Does Perforation Increase the Risk of Meniscus Tear? A Biomechanical Study Using Robotic and Arthroscopic Systems

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INTRODUCTION: Meniscus tears are one of the most common knee injuries particularly among individuals participating in sports-related activities. These injures cause knee dysfunction and most patients experience chronic degenerative changes within the joint leading to osteoarthritis. Surgical management of meniscus tears is a rapidly developing field as new surgical techniques and regenerative medicine strategies are focused on providing better stability to the tissue to reduce retears and promote healing. One such regenerative medicine approach is to inject mesenchymal stem cells (MSCs) into the tissue to promote repair and healing. However, it is not clear if perforating the tissue with stem cell injections biomechanically weakens the meniscus structures. The purpose of this study is to use a robotic system capable of recapitulating in vivo kinematics and kinetics of the native knee joint to directly stress the meniscus before and after perforating the tissue.

METHODS: Five cadaveric knee specimens (age 77.8±14.7y) were used for this study. We screened the specimens radiographically for evidence of osteoarthritis, meniscus health, and for any prior surgery. Soft tissue was removed from the femur and tibia adjacent to the knee joint and potted in a urethane resin. All other soft tissue were left intact. Potted specimens were mounted to a 6 degree-of-freedom (DOF) robotic arm (HR300 Ultra 2500, Kuka Robotics Corp) which was controlled with the SimVitro platform (**Figure 1**). A custom robotic loading profile was created to stress the medial meniscus. The loading profile held the knee at 60° of flexion while simultaneously applying compression force and an internal rotation torque normalized to the specimen donor's height and weight (body weight and body weight*height*0.2, respectively), determined by the internal rotation torques experienced during a deep squat.[1,2] The compression load and internal rotation torque were progressively increased from 50% to 70% of the normalized values at 10% intervals. Each initial trajectory was applied 1 time under load control, in which the compressive load and rotation torque were ramped to the target levels at a slow rate (approx. 180 sec.) while all 6 load and position DOFs were recorded. The motion from the first trial was used to create a position control trajectory in which the knee was moved through the exact same motion as the load control trial at a rapid rate (approx. 2.5 sec.). This rapid, position control trajectory was applied 10 times at each normalized level.

After reaching the 70% load level, the meniscus was arthroscopically perforated in a vertical manner. 10 perforations were made within the meniscus body with a spacing of 2-3 mm, a density and spacing comparable to when meniscus allografts are seeded with MSCs. The 70% load level cycles were then repeated. Additional perforations of the meniscus were added after each 10 cycles of loading until significant meniscus damage was present or other structures failed. Meniscus health was determined by arthroscopic inspection prior to any loading and before and after each cycle by a fellowship-trained orthopedic surgeon. Upon the completion of robotic testing, the knee was dissected, and the meniscus was evaluated a final time.

RESULTS: Meniscal tears were created in 4 of the 5 specimens. All tears were created after cyclic testing following perforation of the tissue. The tears included 3 complete tears (1 radial and 2 longitudinal) and 1 partial tear. The only specimen in which no meniscus damage was observed was from a 57 year old donor who sustained a partial tear of the ACL. Meniscus fraying was arthroscopically observed and extended as meniscus loading and perforation density increased **(Figure 2)**.

DISCUSSION: Given the strength and load-absorbing capability of the meniscus, we did not expect to be able to create isolated tears in the healthy tissue. Perforations were carried out to intentionally compromise the tissue to a point that a tear could be created via biomechanical loading, thereby proving that the meniscus is being directly stressed. Ten perforations did not lead to a measurable weakening of the meniscus tissue. However, these results indicate that a 6 DOF robotic system is a possible testing platform which is capable of stressing the meniscus.

SIGNIFICANCE/CLINICAL RELEVANCE: The robotic system demonstrated high repeatability and modularity during manipulation. We anticipate the results of this study will provide an effective means for further determination of native knee biomechanical properties and evaluation of the effect of meniscal pathology and surgical interventions during robotically applied motion cycles. The platform showcases promising potential for further specified meniscal testing.

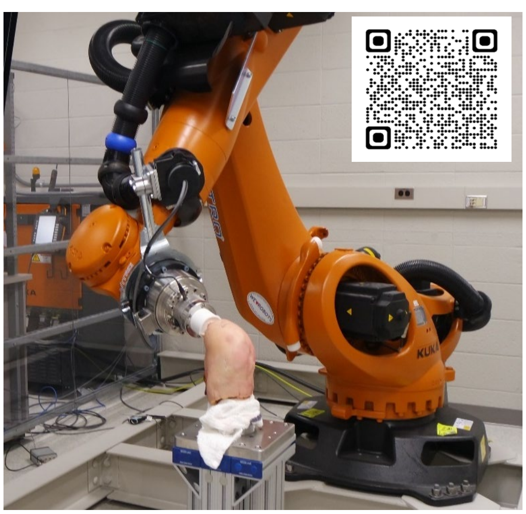

Figure 1: Knee specimen mounted to robotic system. Scan QR code for video.

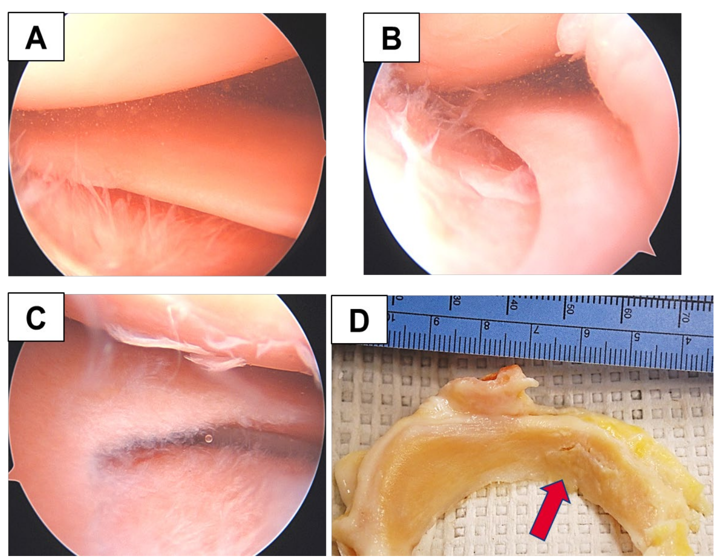

Figure 2: Representative images of meniscus health A) prior to any loading, B) unperforated, 10 cycles at 80%, C) 3x perforated, 40 cycles at 80%, D) 5x perforated, 60 cycles at 80%, longitudinal tear.