The Relationship Between Medial Meniscus Extrusion and Medial Meniscus Posterior Root Forces in the Setting of Meniscotibial Ligament Insufficiency

Justin F.M. Hollenbeck[1], Justin R. Brown[1], Matthew J. Anderson[2], Wyatt H. Buchalter[1], Alexander R. Garcia[1], Amelia H. Drumm[1], Armando F. Vidal[2], Matthew T. Provencher[2]
[1]Steadman Philippon Research Institute, Vail, CO; [2]The Steadman Clinic, Vail, CO
jhollenbeck@sprivail.org

Disclosures: Justin F.M. Hollenbeck (N), Justin R. Brown (N), Matthew J. Anderson (N), Wyatt H. Buchalter (N), Alexander R. Garcia (N), Amelia H. Drumm (N), Armando F. Vidal (3B; Arthrex, Inc. 6; Arthrex, Inc., Stryker, Inc., BodyCAD USA Corp, Gemini Mountain Medical, Smith and Nephew, Vericel Corp.), Matthew T. Provencher (5-Department of Defense (DoD) and National Institute of Health (NIH); 1-Arthrex, Inc and Arthrosurface, Inc; 3B-Arthrex, Inc, Joint Research Foundation (JRF), and Arthrosurface, Inc; 8-SLACK, Inc, AANA, AAOS, AOSSM, ASES, ISAKOS, The San Diego Shoulder Institute, and The Society of Military Orthopaedic Surgeons; 5-Steadman Philippon Research Institute

INTRODUCTION: Medial meniscus posterior root (MMPR) tears frequently result in osteoarthritis if untreated. Prior studies showed meniscotibial ligament (MTL) disruption and extrusion precede these tears. Although meniscus extrusion is common after activity, its effect on medial meniscus root injury remains uncertain. Repairing root tears may not correct extrusion, suggesting prolonged post-operative activity could cause persistent extrusion. For this reason, it is unknown whether managing root tears requires an MTL tenodesis to restore native forces. The aim of this study is to examine the relationship between medial meniscus extrusion and MMPR forces in the setting of MTL insufficiency and tenodesis when the joint is cyclically loaded. We hypothesized that, 1) extrusion resulting from MTL insufficiency will increase MMPR forces; 2) MMPR forces and extrusion will both increase as the number of loading cycles increases; and 3) MTL repair will decrease extrusion and restore MMPR forces to native levels.

METHODS: Fifteen pairs of fresh-frozen, cadaveric human knees were organized in a balanced incomplete block design (BIBD) made of three testing groups: One native group, one group that received a reproduced MTL disruption (MTL Cut), and one that received a reproduced MTL disruption followed by a peripheral centralization procedure using two knotless soft anchors (MTL Tenodesis). Specimens were dissected to the knee capsule, and the femur/tibia bones were potted. A three-axis force sensor was installed inferior to the MMPR such that forces acting on the MMPR can be measured across three axes. Specimens were then mounted in full extension to a dynamic materials testing machine, and baseline meniscal extrusion and three-dimensional (3D) force measurements were captured. 3D MMPR forces were measured from the force sensor, and ultrasound (US) was used to image the medial meniscus. Each specimen was subjected to compressive cyclic loading over 10,000 cycles at a 1 Hz frequency. After the 0^{th} cycle, 100^{th} cycle, $1{,}000^{th}$ cycle, and $10{,}000^{th}$ cycle, a 500 N load was applied, the medial meniscus was imaged, and 3D forces were measured. Medial meniscal extrusion was measured from the resulting US images. Currently, means and standard deviations are reported for 11 pairs, and Pearson correlations were calculated between outcomes. The full data set will be analyzed with an analysis of variance method corresponding to the BIBD. Pairwise group comparisons will be made among the estimated marginal means (Tukey's method).

RESULTS: Eleven pairs of specimens have been tested as of this submission: 6 native, 8 MTL Cut, and 8 MTL Tenodesis. For all states, meniscal extrusion increased as the number of loading cycles increased. The MTL Cut state increased extrusion relative to native, and the MTL Tenodesis state restored extrusion back to native levels (Fig. 1). In all states, MMPR medial shear force and compression decreased as the number of cycles increased. MMPR medial shear force and compression increased in the MTL Cut state compared to the native state, and the Tenodesis state did not restore shear or compression forces (Fig. 2). Meniscal extrusion was weakly correlated to MMPR medial shear at lower numbers of cycles (0^{th}: $R = 0.2$, 100^{th}: $R = 0.5$) and strongly correlated to MMPR medial shear at higher number of cycles ($1{,}000^{th}$: $R = 0.93$, $p < 0.001$; $10{,}000^{th}$: $R = 0.82$, $p = 0.002$).

DISCUSSION: The most important findings are threefold. 1) Meniscal extrusion, MMPR medial shear force, and MMPR compression were higher in the MTL Cut state compared to the native state. 2) While the MTL Tenodesis restored native extrusion, the technique failed to restore root forces to native levels. 3) As the number of loading cycles increased, meniscal extrusion increased, medial shear force decreased, and the Pearson correlation between extrusion and medial shear force was stronger. The first and second findings provide evidentiary support that repair to an MTL-insufficient knee in isolation or in the setting of a root repair may be necessary to reduce risk of MMPR injury or reinjury. While some MTL repair techniques may restore native extrusion, residual elevated MMPR forces may persist. The third finding provides insight into meniscal function as increased meniscal extrusion from repeated joint loading may be protective for the MMPR, and risk of MMPR injury may be higher when the knee is insufficiently loaded repeatedly. This finding also experimentally supports the theoretical assertion that the meniscus, anchored by the roots, transmits femoral compressive loads into circumferential loads.

CLINICAL RELEVANCE: Findings of this study can guide clinical decision-making for whether surgical or non-surgical treatment is necessary to address MTL insufficiency.

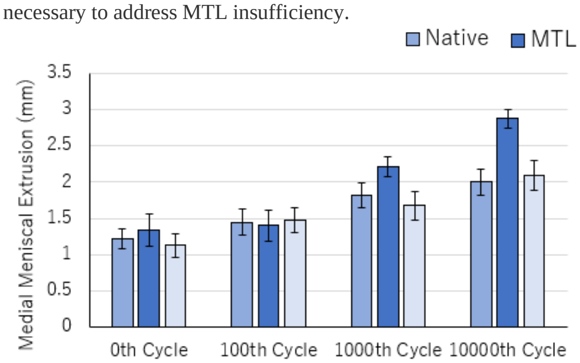

Fig. 1. Medial meniscal extrusion under cyclic loading

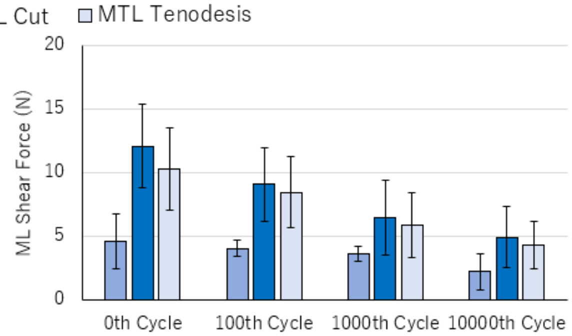

Fig. 2. MMPR Medial-lateral shear force under cyclic loading