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Evaluation of meniscal extrusion with posterior root disruption and repair using ultrasound

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ABSTRACT

Background: Ultrasound techniques have been utilized for detection of discrete meniscus tears and extrusion. Meniscal extrusion is associated with increased contact pressure and decreased contact area contributing to the advancement of knee osteoarthritis. The purpose of this biomechanical study was to detect meniscal extrusion using a clinically available, portable ultrasound device. And further, to show that extent of injury and a weight-bearing state correlate with amount of extrusion.
Methods: A portable, hand-held ultrasound was utilized to image the lateral meniscus in association with (1) an intact posterior root attachment, (2) a 50% cut, (3) a 100% cut, and (4) repaired posterior root attachment. Images were obtained in an unloaded condition, and again under a static, physiologic (70 kg) axial load for above injury levels, and again following repair.
Results: Significant differences in extrusion were noted between the intact and both the 50% cut ($p = 0.028$) and 100% cut groups ($p < 0.001$) all in the loaded position. No significant difference was found in extrusion between intact state and repaired posterior root in the axially loaded position ($p = 0.174$). Both load ($p = 0.003$) and injury level ($p = 0.005$) had significant effects on the mean extrusion of the lateral meniscus.
Conclusion: Sectioning of the lateral meniscus posterior root will produce significantly increased lateral extrusion of the meniscus under physiologic loads. Unlike MRI evaluation, weight-bearing ultrasound images allow a functional assessment of meniscus extrusion. Trans-tibial posterior root repair can restore the lateral meniscus position and integrity.
Clinical relevance: This weight-bearing ultrasound technique can be an important assessment tool for complete evaluation of meniscus injuries.

1. Introduction

Load transmission is considered an integral function of the meniscus, in addition to lubrication, proprioception and joint stabilization. In full extension the lateral meniscal body absorbs nearly 70% of the weight-bearing load, which reduces stress on the articular cartilage and subchondral bone [16]. The menisci will experience tensile, compressive, and shear stresses while transmitting forces during the gait cycle. Due to the microstructure and orientation of the collagen fibers, the compressive loads are distributed in a circumferential manner, also known as "hoop stresses" [4].

Disruptions of meniscal fibers, including radial tears and root tears, have been shown to cause dysfunction of the meniscus as a load-bearing structure [1]. As Ode et al. [5] demonstrated, radial tears of the lateral meniscus produce increased pressure forces and decreased contact area between the femoral and tibial articulations. In addition to structural integrity, the location of the menisci between the femoral and tibial articulations is essential for functional load sharing and stability. Significant meniscal extrusion also increases contact forces through the knee. These additional stresses and associated decreased contact surface area can contribute to the advancement of knee osteoarthritis [2].

Currently, magnetic resonance imaging (MRI) is the most widely used advanced imaging technique for assessing meniscal injuries. The accuracy of diagnosing meniscal tears by MRI has been reported as greater than 90% [8,13]. However, MRI maintains its own set of limitations, including increased cost, increased time of exam, metallic implants, and being a static, non-weight bearing exam. In contrast, ultrasonography can reliably provide physicians with inexpensive, quick, and dynamic information of the meniscus. Several studies have reported the high sensitivity and specificity (>85%) of detecting discrete meniscal tears with modern ultrasound techniques [7,10,12]. Our study expands on the utility of portable, hand-held ultrasonography to detect extrusion in injured menisci.

Tears of the posterior root of medial and lateral menisci can have destructive consequences if not adequately treated. Allaire et al. [1] demonstrated that posterior root tears of the medial meniscus created a 25% increase contact pressure across the medial compartment. Several clinical outcome studies for repair of medial meniscal root tears report improved

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radiographic and clinical results with a high healing rate [3,9,11]. Therefore, repair of meniscal root attachments has garnered increased attention to best preserve knee kinematics.

The purpose of our study was to accurately detail the position of the lateral meniscus in cadaver knees under physiologic loads to determine the integrity of the posterior root. A reliable ultrasound technique was utilized for measuring meniscal position following serial sectioning of the posterior root and following meniscal root repair. We hypothesized that: (1) a significant increase in the amount of lateral meniscal extrusion would be exhibited with 50% and 100% posterior root tears compared to intact menisci, (2) imaging under loaded conditions would yield significantly larger extrusion measurements compared to unloaded state, and (3) meniscal position and extrusion following posterior root repair would correlate with the intact state.

2. Materials and methods

Approval for use of cadaver specimens was granted by our institutional research review board. A pilot trial was performed on an initial three cadaveric knees (not included in the reported data set of ten specimens) in order to obtain data for sample size determination and procedural standardization. An *a priori* power analysis was performed with the alpha-error set to 0.05 and the power level at 0.95. We determined that a sample size of five specimens would be required to achieve significance in our extrusion measurements. Utilizing the *a priori* power analysis and available specimens at our institution, ten fresh-frozen cadaveric lower extremities were obtained from male and female donors (mean age, 68.5 years; range, 24–94 years) (Table 1).

2.1. Specimen preparation

All specimens were initially inspected, radiographically evaluated, and arthroscopically evaluated to ensure there was no evidence of previous knee surgery, significant medial or lateral meniscal tears, gross osseous abnormalities, or deficient ligamentous structures. The specimens were then prepared by transecting the femur approximately 30–35 centimeters (cm) above the joint line and transecting the tibia approximately 22–27 cm below the joint line. The fibula was transected approximately four centimeters proximal to the tibial cut. Care was taken to preserve the collateral and cruciate ligaments and the popliteus muscle in order to maintain native anatomic stability of the knee. Approximately five centimeters of the transected proximal femur and distal tibia was then skeletonized. Finally, the proximal femur and distal tibia of each cadaver knee were fixated in Bondo cement; creating a square potting fixture for the specimen.

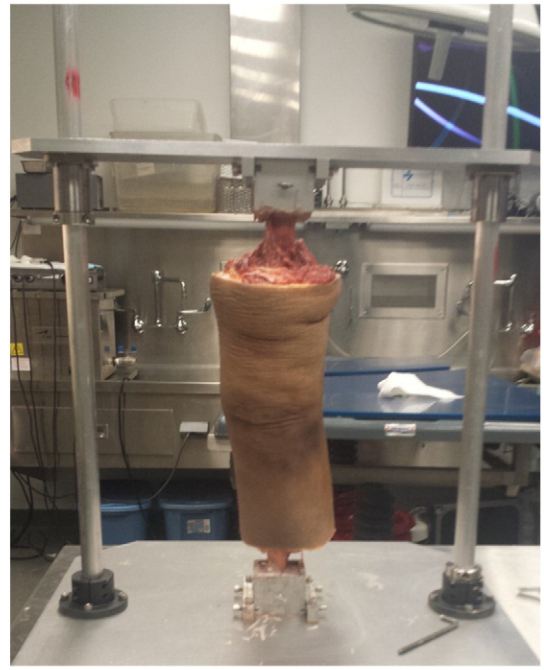

Figure 1. Example specimen placed in the mechanical load frame in unloaded condition ready for ultrasound.

2.2. Testing

Our study utilized a custom-built mechanical load frame to apply static, axial loads through the cadaver knees (Figure 1). Knees were placed into the loading frame in a standing, vertical orientation. Seventy kilograms of weight was placed at the upper, above-knee section to apply a 70 kg physiologic body weight loading of the knee. A Sonosite MicroMaxx (Fujifilm Sonosite, Inc., Bothell, WA) ultrasound machine and 13 to six megahertz HFL38E transducer with a scanning depth of six centimeters were utilized for image capturing. Prepared and potted knees were initially placed into the loading frame and ultrasound images were obtained of the lateral meniscus in the unloaded position and loaded position with 70 kg. All menisci were visualized by placing the transducer longitudinally at the joint line slightly anterior to the lateral collateral ligament. Application of these two loading conditions and ultrasound imaging were then repeated following arthroscopically sectioning the posterior root of the lateral menisci approximately 50% and then 100% using straight and angled biters. Meniscal sectioning was estimated at 50% under direct visualization of the posterior root with the arthroscope. Ultrasound images were uploaded to a Dicom image viewing system for extrusion measurements. We defined extrusion as the

Table 1
Details of the cadaver specimen's characteristics and extrusion measurements used in this study.

			Intact (mm)		50% cut (mm)		100% cut (mm)		Repaired (mm)	
	Specimen	Side	Unloaded	Loaded	Unloaded	Loaded	Unloaded	Loaded	Unloaded	Loaded
1	10250	L	1.1	1.2	1.2	1.7	1.4	1.6	1.3	1.7
2	10938	R	1.7	1.8	1.6	1.7	1.5	2.6	1.4	1.1
3	10528	L	0.87	1.1	1.5	1.5	2	2.2	1.3	1.5
4	11537	L	1.2	1.5	0.87	2	1.2	2	1.2	1.8
5	11071	L	2.4	2.4	2.2	2.2	3.4	3.9	0.64	2
6	11467	L	1.9	2.3	1.7	2.2	3	3.5	2.2	3.3
7	10938	L	1.7	1.3	1.6	1.7	1.4	1.8	1.3	1.7
8	10469	R	1.5	1.8	2.4	2.5	1.3	2.5	1.4	2.6
9	11507	L	1.3	1.1	2.4	2.1	2.1	2.6	1.4	0.74
10	10321	L	1.4	1.5	1	1.6	1.5	2.1	0.85	2.2
		Average	1.51	1.60	1.65	1.92	1.88	2.48	1.30	1.86
		Std. Dev.	0.44	0.47	0.55	0.33	0.76	0.73	0.41	0.73