# Evaluation of Thin-Slice (1mm) Axial Magnetic Resonance Imaging on the Diagnostic Accuracy of Meniscus Tears

A thesis submitted to the University of Arizona College of Medicine – Phoenix
in partial fulfillment of the requirements for the degree of Doctor of Medicine

Drew Albert
Class of 2018

Mentor: Jimmy Leung, MD

**Abstract**

*Background and Significance:* This investigation assessed the diagnostic accuracy of thin-slice (1mm) axial Magnetic Resonance Imaging (MRI) in the detection and classification of meniscal tears. Meniscal injuries are a common reason for knee pain and the use of MRI has become standard in their assessment.[1] However, the classification of tears and not merely the detection of lesions has become increasingly important to surgeons in deciding between surgery and conservative management.[2,3] There is a growing body of literature examining the utility of axial MR images in aiding radiologists to more accurately describe and classify morphological characteristics of meniscus tears.[4,5,6,7,8] However, the thick-slice (4-5mm) axial sequences utilized at many institutions typically only produce 1-2 images on which the menisci can be visualized, which does not provide the required detail to accurately describe the morphological characteristics of meniscal lesions.[4,9]

*Research Question:* This study adds to the growing body of literature examining the diagnostic capabilities of MRI with TSAi to accurately describe meniscal tear morphologies.

Methods: Imaging reports from 107 patients with clinically suspected meniscus injuries who underwent MRI with thin-slice axial imaging were compared to arthroscopic findings using receiver operating characteristic (ROC) analysis to assess the diagnostic accuracy of MRI with thin-slice axial imaging (TSAi).

*Results:* The sensitivity and specificity of MRI with TSAi for meniscal tear detection were found to be 91% and 37.5% respectively. Furthermore, MRI with TSAi was highly specific for bucket handle (98.5%) and root ligament tears (94.1%).

*Conclusion:* The findings of our investigation indicate that MRI with TSAi may assist surgeons in determining the need for operative versus conservative management. MRI with TSAi may be particularly helpful in the case of root tears, which were not as readily identified with traditional MRI techniques and often require surgical intervention due to morbidity associated with unrepaired root tears.

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## Introduction

Knee pain is a common reason for visits to physicians and within this group, meniscal tears are highly prevalent (9-33%).[10-13] In fact, meniscus pathology is often even identified in asymptomatic knees.[14] Additionally, meniscal injuries may be associated with early onset of osteoarthritis as well as subsequent knee soft tissue injuries due to altered meniscal kinematics.[15] The use of MRI has become customary practice in diagnosis of meniscal tears. A common diagnostic strategy is history and physical examination followed by plain film radiographs and subsequently MRI.[1] The results of MRI in addition to other factors such as lesion chronicity and the patient's age affect the treatment and more specifically, the decision for surgery or conservation management of patients with meniscus tears.[2,3] Given that diagnostic imaging represents the fastest growing segment of costs in the US healthcare system[16] and the central role of MRI in the diagnosis and management of meniscus tears, implementing MRI protocols that provide accurate and clinically useful information that enhances cost-effective decision making is of utmost importance.

MRI has consistently been found to be highly accurate in the diagnosis of meniscus tears. The sensitivity of MRI in detecting meniscus tears relative to arthroscopy, which is the gold-standard for diagnosis, has been reported to fall anywhere between 80% and 99%.[17-23] However, merely detecting lesions is often no longer sufficient to accurately guide the management of patients. Surgeons are increasingly reliant on accurate descriptions of the morphological characteristics of meniscal lesions and their proximity to vascular zones to direct therapy.[3,24] For instance, many surgeons regard unstable longitudinal and flap tears to be amenable to surgical intervention, whereas horizontal radial, and complex tears are generally less suitable to surgery.[25,26] Furthermore, meniscal root avulsions were historically managed conservatively, however unrepaired root tears may lead to rapid joint degeneration and the evidence subsequently now reports that root tears be repaired.[7,8,19,27] More to the point, traditional surgical therapy for meniscus tears involved a total or partial meniscectomy. More recently, meniscus repair has replaced meniscectomy as the preferred surgical technique when the morphology of the lesions is amenable to repair, which makes accurate radiographic characterization all the more important for surgical planning. In addition to avoiding unnecessary procedures, more precise diagnostic imaging is a tool that surgeons can utilize to improve patient satisfaction and minimize the likelihood of negative long-term outcomes such as chronic pain and disability that more often complicate meniscectomy then they do meniscus tear repairs.[24]

There is a growing subset of literature examining the utility of axial MR images in allowing for more descriptive characterization of meniscal lesions relative to sagittal and coronal images.[5-9,27-29] Tarhan and colleagues[8] demonstrated that thick-slice (4-5mm) axial images improved sensitivity and specificity of lesion detection in the lateral meniscus. Although Lee et al[6] did not compare their radiologic findings to arthroscopic data, their work showed that axial images improved the detection of vertical tears and displaced fragments. Both of the aforementioned studies were limited by the use of standard knee MR image acquisition protocols, which include thick 4-5mm slice axial images that typically allow the menisci to only be visualized on one or two images. There is a growing body of literature providing evidence that reformatted axial images and obtaining axial images at thinner slice intervals may enhance the diagnostic capabilities of knee MRI.

For instance, the work of Ohishi et al[7] showed that axial reconstructed images from 3D MRI data sets aided in the morphological diagnosis of radial tears, whereas horizontal tears remained difficult to detect and the false-positive rate in the medial meniscus was also found to be relatively high. Additionally, Savoye et al[9] showed that axial images aid in the diagnosis of posterior horn lateral meniscus (PHLM) tears, although the study was limited by technical challenges of arthoscopic evaluation of the PHLM. Lastly, Gokalp and colleagues[5] found that thin-slice (1mm) proton density weighted (PDW) axial images improved sensitivity and specificity of imaging and proved particularly useful in the classification of vertical and vertical-horizontal tears.

The present investigation aimed to evaluate the diagnostic capabilities of thin-slice axial imaging (TSAi) in characterization of meniscal tears. Although technologies are available to directly create 3-D images of the meniscus, these images are cumbersome to interpret as they often not only require additional software to generate the images, but they are also more time consuming to interpret and not as readily available as TSAi. By adopting TSAi, we opt for a practical, readily available supplement to the conventional MRI imaging protocol that we feel will assist the modern orthopedic surgeon. The authors postulated that the systematic use of thin-slice axial MR images would allow more accurate morphologic classification of meniscal tears than standard MRI protocol with thick-slice axial images. Furthermore, since TSAi only adds images to the standard MRI data set, it was hypothesized that overall tear detection rate with TSAi would be comparable to standard MRI protocols. Improved radiologic characterization of meniscal tear location and morphology has the ability to impact orthopedic care planning and ultimately may improve patient outcomes.

## Material and Methods

*Patients*

The present investigation was a retrospective review of the available imaging and arthroscopy reports for patients who underwent both knee MRI and arthroscopic surgery at Southwest Diagnostic Imaging or Scottsdale Healthcare (Honor Health) facilities over a 2-3 period (2012-2015) since the addition of TSAi to the MRI protocol at Southwest Diagnostic Imaging. An initial query of the Scottsdale Healthcare surgery database was performed to identify patients who had undergone knee arthroscopy for an indication of meniscal tear after approval of the appropriate institutional review board was obtained. The image database at Southwest Diagnostic Imaging was then queried to identify arthroscopy patients who had undergone knee MRI with TSAi. Patients were excluded if they met any of the following criteria: not having arthroscopic surgery subsequent to MRI, delayed surgery (>1 year after imaging),[9] and clinical history of previous meniscus surgery or ACL injury. One-hundred and seven (n=107) patients met criteria for inclusion in the review. Our study included 49 right knees and 58 left knees of 50 men and 57 females with an average age of 54.6 years (range 17-87). The average time between MRI and arthroscopy was 45 days.

*MRI Protocol and Image Analysis*

MRI was performed using systems in place at Southwest Diagnostic Imaging outpatient imaging facilities with patient lying supine and knee fully extended. Standard MRI protocol was followed for all cases. A localization sequence was obtained and followed by multiplanar sequences: 1) Axial plane fast relaxation fast spin echo (FRFSE) T2 fat-saturated (FS), 2) Sagittal plane fast spin echo (FSE) T2 FS, 3) Sagittal plane FSE proton-density weighted (PDW), 4) Coronal plane FRFSE T2 FS, 5) Coronal plane FSE PDW, 6) Axial plane FSE T2 FS with 1mm slice thickness (representing the TSAi sequence).

Five experienced radiologists, four of who are fellowship-trained musculoskeletal imaging specialists, evaluated images. The radiologists were blind to the arthroscopic findings. Abnormal signal intensity within the meniscus with extension towards the meniscal circumference and abnormal meniscus morphology were the criterion for the diagnosis of meniscal tear. Arthroscopy was performed by a group of 19 orthopedic surgeons in the local community. Arthroscopists were not blind to the results of MRI owing to the retrospective nature of this study. Imaging findings were subsequently compared to arthroscopy findings.

*Data collection*

The investigator extracted data about tear characteristics from the imaging and arthroscopy reports. Variable data collected included information about tear laterality, compartment (e.g. anterior, middle, posterior, root), and morphology/orientation. The tear morphology classification system utilized in this investigation (Table 1) was similar to that found in previous investigations (Site Gokalp, etc). Cases in which the radiologist or arthroscopist did not describe the meniscus tear location or morphology in accordance with the aforementioned schema were not included in data analysis. Complex and degenerative tears were also excluded from the subanalysis by morphology, but were included in the analysis of overall tear detection rates. The presence of a meniscal tear was assessed on a tear-by-tear basis rather than meniscus-by-meniscus basis. For example, if a patient had multiple discrete tears in a meniscus, then those tears were coded separately to capture the maximum number of tears since the objective of this investigation was to evaluate tear morphology.

Table 1 – Meniscus tear morphology classification schema

| Meniscus Tear Morphology | |
|---|---|
| Vertical | Perpendicular to tibial plateau. |
| Horizontal | Parallel to tibial plateau. Splits the meniscus into superior and inferior portions in the sagittal and axial planes. |
| Vertical-Horizontal | Oblique to tibial plateau. |
| Radial | Perpendicular to the c-shaped circumference of meniscus in axial plane. |
| Longitudinal | Parallel to the c-shaped circumference of meniscus in axial plane |
| Flap | Tear of the meniscal midsubstance in which the tear changes direction leaving a displaceable fragment. |
| Bucket-Handle | Longitudinal tear in which the inner aspect of the tear is displaced so as to resemble the shape of a bucket handle. |
| Complex | Tear with complex features unable to be ascribed to a distinct tear morphology |
| Degenerative | Degenerative fraying of the meniscus related to wear-and-tear. |

*Statistical Analysis*

STATA data analysis software was utilized to carryout statistical analysis. Arthroscopic data was used as the reference values for evaluation of MRI findings. Categorical data were expressed as percentages and frequencies. Continuous variables were expressed as mean $\pm$ standard deviation. Sensitivity and specificity of MRI with TSAi for tear detection and characterization of specific tear morphologies were calculated using ROC analysis. A McNemar's test was utilized to detect any differences in percentages of tear morphologies between the two diagnostic modalities. A p-value of $\leq$0.05 was indicative of a statistically significant difference between the two modalities.

**Results**

The present investigation was a retrospective review of the available imaging and arthroscopy reports for patients who underwent both knee MRI and arthroscopic surgery at Southwest Diagnostic Imaging or Scottsdale Healthcare (Honor Health) facilities over a 2-3 period (2012-2015) since the addition of TSAi to the MRI protocol at Southwest Diagnostic Imaging. In total, MRI with TSAi identified 90 meniscus tears while arthroscopy identified 99 tears. One-hundred and seven (n=107) patients met criteria for inclusion in the review. Our study included 49 right knees and 58 left knees of 50 men and 57 females with an average age of 54.6 years (range 17-87). The average time between MRI and arthroscopy was 45 days. The sensitivity and specificity of MRI with TSAi for tear detection in our investigation were 90.9% and 37.5% respectively as is evident in Table 2. Our data indicated, as can be seen in Table 3, that MRI with TSAi may be particularly helpful in characterizing a few specific lesion morphologies. For instance, there were no significant difference in bucket handle tear detection rate and negative test rates between MRI and arthroscopy. Additionally, detection rates of horizontal and oblique tears approached the level of no significant difference. As is evident in Table 4, the specificity of MRI with TSAi for the various tear morphologies examined in this investigation was uniformly high. Specificity for detection of radial, flap, and bucket handle tears all exceeded 92% and specificities for vertical, horizontal and oblique tears were all greater than 87%.

Knee MRI with TSAi was also accurate in localizing lesions to a couple specific anatomic regions of the menisci. For instance, there was no significant difference between our MRI protocol and arthroscopy for localization of lesions to the anterior compartment and meniscal roots (p-vaues were 0.5 and 0.62 respectively). Furthermore, our knee MRI protocol demonstrated high specificity for tears in the anterior, middle, and root compartments with respective values of 100%, 88.4% and 92.5%.

Table 2 – Tear Detection by Modality

| | | | |
|---|---|---|---|
| | Arthroscopy Positive | Arthroscopy Negative | Total |
| MRI Positive | 90 | 5 | 96 |
| MRI Negative | 9 | 3 | 11 |
| | | | |
| **Total** | 99 | 8 | 107 |
| | | | |
| **Sensitivity** | 90.9% | | |
| **Specificity** | 37.5% | | |

Table 3 - Compartment and Morphology

| | Arthroscopy<br>N=79 | MRI<br>N=95 | P-Value[1] |
|---|---|---|---|
| **Morphology (n, %)** | | | |
| Vertical | 1 (2.2) | 10 (16.4) | 0.22 |
| Horizontal | 1 (2.2) | 7 (11.5) | 0.37 |
| Oblique | 4 (8.9) | 8 (13.1) | 0.37 |
| Radial | 12 (26.7) | 7 (11.5) | 0.10 |
| Flap | 16 (35.6) | 9 (14.8) | 0.07 |
| Longitudinal | 1 (2.2) | 0 (0.0) | 1.0 |
| Bucket Handle | 5 (11.1) | 5 (8.2) | 1.0 |
| No Tear | 5 (11.1) | 15 (24.6) | 0.58 |
| **Compartment (n, %)** | | | |
| Anterior | 3 (5.6) | 2 (3.7) | 0.50 |
| Middle | 3 (5.6) | 12 (22.2) | 0.22 |
| Posterior | 43 (79.6) | 34 (62.9) | 0.38 |
| Root | 5 (9.3) | 6 (11.1) | 0.62 |

[1]McNemar's Test used to compare proportions between Arthroscopy and MRI.

Table 4 - Diagnostic Capabilities of MRI versus Arthroscopy

| | Sensitivity (%) | Specificity (%) | PPV (%) | NPV (%) |
|---|---|---|---|---|
| **Morphology (n, %)** | | | | |
| Vertical | 0.0 | 87.2 | 0.0 | 97.1 |
| Horizontal | 0.0 | 89.7 | 0.0 | 97.2 |
| Oblique | 50.0 | 89.5 | 20.0 | 97.1 |
| Radial | 33.3 | 92.9 | 66.7 | 76.5 |
| Flap | 46.2 | 96.3 | 85.7 | 78.8 |
| Longitudinal | n/a | n/a | n/a | n/a |
| Bucket Handle | 80.0 | 97.1 | 80.0 | 97.1 |
| No Tear | 0.0 | 77.1 | 0.0 | 84.4 |
| **Compartment (n, %)** | | | | |
| Anterior | 33.3 | 100.0 | 100.0 | 95.3 |
| Middle | 0.0 | 88.4 | 0.0 | 97.4 |
| Posterior | 77.8 | 50.0 | 87.5 | 33.3 |
| Root | 75.0 | 92.5 | 50.0 | 97.4 |

Diagnostic indices calculated using ROC analysis.

## Discussion

MRI is a commonly used tool in the workup of knee pain and knee injuries. There are a variety of internal derangements that can occur within the soft tissues of the knee ranging from ligamentous injuries to meniscal lesions and cartilage pathology. Meniscus tears, specifically, are associated with twisting, cutting and squatting injuries. Lesions of the menisci can predispose to premature joint degeneration and instability, which can be explained by their biomechanical role to stabilize the joint and dissipate compressive forces being transmitted to the articular cartilage.[30] MRI has been shown to play a valuable role in the selection of surgical candidates with a variety of internal knee derangements[3].

Although MRI is widely considered the definitive non-surgical test to evaluate for meniscus injuries, the sensitivity of conventional MRI techniques varies widely in the literature from 80% to approaching 100%.[17-23] The sensitivity for tear detection using our protocol was in keeping with the values reported in the literature. This finding is expected as the authors of the present investigation did not anticipate that the diagnostic accuracy of our MRI with TSAi protocol would be discordant with literature references for conventional image acquisition protocols as it is unlikely that adding an additional sequence in the axial plane would dramatically alter diagnostic capabilities of a test that already has sensitivity approaching 100% by some accounts.

Historically, the coronal and sagittal imaging planes have been found to be most helpful in meniscus tear detection and it can therefore be inferred that much of the diagnostic accuracy of knee MRI is owing to images obtained in those imaging planes. However accurate coronal and sagittal images may be in detecting tears, their ability to characterize tear morphology is lacking.[8, 24] Imaging in the axial plane is typically obtained using 4-5mm thick slices, which taken in isolation are limited in their sensitivity to detect meniscal injuries.[3] However, there is a growing body of literature to suggest that imaging in the axial plane may in fact be more helpful than previously thought. A few authors have proposed that the acquisition of a sequence of thin (1mm) slice MR images in the axial plane dedicated to imaging the menisci might enhance the diagnostic capabilities of knee MRI.[5,7,9] Our data contribute further evidence to the small body of literature suggesting that thin-slice MRI sequences obtained in the axial plane can enhance the diagnostic capabilities of knee MRI.

The authors of the present investigation postulated that MRI with TSAi would allow radiologists to better characterize the orientation of meniscus tears. The results of our investigation indicate that TSAi is accurate in the diagnosis of a few specific tear morphologies and locations. For instance, MRI with TSAi was found to be highly specific for characterization of each particular tear morphology assessed in this investigation save for longitudinal tears. Our data set did not include any radiographically detected longitudinal tears and calculation of diagnostic accuracy characteristics for this specific tear type was therefore not possible. Our investigation provides evidence that the quasi 3-D image of the menisci produced by TSAi reliably allows trained musculoskeletal radiologists to describe meniscus tear morphologies with a high degree of specificity. The information attained from MRI with TSAi may therefore be clinically useful in surgical candidate selection as orthopedic management varies by tear morphology to an extent.[30]

The sensitivity of TSAi for tear morphology characterization was relatively low in our investigation compared to similar studies.[8] Although there was no difference in diagnostic capabilities between the MRI with TSAi and arthroscopy with respect to identifying bucket-handle and negative tests, there was heterogeneity between the two tests for the remainder of tear morphologies. This phenomenon may be explained in part by the lack of standardization of arthroscopic tear morphology descriptions in our study that was a byproduct of the retrospective study design. Additionally, the number of different arthroscopists whose records were included in the data set may also have contributed to the relative heterogeneity.

In addition to tear morphology, characterization of the location of lesions within the meniscal compartments is also becoming increasingly important in directing orthopedic care.[25-27] Our data indicate that MRI with TSAi is specific for the detection of tears in the anterior, middle, and root compartments. It may be that the incorporation of additional axial images enhances the ability of radiologists to detect lesions confined to the meniscal roots and to accurate assess the extension of more anterior lesions into the root. This finding has the ability to impact clinical management, as surgical intervention is increasingly favored in the management of root tears owing to their association with poor outcomes such as pain, accelerated rates of joint degeneration, and immobility if left unrepaired.[30]

In addition to the potential clinical benefits of MRI with TSAi, the feasibility of this protocol should also be noted. Since thin-slice images were taken only at the level of the meniscus only approximately 10 slices were needed to complete the study. These additional images added on average less than three minutes of exam time to the study. Furthermore, our protocol used widely available commercial sequences (TSE and FSE). These factors suggest that adding TSAi to the knee MRI protocols will be feasible and time-effective for many centers and additionally may impact the clinical care their patients receive.

*Limitations*

Our study had a few limitations. Most importantly, the retrospective nature of this review imposed a few limitations that make our data less generalizable. First, we relied on the interpretations and non-standardized lesion characterization of pre-existing radiologic interpretations from a few different image interpreters. An identical issue was encountered with the lack of uniform lesion morphology characterization inherent in our reliance on existing arthroscopy reports. A prospective study would allow for stricter categorization of tear types as well as blinding of image interpreters and arthroscopists to the results of the other method of meniscus evaluation. Additionally, the lack of a comparison group limits the utility of our findings. For instance, comparing the performance of MRI with and without TSAi would allow future investigations to answer the question of whether the addition of TSAi to conventional MRI requisition protocols affords increased diagnostic capabilities in terms of tear morphology characterization. Conducting a study of this nature was felt to be outside of the scope of the four-year timeframe allocated for completing this project to fulfill the graduation requirements for the degree of Doctor of Medicine at the University of Arizona College of Medicine – Phoenix. Lastly, although the authors postulate based on existing evidence that radiographic description of tear types is helpful in guiding surgical management, this investigation did not directly investigate the correlation of radiographic findings with outcomes of surgical management.

**Future Directions**

There have been few studies to date that have investigated the diagnostic accuracy of thin-slice axial MR images in the setting of meniscal injuries. The results of the present investigation provide favorable evidence that MRI with TSAi is a feasible protocol that can be implemented in community-based outpatient radiology centers and suggest that MRI with TSAi may allow for accurate characterization of meniscus tear morphologies. We propose that more high-quality studies evaluating the categorizing meniscus tear morpohlogies using MRI with TSAi and their relation to patient-centered surgical outcomes are needed.

**Conclusion**

Taken in whole, our data support the growing body of literature suggesting that MRI with TSAi shares similar overall tear detection accuracy to standard MRI image acquisition sequences, however is superior in allowing radiologists to accurately describe specific tear morphologies. Incorporating TSAi into knee MRI protocols is relatively cost-effective and easy to implement and interpret relative to technologies that directly create a true 3-D image of the menisci. The results of the present investigation support the incorporation of TSAi into knee MRI acquisition sequences in institutions with the capability to do so.

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