Validation of MRI Quantification for Meniscus Volume Resection Following Partial Meniscectomy

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Introduction: The medial and lateral meniscus are crescent-shaped fibrous pads of the knee joint located between the femur and tibia.\(^1\) They provide shock absorption, pressure redistribution, joint stability, and proprioception, and contribute to the smooth motion of the knee joint.\(^2\), \(^3\) However, meniscus tears are among the most common injuries seen by the orthopaedic surgeon, and meniscectomy is the most common orthopaedic procedure performed in the United States.\(^4\) The outcomes of arthroscopic partial meniscectomy have been well documented, and in most studies, the short-term outcomes are excellent. However, long term studies suggest that there remains a significant risk of developing osteoarthritis in the affected knee compartment. Chatain, et al. demonstrated that 10 years after medial meniscectomy, 85% of patients were free of symptoms, but 21% demonstrated radiographic changes consistent with early OA.\(^5\) In the lateral compartment, 39% demonstrated radiographic changes. It is hypothesized that these changes are due to alterations in contact mechanics following meniscectomy although this has yet to be confirmed. In addition, it is assumed that larger resections result in higher rates of OA. However, quantification of resection volumes are challenging as surgically removed tissue is often destroyed through the process of cutting and shaving torn edges of the residual meniscus. MRI-based quantification, comparing pre- and post-surgical meniscus volumes remains the most promising strategy for quantifying resection volumes. Our research group has established methods to image and quantify at high-resolution meniscus volume and have demonstrated excellent reproducibility with this technique. However, the accuracy of these methods has not been evaluated and warrants further investigation. Thus it is the purpose of this study to evaluate the accuracy of meniscus volume quantification following partial meniscectomy of MRI measured meniscus volume when compared to direct methods.

Methods: A total of 8 meniscectomies were performed in fresh-frozen cadaveric knees. Knees without history of knee trauma or diagnosis of osteoarthritis were included. MRI acquisition was performed before and after each procedure. The high-resolution isotropic CUBE sequence was acquired on all knees using our high-field short-bore 3T MRI scanner (GE Healthcare, Milwaukee, WI, USA) with an 8-channel phased array knee coil (Invivo, Orlando, FL, USA).

Meniscectomy: All meniscectomies were performed by a board certified orthopaedic surgeon. A range of meniscal resections, from small to large, but similar to those performed in clinical practice were performed. Surgical methods were limited to sharp dissection using a scalpel to retain all resected tissue for later volume measurements. Resected meniscus tissue was removed and placed in phosphate-buffered saline. Volume was then calculated using Archimedes methods for measuring small volumes where the volume of tissue is equal to the volume of displaced fluid.
MRI Protocol: The imaging protocol included high-resolution sagittal 3D FSE (CUBE): TR/TE = 2200/43 ms, field of view of 16 cm, 320 x 320 matrix size, and slice thickness 0.5 mm.

Image Post Processing: To measure pre and post surgical menisci volumes, menisci body and horns were manually segmented on FSE images using Bezier-splines created with in-house software written in MATLAB (The MathWorks, Inc., Natick, MA). All segmentations were manually corrected to avoid areas of fluid surrounding menisci, and performed in pairs to ensure matched regions were included. Regions were combined to form a 3D mask and volume within the region was calculated based on in-plane resolution and slice thickness. Using these same methods, we have previously established excellent reproducibility (ICC > .90) for total meniscus volume calculations in human subjects.

Statistical Analyses: Pre- and post-meniscectomy MRI-measured meniscus volume was recorded. Then, the difference of the pre- and post- surgical meniscus volumes was calculated (pre-surgical volume - post-surgical volume) and compared to direct measures of meniscal tissue removed during surgery using Interclass Correlation Coefficient [ICC(3,1)] and standard error of measurement (SEM = Standard Deviation x √(1 - ICC)).

**Results:** ICC's revealed excellent agreement between measures (ICC=0.95). These results reveal a SEM of 0.1 cm³, or approximately 4% of the meniscus volume. The range of meniscus resection volumes in our preliminary data has been 5% - 65% of total meniscus volume. These results are shown in Figure 2.

**Discussion:** These data suggest that MR-based measures of meniscus volume resection following partial meniscectomy are very similar to direct measures of volume resection in cadaveric knees. The errors we observed in the current study suggest that there are limitations in this method to quantify small resection volumes (<5%); however, the majority of meniscus resections performed by our clinical partners are generally much larger than this, suggesting these methods are appropriate in most cases.

**Significance:** Our findings suggest that accurate methods of meniscus resection quantification in in vivo knees is possible and can be used to elucidate if meniscus injury and subsequent partial meniscectomy result in abnormal knee kinematics and altered joint loading mechanics.

![Figure 1](image_url) **Figure 1.** Example of meniscus segmentation in pre-surgical (A) and post-surgical (B) cadaveric knees.
Figure 2. Scatter plot of MRI-measured resection volumes and direct measures of resection volumes.