to evaluate early morphologic changes of the menisci from MRIs obtained at 6, 12, and 24 months post-surgery of either ACLR or the bridge-enhanced ACL restoration (BEAR) and compare the morphology to the contralateral limb for both surgical groups [4]. It was hypothesized that the CSA and SI would be significantly higher in the surgical limb than the contralateral limb, and that there would be no differences found between the surgery types.

METHODS: Data were collected from 82 patients (42 females and 40 males, median age 17.6; 57 BEAR, and 25 ACLR) who underwent unilateral ACL surgery and then MRI at 6, 12, and 24 months post-surgery. The medial and lateral menisci of the surgical knee were automatically segmented from the MRI stack using custom software [5]. Cross-sectional profiles that quantify meniscal morphology were generated by rotating an intersecting plane through the meniscus (Fig. 1A). Sixty CSA measurements (Fig. 1B) were taken from the anterior root (0%) to the posterior root (100%) and the average SI was extracted from each meniscus cross-section (Fig. 1C). SI values were normalized using the anterior cortex of the femur and scaled using the measure for the background noise to account for MRI scanner hardware variations [5]. CSA differences were taken by subtracting the surgical limb CSA from the intact CSA at each of the sixty CSA locations along the arc length of the meniscus. Statistical parametric mapping was used to conduct two-tailed t-tests at each of the sixty locations to compare the CSA and average SI differences between the patient's surgical and contralateral limb.

RESULTS: Significant differences were found in both the medial and lateral menisci between the contralateral limb and the surgical limb at all time points (6, 12, and 24 months). The CSA of the lateral meniscus on the operative side was significantly larger ($p < .001$) than the contralateral limb with a maximum difference of 8 mm^2 in the anterior region and 5mm^2 in the posterior region (Fig. 2A) with a decrease of 1mm^2 seen at 24 months (Fig. 3). The CSA of the medial meniscus on the operative side had significantly larger ($p <.001$) CSA of the surgical limb in the anterior region with a maximum difference of 3mm^2 with a decrease of 0.55mm^2 between 6 and 24 months (Fig. 2B). The SI profiles were significantly different ($p < .001$) in the anterior, middle, and posterior regions of the lateral meniscus with a maximum SI difference of 0.9 with the surgical limb having a higher SI. A maximum difference of 0.7 was detected in the medial meniscus with the surgical limb having a significantly higher SI ($p = 0.005$), specifically in the middle and posterior regions, which remained even 24 months post-surgery. There were no significant differences in menisci morphological changes (CSA and SI) between surgery types (BEAR vs ACLR).

DISCUSSION: Our findings suggest significant early morphological changes occur in both the lateral and medial menisci. Higher CSA and SI are present regardless of whether the patient underwent an ACL reconstruction or ACL restoration procedure. The increase in CSA suggests meniscal swelling after surgery, and it remains unchanged even 24 months after surgery. This is further confirmed by the detection of higher SI, which is thought to indicate increased fluid retention in the tissue [6]. Cartilage has also been noted to demonstrate compositional changes consistent with swelling after 24 months post-ACL surgery [3]. The meniscal results of the present work coincide with these observations. They suggest both tissues are sensitive to the biological and biomechanical environment. These changes may alter the loading environments of the knee and accelerate knee osteoarthritis progression. Future work should incorporate dynamic simulations of surgical knee geometries. This will help identify and quantify changes in mechanical loading to track biomechanical changes over time. A limitation of this study was the use of a contralateral limb as a control, which may not be truly representative of a completely non-injured state. The control limb may be preferentially loaded in the post-operative period. This study shows that changes evident at 6 months are found similarly at 24 months. Therefore, it would be ideal to also track morphological differences at 5 or 10 years post-surgery. This could help detect if the tissue progression persists over a longer period or if it correlates with the future development of articular cartilage damage. Overall, these findings emphasize the importance of monitoring meniscal morphology over time following ACL surgery. This may help better anticipate long-term joint health outcomes and guide osteoarthritis prevention strategies.

SIGNIFICANCE/CLINICAL RELEVANCE: This work highlights that meniscal swelling and fluid retention persist for two years following ACL surgery, suggesting early markers of potential biomechanical function and regional changes known to increase the risk of degenerative meniscal tears. Identifying these morphological changes may allow for earlier intervention and improved long-term meniscal and joint preservation strategies.

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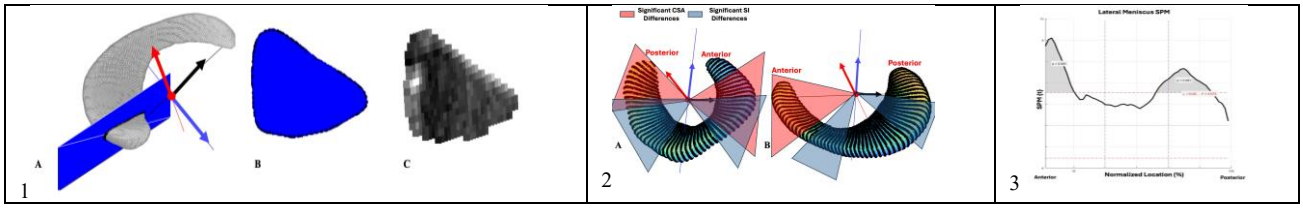

Fig. 1 A) Plane intersecting 3D meniscus model; B) Cross-section of meniscus at point of intersection; C) SI profile. Fig. 2 Significant CSA (red) and SI (blue) differences of the (A) lateral and (B) medial menisci; Fig.3 Lateral Meniscus SPM between 24-month post-surgery surgical and contralateral limbs.