Meniscus Displacement Following Surgical Repair or Allograft: A Pilot Study to Establish Methodology

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INTRODUCTION: The menisci are critical to load distribution, shock absorption, and joint stabilization. When the meniscus is torn, it extrudes outward, and the mechanical load transfer is disrupted, placing more load directly on the underlying articular cartilage. While cartilage contact mechanics under knee load has been studied in vivo and in healthy cadaver knees[4,5], it is unknown how the meniscus itself deforms or the extent by which surgical treatment restores meniscus deformation. The impact of meniscus disruption or lack of surgical restoration of deformations can be joint pain, inflammation, reduced mobility, and accelerate the development of osteoarthritis. Common surgical treatment for meniscal tears is an arthroscopy meniscus repair[1]. However knee mechanics, specifically meniscus displacement, is not well known following surgical repair. When a torn meniscus is not amendable to repair, a meniscus allograft transplant (MAT) can be used[1]. The effect of MAT on knee biomechanics and meniscus displacement immediately following mid-body segmental is also unclear. Thus our objective 1 is to investigate in-vivo knee biomechanics following meniscus repair, and our objective 2 is to investigate the mechanical function of mid-body segmental MAT under physiological joint loading in human cadaver knees. These objectives will establish a method to quantify meniscus displacements and provide insight of repair integrity under physiological loading.

METHODS: *Obj 1*: Five participants were imaged using a custom MRI-compatible loading device. Study was approved by the Institutional Review Board and informed consent was obtained. The healthy group (n=3) consisted of adult participants (aged 26.3 ±3.06, 2 females, 1 male) with no history of hypermobility, knee joint injury, surgery, or congenital abnormality. The surgical repair group (n=2) consisted of an 18-year-old female 1 month post-surgical repair of the medial meniscus and a 22-year-old male with a history of a right knee bucket-handle tear of the lateral meniscus, which was surgically repaired five years prior, re-torn, and repaired again one year prior to the study. For each participant, the leg was placed in a custom MRI-compatible loading device (Fig 1B). Loads were applied and forces were measured using an MRI-compatible load cell and custom LabView software. Participant's knees were scanned at 0° and 30° at both low load (10% bodyweight) and high load (50% bodyweight) conditions. Images were acquired using a Proton Density Turbo Spin Echo (PD-TSE) scan (TR: 9930ms, TE: 26ms, voxel size =0.6mm x 0.6mm x 0.7mm, scan time = 5:09 minutes). *Obj 2:* A cadaver right knee was acquired from an 81 year old female donor. The donor had no documented osteoarthritis or history of knee injury, surgery, or replacement. To prepare the knee for the loading device, all soft tissue was removed 4″ above and below the patella while all skin and musculature surrounding the knee joint capsule was left intact. The exposed femur and tibia bones were potted in bone cement. The knee was then fixed into a custom MRI-compatible loading device of a similar design to the in-vivo loading device (Fig 1A). Compressive loads were applied and measured using an MRI-compatible load cell and custom LabView software. The knee was scanned at 0° and 30° flexion at both low load (10% bodyweight) and high load (50% bodyweight). Images were acquired for each condition using a **S**ampling **P**erfection with **A**pplication optimized **C**ontrasts using different flip angle **E**volution (SPACE) scan (TR:1300ms, TE 38ms, voxel size =0.5mm x 0.5mm x 0.5mm, scan time = 7:21 minutes). After intact condition scanning, a segmental meniscus allograft transplant of the lateral meniscus was performed and the knee was immediately scanned again following the same procedure. *Analysis*: Images were analyzed as previously established[2,3]. Scans were resampled to 0.2 voxel size and RAS coordinate system. The tibia of the low and high load conditions was aligned and registered in ITK-SNAP. Meniscus outlines were manually segmented in the axial and coronal view using 3D Slicer. Meniscus displacements were calculated as the difference from low load to high load conditions. Displacements were averaged with the anterior, mid-body, and posterior regions of each menisci (Fig 2).

RESULTS: *Obj 1*: For both flexion angles the one month post repair showed greater displacements in the medial(+x)/lateral(-x) and anterior(+y)/posterior(-y) direction compared to the other groups. At 0° mean medial meniscus displacements were Δx Healthy: -0.260mm, Δx Past Tear: -0.267mm, Δx One Month: 0.952mm. Δy Healthy: -0.308mm, Δy Past Tear: -0.568mm, Δy One Month: -1.867mm. At 30° mean medial meniscus displacements were Δx Healthy: -0.230mm, Δx Past Tear: 0.028mm, Δx One Month: -0.822mm. Δy Healthy: -0.062mm, Δy Past Tear: 0.101mm, Δy One Month: 0.067mm. *Obj 2*: The segmental MAT showed less displacement in both the medial-lateral and anterior-posterior direction than the intact cadaver knee. At 0° mean meniscus displacements were Δx Intact: -4.217, Δx Segmental: -0.239mm, Δy Intact: 0.404mm, Δy Segmental: 0.086mm. At 30° mean displacements were Δx Intact: -2.892mm, Δx Segmental: 1.175mm, Δy Intact: -3.289mm, Δy Segmental -3.806mm.

DISCUSSION: These pilot data confirmed feasibility of using MRI compatible loading devices for *in vivo* and cadaver studies of knee loading and displacements. This data provides evidence of deformational differences between native menisci and segmentally repaired menisci and also demonstrated the acute biomechanical efficacy of segmental MAT. Limitations include limited sample size of our groups.

SIGNIFICANCE/CLINICAL RELEVANCE: Results of this study can lead to more informative surgical decision-making and facilitate innovation of MAT surgeries and transplant development.

REFERENCES:

1. Houck DA et al. 2018 2. Meadows KD et al. 2023 3. Meadows KD et al. 2024 4. Steineman, B.D. et al. 2025 5. Hongsheng et al. 2015

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IMAGES AND TABLES:

Figure 1A. Set up of in-vivo loading device.
Figure 1B. Set up of cadaver knee loading device.

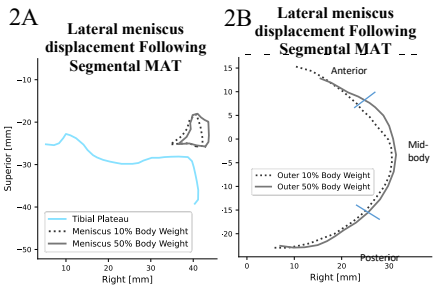

Figure 2A. Coronal view of lateral meniscus displacements following segmental MAT at 0° flexion.
Figure 2B. Axial view of lateral meniscus displacements following segmental MAT at 0° flexion.

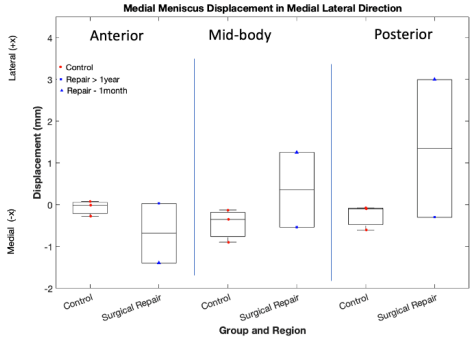

Figure 3. Medial meniscus displacements of healthy and tear groups at 0° flexion across the three regions of the meniscus. Individual data points of each participant are plotted. Positive values indicate lateral movement while negative values indicate medial movement.