

# Analysis of Low-Field Magnetic Resonance Imaging Scanners for Evaluation of Knee Pathology Based on Arthroscopy

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**Background:** In recent years, few studies have evaluated low-field magnetic resonance imaging (MRI) diagnoses compared with intraoperative findings of the knee.

**Purpose:** To determine the accuracy and sensitivity of low-field MRI scanners in diagnosing pathology of the menisci, cruciate ligaments, and osteochondral surfaces.

**Study Design:** Cohort study (diagnosis); Level of evidence, 2.

**Methods:** MRI examinations without intra-articular contrast were performed on 379 patients for knee pathologies over a 4-year period. The MRI examinations were done using a 0.2-tesla scanner utilizing a dedicated knee coil and read by 1 of 3 board-certified, musculoskeletal fellowship-trained radiologists. Within a mean time of 50 days after MRI, all patients underwent knee arthroscopy performed by 1 of 2 sports fellowship-trained orthopaedic surgeons. Operative notes from the knee arthroscopies were then reviewed by a single independent observer, and the intraoperative findings were compared with the MRI reports.

**Results:** For medial meniscus tears, the sensitivity, specificity, positive predictive value, and negative predictive value were 83%, 81%, 89%, and 71%, respectively. For lateral meniscus tears, the values were 51%, 93%, 84%, and 73%, respectively. For anterior cruciate ligament (ACL) tears, the values were 85%, 94%, 69%, and 97%, respectively. For osteochondral lesions, the values were 8%, 99%, 29%, and 94%, respectively. For posterior cruciate ligament (PCL) tears, the specificity and negative predictive value were 99% and 100%, respectively.

**Conclusion:** Low-field MRI was an accurate tool for evaluation of medial meniscus and ACL tears. However, within the study population, it is not as effective in diagnosing lateral meniscus tears and showed a poor ability to detect osteochondral lesions. More information is needed to properly assess its ability to diagnose PCL tears.

**Keywords:** low-field MRI; meniscus; ACL; PCL; osteochondral lesion

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In the United States alone, knee injuries accounted for more than 18 million physician visits during 2010.<sup>25</sup> The most powerful and comprehensive imaging tool for diagnosing such injuries is magnetic resonance imaging (MRI). While high-field (>1.0 tesla) MRI scanners continue to be the most commonly used, there is growing interest in the utilization of low-field (<0.5 tesla) extremity scanners. They are smaller, less expensive, easier to install, and allow for quicker patient diagnoses in an office setting. In contrast,

high-field scanners have superior image quality because of higher signal-to-noise ratio (SNR), contrast, and resolution.<sup>11,12,21,27,34,35</sup> It is possible for low-field scanners to improve image quality by increasing scan duration, although doing so also increases the chance of motion artifacts.<sup>2,11,12,21,35</sup> While low-field MRI images may not be able to rival the quality of those produced using high-field scanners, it is important to consider whether or not they can provide comparable diagnosis levels to justify their logistical benefits.

When compared with surgical findings, the use of low-field extremity MRI scanners for identifying medial meniscus pathology has been promising (sensitivity, 77%-96%; specificity, 71%-100%); however, results for identifying pathology of the lateral meniscus have been more variable.<sup>1,4,8,9,13,19,22,23,32</sup> While most studies show low-field MRI to be a good identifier of lateral meniscus pathology (sensitivity, 75%-93%; specificity, 94%-100%), studies by Kinnunen et al<sup>19</sup> and Fischer et al<sup>8</sup> found much lower accuracies (sensitivity, 25%-51%; specificity, 96%-97%).<sup>1,4,9,13,23,32</sup> There is no known anatomic reason for this difference, and Fischer et al<sup>8</sup> speculated that a higher prevalence of medial

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meniscus tears may have caused the radiologists to “over-read” tears of the medial meniscus and “under-read” those of the lateral meniscus. Low-field MRI findings compare favorably with those found using high-field scanners for the medial meniscus (sensitivity, 76%-97%; specificity, 80%-100%) and lateral meniscus (sensitivity, 67%-96%; specificity, 94%-100%).<sup>3,4,6,8,17,24,26,28,30</sup>

Low-field MRI has also been an accurate tool in diagnosing anterior cruciate ligament (ACL) tears (sensitivity, 75%-98%; specificity, 85%-100%), again comparing well with high-field findings (sensitivity, 75%-97%; specificity, 93%-100%).<sup>4,8,9,19,20,22,32</sup> Posterior cruciate ligament (PCL) tears have not been adequately studied using low-field MRI because of their low rate of occurrence. Riel et al<sup>32</sup> found low-field MRI to correctly identify all 3 PCL tears in their study (sensitivity, 100%; specificity, 100%), although it is difficult to make any conclusions with such a small sample size. Lokannavar et al<sup>22</sup> had the same results for 2 PCL tears (sensitivity, 100%; specificity, 99%). While previous studies have done well to demonstrate the strengths and weaknesses of low-field MRI, few have exclusively compared low-field MRI findings with pathology found during knee arthroscopy using musculoskeletal fellowship-trained radiologists. In addition, most studies in the current literature have either small sample sizes or multiple surgeons performing knee arthroscopy.

The goal of this study was to investigate the effectiveness of low-field extremity MRIs in identifying pathology of the knee. Our study is the first to our knowledge to include osteochondral lesion analysis in the comparison of low-field scans of the knee with arthroscopic surgical findings. We hypothesize that a low-field MRI will be accurate in determining tears of the medial meniscus, lateral meniscus, ACL, and PCL when compared with the gold standard of arthroscopic surgical findings. We do not believe it will be able to accurately identify osteochondral lesions because of limitations in image resolution.

## MATERIALS AND METHODS

This retrospective study was conducted on patients who had an MRI performed over a 4-year period from November 25, 2008, to December 19, 2012. In-office patient evaluations were performed by the orthopaedic surgeons noted in the study. MRIs were originally ordered after history, physical examination, and radiographs and were primarily concerning for pathology of the menisci, cruciate ligaments, or osteochondral surfaces. Patients were also indicated for MRI if they failed a period of conservative management and the history, physical, and radiographic examinations were inconclusive regarding a diagnosis. If a patient's insurance provider did not authorize a low-field MRI, they were referred to an outside facility with a high-field scanner and not included in the study. Patients who had failed conservative management were indicated for surgery. Only patients who underwent an arthroscopy following MRI were included. Patients with a previous history of surgery on the affected knee were excluded from the study. Thirty-one patients were removed from the study because

the time between their MRI and surgery was greater than 180 days. Additionally, 1 patient was removed because the MRI had extensive motion artifacts. The resulting population consisted of 379 patients (206 males, 173 females). Their ages ranged from 14 to 88 years, with a mean age of 47.5 years at the time of the MRI. A total of 189 patients had the right knee affected, and 190 patients had the left knee affected.

These patients had arthroscopic knee surgery within a mean 50.1 days (range, 1-169 days) after having the MRI performed. The arthroscopic surgeries were performed by 1 of 2 board-certified orthopaedic surgeons fellowship trained in sports medicine with more than 17 and 19 years of experience. MRI images and reports were reviewed by the surgeons prior to surgery, and the MRI reports were available to the surgeons at the time of surgery. Operative reports were dictated independent of the MRI readings, and the 2 were later compared by an independent observer blinded to patient information. Institutional review board approval was not necessary for this study, as it was a retrospective review of data done in such a way that the reviewer was blinded to all patient identifiers.

## Magnetic Resonance Imaging

An MRI of the knee was performed on a 0.2-tesla scanner utilizing a dedicated knee coil (E-scan Opera; Esaote, Genoa, Italy). The gradient magnetic fields for the system operate at 20 mT/m and have a slew rate of 25 mT/m/ms.

Each patient signed a consent form and was screened by the MRI technician for safety. The MRI technician placed each patient's leg in supine position with the knee in full extension. The following acquisitions were obtained: proton density (PD)-weighted oblique sagittal plane, non-fat saturated T2-weighted fast spin echo (FSE) oblique sagittal and oblique axial planes, gradient echo (GRE) oblique coronal plane, and short Tau inversion recovery (STIR) oblique coronal plane. The average imaging time was about 40 minutes, and the imaging parameters are displayed in Table 1. For comparison, scan time for a 3.0-tesla knee MRI runs about 20 minutes.<sup>31</sup>

## Interpretation of the MR Images

Each image was read in an independent prospective manner by 1 of 3 board-certified radiologists with MR musculoskeletal fellowship training. One radiologist has more than 22 years of experience reading musculoskeletal MR images, and the other 2 have more than 8 years of experience. The radiologists were provided with basic demographic information, including the patient's date of birth, sex, name, suspected pathology, and relevant symptoms presented in the initial history and examination.

## Data Collection

Data collection was performed between January and April of 2013. The MRI readings and operative reports were evaluated to compile the necessary data. The MRI readings were compared with the postoperative surgical findings in

TABLE 1  
MRI Parameters at 0.2-Tesla<sup>a</sup>

Type of MR Image	TE, ms	Thickness, mm	Inter-section Gap, mm	Field of View, cm	Matrix, pixels	No. of Excitations
PD-weighted oblique sagittal	26	4	1	18	512 × 512	1
T2-weighted FSE oblique sagittal	90	4	1	18	256 × 256	1
T2-weighted FSE oblique axial	90	4	1	16	256 × 256	1
GRE oblique coronal	16	4	1	18	512 × 512	3
STIR oblique coronal <sup>b</sup>	25	4	1	20	256 × 256	1

<sup>a</sup>Repetition time (TR) varied by patient. TE, echo time; PD, proton density; FSE, fast spin echo; GRE, gradient echo; STIR, short Tau inversion recovery.

<sup>b</sup>Inversion time (TI), 75 ms.

TABLE 2  
MRI Findings Compared With Arthroscopic Findings (N = 379 Patients)

	MRI Findings, %			
	Sensitivity	Specificity	Positive Predictive Value	Negative Predictive Value
Medial meniscus tear	83	81	89	71
Lateral meniscus tear	51	93	84	73
ACL tear	85	94	69	97
PCL tear	N/A <sup>a</sup>	99	0 <sup>a</sup>	100
Osteochondral lesion	8	99	29	94

	Arthroscopic Findings, n			
	True Positive	True Negative	False Positive	False Negative
Medial meniscus tear	207	104	25	43
Lateral meniscus tear	81	206	15	77
ACL tear	46	304	21	8
PCL tear	0	374	5	0
Osteochondral lesion	2	350	5	22

<sup>a</sup>No PCL tears were identified during arthroscopy. N/A, not applicable.

the operative reports. Positive findings were only indicated if a tear or osteochondral lesion was explicitly stated in the MRI report. The terms tendinosis, tendinopathy, fraying, fibrillation, degeneration, attenuation, fringe, and scuffing were not categorized as tears in this study. Chondromalacia was not categorized as well.

### Statistical Analysis

MRI readings were compared with surgical findings to identify true positive, true negative, false positive, and false negative pathologies. True positive was defined as a tear or lesion identified on MRI and confirmed by surgical findings. True negative was defined as a nontear or nonlesion identified on MRI and confirmed by surgical findings. False positive was defined as a tear or lesion identified on MRI that was not confirmed by surgical findings. False negative was defined as a nontear or nonlesion identified on MRI that was found to be a tear or lesion by surgical findings. We then calculated sensitivity, specificity, positive predictive value, and negative predictive

value. Sensitivity was defined as the number of true positive pathologies divided by the sum of true positive and false negative pathologies. Specificity was defined as the number of true negative pathologies divided by the sum of true negative and false positive pathologies. Positive predictive value was defined as the number of true positive pathologies divided by all positive diagnosed pathologies. Negative predictive value was defined as the number of true negative pathologies divided by all negatively diagnosed pathologies.

### RESULTS

After comparing the MRI reports with the gold standard of arthroscopic surgical findings, we found a total of 250 medial meniscus tears, 158 lateral meniscus tears, 54 ACL tears, no PCL tears, and 24 osteochondral lesions. Table 2 shows the sensitivity, specificity, positive predictive value, and negative predictive value for the MRI readings of the menisci, cruciate ligaments, and osteochondral surfaces.

## Meniscus

**Medial Meniscus Tears.** MRI correctly identified 207 of the 250 medial meniscus tears, for a sensitivity of 83%. Additionally, 104 of the 129 knees without medial meniscus tears were correctly identified, for a specificity of 81%. There were 25 false positives and 43 false negatives. Of the 43 false negatives, 21 (49%) were identified as normal on MRI, 13 (30%) showed grade I or II signal, and 9 (21%) showed degeneration or fraying. When compared with surgical findings, the positive predictive value of the low-field MRI for diagnosis of medial meniscus tears was 89%. The negative predictive value was 71%.

**Lateral Meniscus Tears.** MRI correctly identified 81 of the 158 lateral meniscus tears, for a sensitivity of 51%. Additionally, 206 of the 221 knees without lateral meniscus tears were correctly identified, for a specificity of 93%. There were 15 false positives and 77 false negatives. Of the 77 false negatives, 51 (66%) were identified as normal on MRI, 12 (16%) showed grade I or II signal, and 15 (19%) showed degeneration or fraying. The false negatives were primarily found to be small tears of the inner surface of the body of the lateral meniscus. They were debrided to healthy meniscal tissue to prevent further propagation of the tear into the body of the meniscus. One of the false positives was read as having both grade II signal and fraying. When compared with surgical findings, the positive predictive value of the low-field MRI for diagnosis of lateral meniscus tears was 84%. The negative predictive value was 73%.

## Cruciate Ligaments

**Anterior Cruciate Ligament.** MRI correctly identified 46 of the 54 ACL tears, for a sensitivity of 85%. Additionally, 304 of the 325 knees without ACL tears were correctly identified, for a specificity of 94%. There were 21 false positives and 8 false negatives. Of the 21 false positives, 20 (95%) were read as partial-thickness tears on MRI, and 1 (5%) was read as a full-thickness tear. Of the 8 false negatives, 6 (75%) were read as normal and 2 (25%) were read as fraying. Six (75%) of these were found to be full-thickness tears during arthroscopy, and 2 (25%) were partial-thickness tears. When compared with surgical findings, the positive predictive value of the low-field MRI for diagnosis of ACL tears was 69%. The negative predictive value was 97%.

**Posterior Cruciate Ligament.** No patients were found to have PCL tears in this series of knee arthroscopies. Additionally, 374 of the 379 knees without PCL tears were correctly identified, for a specificity of 99%. There were 5 false positives, 4 of which were read as partial-thickness tears and 1 as a full-thickness tear on MRI. When compared with surgical findings, the negative predictive value was 100%. Sensitivity and positive predictive value are not applicable as no PCL tears were found in the study.

## Osteochondral Lesions

MRI correctly identified 2 of 24 osteochondral lesions (1 in the trochlear groove and 1 in the lateral compartment), for a sensitivity of 8%. Additionally, 350 of the 355 knees

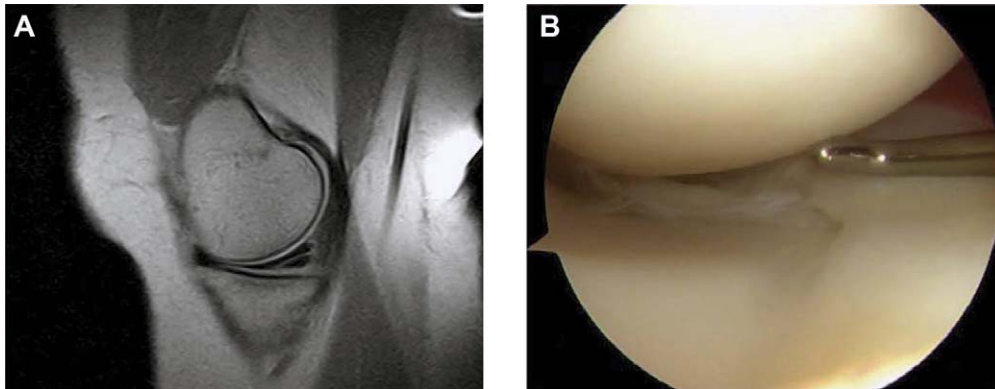
without osteochondral lesions were correctly identified, for a specificity of 99%. There were 5 false positives and 22 false negatives. When compared with surgical findings, the positive predictive value of the low-field MRI for diagnosis of osteochondral lesions was 29%. The negative predictive value was 94%.

## DISCUSSION

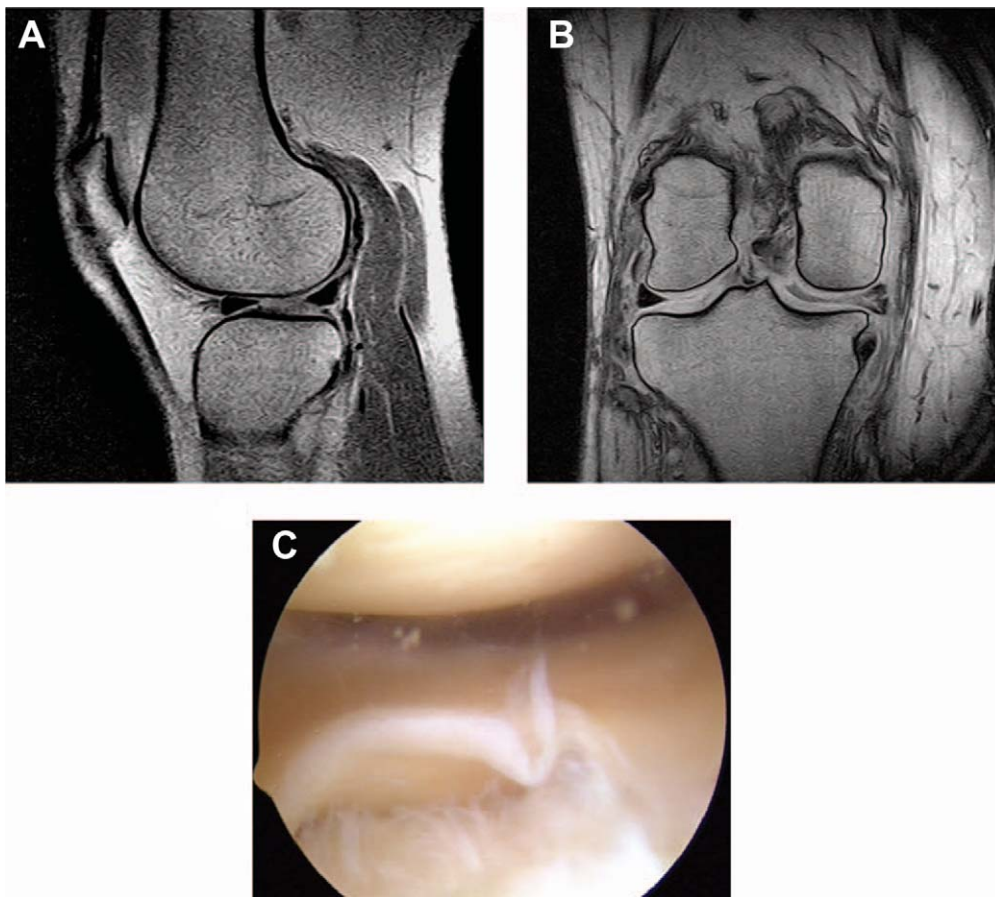
Low-field MRIs are less expensive, can be installed in an office setting, and allow for both imaging and diagnosis to occur in a single patient visit. However, these benefits are not without drawbacks, as low-field scanners lack the image quality of their high-field counterparts. Both types of scanners have their own strengths and weaknesses, with no clear distinction as to which is better able to balance cost and accessibility with diagnostic efficacy. If low-field scanners are able to identify pathology at a high level, then their logistical benefits may outweigh any shortcomings in image quality. Few publications have evaluated the efficacy of low-field MRI in recent years, and in this study, we assessed low-field MRI readings to the gold standard of knee diagnosis: arthroscopy.

The low-field extremity MRI scanner used in this study was a good predictor of medial meniscus tears (sensitivity, 83%; specificity, 81%) (Figure 1), but not lateral meniscus tears (sensitivity, 51%; specificity, 93%) (Figure 2). Previous studies comparing low-field MRI to surgical findings have shown similar results for the medial meniscus (sensitivity, 77%-96%; specificity, 71%-100%), but lateral meniscus findings have commonly been much better (sensitivity, 75%-93%; specificity, 94%-100%).<sup>1,4,8,9,13,19,22,23,32</sup> However, there have been 2 studies, by Kinnunen et al<sup>19</sup> and Fischer et al,<sup>8</sup> that showed low-field MRI to be a poor predictor of lateral meniscus tears (sensitivity, 25%-51%; specificity, 96%-97%). These findings match ours more closely, although it is unclear why our results may differ from the other studies. We are also unaware of any reason why such differences would exist between the medial and lateral menisci. Because of greater fixation, less mobility, and its function as a secondary stabilizer of anterior translation, medial meniscus tears tend to be more prevalent and more symptomatic.<sup>7,14</sup> Fischer et al<sup>8</sup> considered the fact that a greater incidence of medial meniscus tears may have caused the radiologists to anticipate findings and therefore “over-read” tears of the medial meniscus and “under-read” those of the lateral meniscus. We also found a greater number of medial meniscus tears (n = 250) than lateral meniscus tears (n = 158), and agree that this may have been a contributing factor. Similarly, high-field MRI has been shown to be a good predictor of medial meniscus (sensitivity, 89%-97%; specificity, 79%-100%) and lateral meniscus tears (sensitivity, 67%-96%; specificity, 91%-100%), with results for the lateral meniscus again being more variable.<sup>3,4,6,8,17,24,28,30</sup>

Our findings also showed low-field MRI to be a good identifier of ACL tears (sensitivity, 85%; specificity, 94%), which is comparable with other low-field (sensitivity, 75%-98%; specificity, 85%-100%) and high-field (sensitivity,



**Figure 1.** True positive MRI and arthroscopic findings of a medial meniscus tear for a single patient. (A) Proton density-weighted oblique sagittal view using an E-scan Opera Esaote 0.2-tesla scanner. (B) Standard anterolateral viewing portal with 30° arthroscope evaluating medial meniscus.



**Figure 2.** False negative MRI and arthroscopic findings of a lateral meniscus tear for a single patient. (A) Proton density-weighted oblique sagittal view using an E-scan Opera Esaote 0.2-tesla scanner. (B) Gradient echo (GRE) oblique coronal view from the same MRI scan showing the lateral (left) and medial (right) menisci. (C) Standard anterolateral viewing portal with 30° arthroscope evaluating the lateral meniscus following resection.

75%-97%; specificity, 93%-100%) MRI studies.<sup>4,8,9,19,20,22,32</sup> As in other low-field MRI studies, we were unable to make any conclusions regarding the PCL. No PCL tears were present in this study, so more information is needed to

assess the accuracy of low-field MRI in identifying such pathology (specificity, 99%). We also found that low-field MRI was not able to accurately diagnose osteochondral lesions of the knee (sensitivity, 8%; specificity, 94%), and

to our knowledge, this is the first study to evaluate such pathology. Riel et al<sup>32</sup> compared low-field MRI to surgical findings for grade III cartilage lesions and found it much more accurate (sensitivity, 72%; specificity, 100%).

Possible confounding factors in our study include our use of multiple surgeons and radiologists, as variability between the 3 radiologists as well as between the radiologists and the surgeons may exist. Each radiologist is highly experienced in musculoskeletal radiology and works within the same radiology group, so we would expect any variability among radiologists to be limited. Additionally, the radiologist readings were done in a prospective manner, which may reduce bias, and Cotten et al<sup>4</sup> found there to be excellent agreement between experienced musculoskeletal radiologists when reading both low- and high-field MRIs of the knee. Future studies could control for this confounder by using a single radiologist, although including MRI readings from a group of radiologists more accurately mimics reality and strengthens the clinical relevance of the results. Any variability that may exist between the radiologists and surgeons would again be representative of the process in a real clinical setting. Lastly, operative reports from our 2 surgeons both produced similar results with regard to the diagnostic ability of low-field MRI, so there is no reason to believe they differ in their interpretation of knee pathology.

Another limitation within any study of this nature is the difficulty of assessing false positive and false negative results for patients who never had surgery. Patients who did not pursue surgery despite showing a tear or lesion on the MRI were likely able to tolerate or resolve their symptoms through conservative management. While patients are often able to live with small tears of the menisci or cruciate ligaments through physical therapy or activity modification, it would not be surprising if some of these patients may have been incorrectly diagnosed with tears on MRI. The same issues arise when assessing false negative results, as patients with negative results would be less likely to pursue operative management. When patients in our study who had MRI findings did not show ligament or cartilage tears indicating surgery, a conservative treatment plan was initiated to address other concomitant conditions such as patellofemoral syndrome and chondromalacia patellae, iliotibial band syndrome, and gait and alignment abnormalities. The conservative treatment plan included at least 3 months of physical therapy and, in some cases, cortisone and viscolubricant injections. With that said, patients with negative MRIs who subsequently failed conservative management would have been likely to receive a repeat MRI, an MR arthrogram, or diagnostic arthroscopy. Patients only underwent arthroscopy if dedication and compliance to the conservative treatment plan failed to provide long-term relief of symptoms. This is also a difficult issue to control for without exposing patients to unnecessary surgery.

Low- and standard high-field MRIs are still the most commonly used imaging techniques for diagnosing soft tissue injuries to the knee, although they are not the only options. Recent advances in MRI technology have led to the availability of 3.0-tesla scanners. These super-high-field

scanners offer superior imaging quality but do so at increased cost. Studies have not shown that 3.0-tesla scanners are better able to identify medial meniscus (sensitivity, 91%-100%; specificity, 66%-96%) or lateral meniscus (sensitivity, 67%-94%; specificity, 79%-97%) tears in comparison with other scanners.<sup>5,15,16,18,31,33</sup> However, they have shown promise in better identifying tears of the ACL (sensitivity, 100%; specificity, 98%-100%) and cartilage lesions (sensitivity, 76%; specificity, 95%).<sup>5,16,18,33</sup> Another option for diagnosing pathology of the knee is the use of ultrasound. While conventional MRI is still the preferred diagnostic tool, ultrasound is faster, less expensive, and has shown promising results in identifying tears of the menisci and ACL.<sup>10,29,33</sup> However, unlike MRI, ultrasound is a targeted diagnostic tool and is only able to evaluate 1 area of the knee at a time, making it less useful for diagnoses in which a specific pathology is unknown. The same limitation exists for low-field MRI, as its inability to accurately diagnose lateral meniscus tears and osteochondral lesions limits its ability to provide a comprehensive evaluation of the knee in comparison with high-field MRI. While less expensive imaging tools such as low-field MRI and ultrasound are gaining popularity in the current cost-conscious health care climate, it is important to understand the limitations they present as well. If the use of low-cost diagnostic imaging does not yield enough information to make an accurate diagnosis, then their use may in fact increase costs, as more expensive tests may still be needed.

Low-field extremity MRI scanners are accurate tools for identifying tears of the medial meniscus and ACL; however, in our study population, they were poor indicators of lateral meniscus tears and osteochondral lesions. The MRI is a useful tool for identifying the extent of knee pathology, but it is not without limitations. Both low- and high-field MRI should always be used in conjunction with the patient's history, symptoms, and physical examination when formulating a treatment plan.

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