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Accuracy of standard magnetic resonance imaging sequences for meniscal and chondral lesions versus knee arthroscopy. A prospective case-controlled study of 719 cases

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Abstract

Background: Magnetic resonance imaging (MRI) is commonly used for diagnosis and as a research tool, but its accuracy is questionable. The goal of this study was to compare the accuracy of knee MRI with clinical assessment for diagnosing meniscal tears, and to determine the accuracy of MRI for grading chondral lesions, relative to arthroscopy.
Methods: Physically active patients presenting with mechanical symptoms warranting a knee arthroscopy and satisfying the inclusion criteria, had both a knee arthroscopy and MRI performed. Arthroscopic findings were compared with those of MRI, using the International Chondral Research Society grading for chondral damage, and the presence or absence of a meniscal tear.
Results: A total of 719 patients were recruited over a period of 6.5 years, average age 52 years (standard deviation, SD 5.2), male:female = 493:226. Kappa scores with standard errors (SE) for agreement between MRI and knee arthroscopy were 0.41 (SE 0.1) for medial meniscal tears, and 0.44 (SE 0.1) for lateral meniscal tears. For the grade of chondral damage, the Kappa scores with SE values were 0.09 (0.1), 0.17 (0.1), and 0.22 (0.07) for anterior, medial and lateral compartments, respectively. Using areas under the receiver operating characteristic curves, we found clinical assessment was more accurate than MRI for diagnosis of lateral meniscal tears ($P < 0.001$), and of similar accuracy for the diagnosis of medial meniscal tears ($P = 0.12$).
Conclusions: MRI has relatively poor correlation with arthroscopic findings for grading the chondral damage and was less accurate than clinical assessment for the diagnosis of lateral meniscal tears.

Introduction

Knee arthroscopy is the gold standard diagnostic tool for intra-articular knee pathology but it is invasive and expensive. However, it enables treatment to be performed at the same time. A sufficiently accurate diagnostic modality could reduce the number of purely diagnostic arthroscopies performed. However, the imaging modality would have to be of sufficient accuracy to ensure that significant intra-articular pathology is not missed.

Magnetic resonance imaging (MRI) has evolved as the imaging method of choice for evaluating knee pathology. It is non-invasive and free of known adverse effects, but is relatively expensive and there is some debate over its accuracy and the cost–benefit ratio.[1,2] MRI is potentially useful as a research tool, but again its accuracy is fundamental to the validity of that research.

The goal of the present study was to determine the accuracy of MRI for both meniscal and chondral lesions relative to knee arthroscopy, and to compare the accuracy of MRI with that of clinical assessment for meniscal lesions.

Materials and methods

Patients presenting to the main author, a sub-specialist sports orthopaedic surgeon, between 1st March 2013 and 30th November 2019 who satisfied the inclusion criteria in Table 1 were invited to take part in the study. The goal of the selection criteria was to recruit those patients in whom an accurate non-invasive diagnostic

Table 1 Inclusion and exclusion criteria used for patient enrolment

Inclusion criteria	Exclusion criteria
Symptoms preventing usual physical activities, for more than 6 weeks.	Night-ache
Onset of knee symptoms over a period of 3 days or less	Systemic symptoms
Painful catching sensations, pseudo-locking	Previous knee surgery requiring ligament, meniscal or chondral surgery
If onset was during a sports activity, able to continue the activity at the time	Unable to undergo an MRI (claustrophobia, cochlear implant, pacemaker, other reasons), or refusing to have an MRI
Symptoms aggravated by uneven ground, twisting and pivoting	Laxity > grade 2 in any plane(s)
Medically fit for a general anaesthetic	Acute onset of locking of the knee
Knee effusion with joint line / joint surface tenderness	Connective tissue or rheumatologic condition
At least 18 years of age and skeletally mature	
Arthroscopy performed within 4 weeks of the MRI	Unwilling to undergo a knee arthroscopy

modality would be potentially most useful for preventing an unnecessary, purely diagnostic, knee arthroscopy.

This study was reviewed and approved by Barton Private Hospital Ethics Committee (Australian Capital Territory) and has therefore been performed in accordance with the ethical standards contained within the Declaration of Helsinki. Patient anonymity was preserved throughout.

Clinical assessment

All patients underwent a clinical assessment comprising patient history and physical examination. The clinical examination selection criteria are detailed in Table 1, and these criteria have been used previously.[3] To specifically diagnose a meniscal tear, two of the following three findings were required; (1) joint-line tenderness, (2) pain during McMurray's test, and/or (3) an effusion. Patients with these physical findings were consented to undergo a knee arthroscopy as long as medically fit to do so. If they already had, or agreed to have an MRI performed, they were asked to take part in the study.

MRI assessment

The MRI was performed on a 1.5T or 3T MRI machine with standard MRI sequences. The area of most severe chondral damage seen on the MRI was graded for each compartment using the validated International Cartilage Repair Society (ICRS) criteria, shown in Table 2.[4,5] To diagnose a meniscal tear, this was defined as an abnormal meniscal signal extending to one of the articular surfaces on contingent slices, missing meniscal tissue, and/or a displaced fragment.[6,7] The images were reported on by nine separate radiologists, all fellowship trained with a sub-specialist interest in musculoskeletal MRI. The main author also reported on the images independently and before reading the MRI report. The level of agreement between the main author and the radiology reports was calculated for meniscal tears and chondral injuries. The occurrence of any other pathology, diagnosed on the MRI was recorded.

Table 2 International cartilage research society (ICRS) grading system for chondral damage

Grade	Description
0	Normal
1	Superficial lesions (cracks or fissures), softening
2	Lesions <50% of the chondral thickness
3	Lesions >50% of the chondral thickness, but not through the subchondral bone
4	Lesions extend to the subchondral bone

Surgical technique

All arthroscopies were performed by the main author under a general anaesthetic. The MRI images were not reviewed again before surgery to reduce the influence that the MRI images and/or the radiologist report may have on the surgeon's grading of chondral damage and diagnosis of a meniscal tear. The severity of the worst area of chondral damage in each of the compartments was recorded using the ICRS system as well as the presence or absence of a meniscal tear. The definition of an arthroscopic meniscal tear was a disruption of the joint surface of the meniscus into which the tip of the arthroscopic probe could be introduced, and/or a portion of the meniscus could be displaced with probing.[8]

Statistical analysis

Statistical analysis was performed using SSPS computer software (version 22; IBM).

The sensitivity, specificity and accuracy of clinical assessment and MRI, for the diagnosis of medial or lateral meniscal tears was calculated using the arthroscopy as the gold standard.

We used frequencies statistics to determine the Kappa scores and level of agreement between the MRI and arthroscopic findings, for the presence of a meniscal tear in the medial and lateral compartments.

The intrinsic accuracy of clinical assessment and MRI for diagnosing meniscal tears was expressed as the receiver operating characteristic (ROC) curve. The area under the ROC curve and z-statistic was then used to compare the accuracy of the clinical assessment with that of MRI for the diagnosis of medial and lateral meniscal tears, using dichotomous variables and a pairwise comparison.[9]

We used chi-squared tests to determine the Kappa scores and level of agreement between the MRI and the arthroscopic findings,

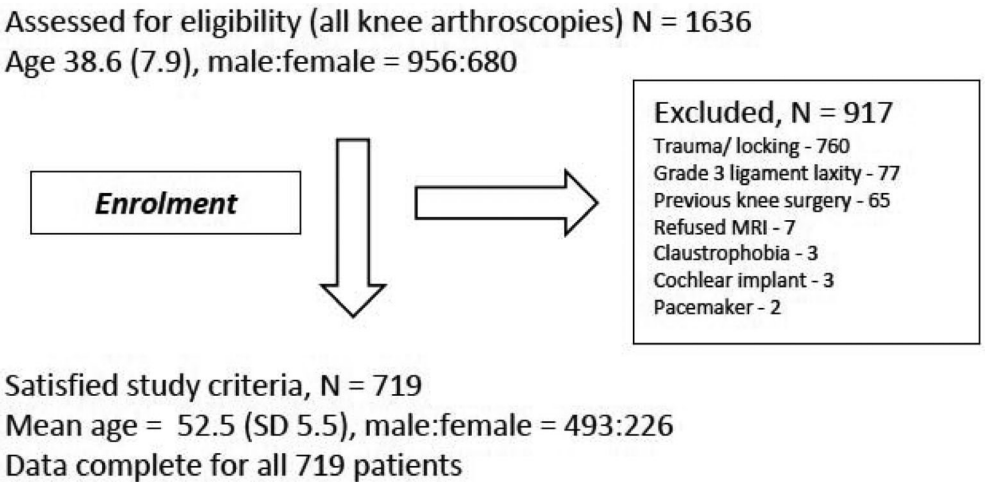

Fig 1. Flow chart summarizing patient recruitment process for the study.

for the ICRS grade of chondral damage in each of the three compartments of the knee.

The level of agreement between the orthopaedic surgeon and the radiology reports was calculated using the Cohen's Kappa score, for chondral damage and meniscal tears.

Results

During the period first March 2013 and 30th November 2019, 719 patients were enrolled in the study. Figure 1 summarizes patient enrolment data. Seven patients refused to have an MRI performed, but no patients with complete data refused to take part in the study. There were no patients in whom the MRI diagnosed unexpected pathology or altered the treatment plan.

Statistical analysis

The Cohen's Kappa score for the interobserver agreement between the orthopaedic surgeon and radiology report was found to be 0.79 (P = 0.008) for meniscal tears and 0.78 for chondral damage (P = 0.008).

The sensitivity, specificity, accuracy, positive predictive value (PPV), negative predictive value (NPV) and ROC of clinical assessment and MRI for the diagnosis of meniscal tears are shown in Table 3. For medial meniscal tears clinical assessment had greater specificity (P = 0.03) and PPV (P = 0.02), than MRI, while for lateral meniscal tears it had greater specificity (P = 0.002), PPV ($P < 0.001$) and accuracy ($P < 0.001$).

The level of agreement between the MRI and arthroscopic findings for the presence of a tear in the medial or lateral meniscus was moderate, with Kappa scores of 0.44 (SE 0.1) and 0.41 (SE 0.1), respectively.[10]

The level of agreement between the MRI and the arthroscopic findings for the ICRS grade of chondral damage the anterior, medial and lateral compartments was slight to fair.[10] The Kappa scores were 0.09(SE 0.06), 0.17 (SE0.06) and 0.22 (SE 0.07) respectively.

ROC comparisons

Diagnostic accuracy of MRI versus clinical assessment for meniscal tear was determined using arthroscopy as the gold standard and the area under the curve (AUC) of the ROC curve.

Clinical assessment was more accurate than MRI for diagnosis of lateral meniscal tears ($P < 0.001$), while for medial meniscal tears there was no difference (P = 0.12).

Sample size calculation

A *post hoc* power analysis was performed. Taking an α value of 0.05 (Type I error), a β value (Type II error) of 0.20, with AUC values of 0.84 and 0.61, and a correlation value of 0.4, the number of negative cases required is 132, and number of positive cases is 333, with total sample size of 465. Therefore, the study was adequately powered to compare the accuracy of clinical assessment with that of MRI using knee arthroscopy as the gold standard.

Discussion

In those patients satisfying the inclusion criteria used in this study, we found that clinical examination was as accurate as MRI for the diagnosis of medial meniscal tears, and more accurate for the diagnosis of lateral meniscal tears. Using Koch's criteria, the accuracy of MRI in the diagnosis of chondral damage was slight to fair, and for meniscal tears it was moderate.[10] The NPV of MRI for medial and lateral meniscal tears was 87% and 85.8%, respectively. Therefore, close to 15% of patients who had normal-appearing menisci on MRI had a meniscal tear at arthroscopy. The PPV of MRI for medial and lateral meniscal tears was 95.6% and 60.9%, respectively. Therefore, up to 40% of patients diagnosed with a meniscal tear on MRI, had no meniscal tear. MRI had a higher chance of false-positive diagnoses than false-negative diagnoses, for meniscal tears.

Knee arthroscopy is commonly used to diagnose and treat intra-articular knee pathology but it is invasive and relatively expensive. An accurate non-invasive imaging modality could reduce the use of knee arthroscopy for diagnosis. The accuracy of MRI for the diagnosis of meniscal tears has been reported to be 80–96% in other

Table 3 The sensitivity, specificity, accuracy, PPV, NPV and ROC for clinical assessment and MRI in the diagnosis of meniscal tears. Range in parentheses

Medial meniscal tears	Clinical assessment	MRI	*P* value
Sensitivity	86.1% (82.3–89.3)	88.3% (84.8–91.3)	0.15
Specificity	99.4% (97.8–99.9)	95.1% (92.1–97.1)	0.03*
Accuracy	92.1% (89.9–93.9)	91.4% (89.1–93.3)	0.77
PPV	99.4% (97.7–99.8)	95.6% (93.1–97.2)	0.02*
NPV	85.4% (82.1–88.2)	87.0% (83.6–89.8)	0.65
ROC AUC	0.86 (SE 0.09)	0.84 (SE 0.05)	0.02 (SE 0.02) 0.33
Lateral meniscal tears			
Sensitivity	80.2% (74.9–84.9)	79.8% (74.5–84.5)	0.84
Specificity	98.9% (97.5–99.6)	70.4% (66.0–74.6)	0.002*
Accuracy	92.1% (89.9–93.9)	73.8% (70.5–77.0)	<0.001*
PPV	97.7% (94.6–99.0)	60.9% (57.1–64.5)	<0.001*
NPV	89.7% (87.2–91.7)	85.8% (82.5–88.6)	0.09
ROC AUC	0.84 (SE 0.08)	0.61 (SE 0.14)	0.23 (SE 0.09) <0.001*

NPV, negative predictive value; PPV, positive predictive value, ROC AUC, receiver operating characteristic area under the curve; SE, standard error.

*Statistically significant.

studies, but this depends upon the specific MRI protocols used.[11–16] Although these figures may appear impressive, clinical assessment has similar levels of accuracy at a fraction of the cost.[14,17] Our study had similar findings.

Any imaging modality that is less than 100% accurate will not obviate the need to perform a knee arthroscopy in patients with significant persistent symptoms. Using the "two-slice rule" the specificity of MRI in the current study was found to be 95.1% and 70.4% for medial and lateral meniscal tears, respectively, and therefore still unable to replace knee arthroscopy as the gold standard.[6] A systematic review by Crawford *et al*. came to similar conclusions.[18]

In those patients with minimal or no symptoms, or if their symptoms resolve, it would be unethical and unnecessary to perform a knee arthroscopy, and therefore impossible to determine the accuracy of knee MRI in this setting.

There were seven patients in our study who declined to have an MRI performed and were excluded from the study. This equates to less than 1% of those patients who presented with mechanical symptoms for which an arthroscopy was recommended. This small percentage of patients is unlikely to influence the study outcomes.

The accuracy of MRIs has a significant influence on the validity of research. There is evidence to support the relatively common finding of MRI diagnosed meniscal "tears" in symptom-free patients.[1,19] Between 6% and 56% of asymptomatic patients have MRI evidence of a meniscal tear, with the prevalence increasing with age and being higher in males.[11] These MRI findings may be false-positive "MRI findings" in normal menisci. The dilemma remains, are these false-positives or symptom-free true positives? Research needs to distinguish between MRI diagnoses and arthroscopically proven diagnoses. These false-positive MRI diagnoses will favour any non-operative treatment for meniscal tears being studied.

Researchers have attempted to distinguish between traumatic and degenerative meniscal tears. Wesdrop *et al*. have shown that this classification is flawed and meniscal tears are likely to be on a continuum.[20] There are no validated criteria for identifying symptomatic meniscal tears on MRI.[2] The natural history and best management will depend upon the specific nature of the tear and the physical activity that the patient wishes to take part in, as well as the symptomatology, and clinical signs, with MRI having a lesser role.

The accuracy of MRI for the diagnosis of chondral lesions has also been reported in other studies. Relative to arthroscopic findings Von Engelhardt *et al*. found kappa scores of 0.32–0.62, or fair to moderate, using Landis and Koch criteria.[21] In the present study, the diagnostic accuracy of was less than this, being slight to fair. The difference may reflect the inclusion criteria used in the two studies and MRI parameters. In patients with degenerative joint disease the final decision with regard to treatment, osteotomies or arthroplasty, is determined by the distribution and severity of the patient's symptoms and arthroscopic findings, rather than the MRI grading of the severity of chondral damage. Friemert *et al*. found that MRI was unable to replace arthroscopy in the diagnosis of chondral lesion of the knee in their prospective study.[22]

There are a number of factors affecting the accuracy of MRI examinations and reports, including the radiologist's experience, the technical properties of the MRI equipment, the available MRI modalities and specific protocols. Accuracy rates of greater than 90% have been reported for MRIs in studies using radiologists specializing in MRI of the knee.[6,22,23] In our study, all nine reporting radiologists were MRI subspecialist and the use of more than one radiologist reflects what occurs in clinical practice. The level of agreement between the orthopaedic surgeon and the radiologists as group was substantial, with Kappa scores of 0.79 for meniscal tears and 0.78 for chondral damage ($P = 0.008$), where 0.8 is defined as close to perfect. This suggests a very high level of agreement, and similar to that found between specialist MRI radiologists.[10,24] The MRI machines used in the present study were either 1.5T or 3.0T and research has found these machines and sequences to have similar accuracy. [15,25–27] The use of standard MRI sequences was performed to reflect customary clinical practice, and the results may not be applicable to more cartilage-specific sequences.

Although MRI is associated with high sensitivity and specificity, and is free of significant risks, the question is whether or not they offer value. Research has found that rather than reducing costs, the

use of MRI can result in an increased number of knee arthroscopies.[4,28] This may be explained by the relatively high number of false-positive diagnoses of meniscal tears, as found in our study.

Previous research has questioned the over-use of knee MRIs in practice, and suggested that the percentage of useful MRIs varies from 18% to 91%, depending upon the clinical presentation.[29] In the study performed by Ben-Galim *et al*., 32% of knees with MRI reports suggesting abnormalities were normal at arthroscopy, and 5% had minimal chondral damage that did not warrant treatment. In 7% patients, there was no correlation between MRI findings and arthroscopic results. The MRI was regarded as misleading in 41%. There was an overall 65% rate of false positives for medial meniscal tears.[30] Krakowski *et al*. evaluated the diagnostic accuracy of physical examination and MRI in knee injuries.[17] Like us, they also reported that MRI was no more accurate than physical assessment of the knee, for the diagnosis of meniscal tears, medial or lateral. Avoiding the use of MRIs in those patients satisfying the inclusion criteria of this study represents a potentially large saving in health care expenditure.

A weakness of the study was that the surgeon could not be blinded with regard to the MRI diagnoses, but the images were not reviewed again prior to surgery. All patients had been referred to a sub-specialist sports orthopaedic surgeon and results may not be applicable to patients presenting to less sub-specialized practitioners.

Conclusions

Clinical assessment was as accurate as MRI for the diagnosis of medial meniscal tears and was more accurate for lateral meniscal tears. MRI was relatively inaccurate for grading chondral lesions. The expense associated with performing an MRI is not warranted in the management of the patients satisfying the inclusion criteria of the study. The limited accuracy of MRI and frequency of false-positive diagnoses of meniscal tears needs to be taken into account when interpreting research. MRI may be most useful only in those patients with atypical clinical presentation or for operative planning.

Conflicts of Interest

None declared.

Author contributions

Mark Porter: Conceptualization; data curation; investigation; methodology; project administration; resources; validation; writing-original draft; writing-review & editing. **Bruce Shadbolt:** Conceptualization; data curation; formal analysis; project administration; software; validation; writing-review & editing.

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