

# Magnetic resonance tomography of the knee joint

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## Abstract

**Objectives** To compare the diagnostic performance of magnetic resonance imaging (MRI) in terms of sensitivity and specificity using a field strength of  $<1.0$  T (T) versus  $\geq 1.5$  T for diagnosing or ruling out knee injuries or knee pathologies.

**Methods** The systematic literature research revealed more than 10,000 references, of which 1598 abstracts were reviewed and 87 full-text articles were retrieved. The further selection process resulted in the inclusion of four systematic reviews and six primary studies.

**Results** No differences could be identified in the diagnostic performance of low- versus high-field MRI for the detection or exclusion of meniscal or cruciate ligament tears. Regarding the detection or grading of cartilage defects and osteoarthritis of the knee, the existing evidence suggests that high-field MRI is tolerably specific but not very sensitive, while there is literally no evidence for low-field MRI because only a few studies with small sample sizes and equivocal findings have been performed.

**Conclusions** We can recommend the use of low-field strength MRI systems in suspected meniscal or cruciate ligament injuries. This does, however, not apply to the diagnosis and

grading of knee cartilage defects and osteoarthritis because of insufficient evidence.

**Keywords** Low-field magnetic resonance imaging · Meniscal tears · Cruciate ligament tears · Knee cartilage defects · Knee osteoarthritis

## Introduction

In patients who present with knee abnormalities, the first step of diagnosis is usually reviewing the clinical history and performing a physical examination involving various manipulative tests. For patients in which the diagnosis is uncertain or the symptoms persist, physicians must use other diagnostic modalities; in the past, this was usually diagnostic arthroscopy [1]. However, due to its invasive nature, orthopaedic surgeons have increasingly turned to magnetic resonance imaging (MRI), a proven reliable and safe modality that offers a combined evaluation of bones, ligaments, and soft tissue [2, 3].

MRI is commonly performed with whole-body high-field scanners using a field strength of  $>1.0$  T. For specific clinical questions in pathologies of the upper and lower extremities, so-called low- (or medium-) field-strength MR scanners, dedicated to the study of extremities, can be used. Open low-field whole-body scanners are less common. Low-field systems have several advantages and disadvantages [2–6], such as lower costs, but have a lower signal-to-noise ratio leading to lower image quality. These characteristics not only lead to divergences amongst radiologists, but also to recurrent discussions about reimbursement. Thus, the purpose of our study was to compare the diagnostic performance in terms of sensitivity and specificity of MRI using a field strength of  $<1.0$  T versus  $\geq 1.5$  T for diagnosing or ruling out knee injuries or knee pathologies.

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## Materials and methods

A preliminary review of the literature had revealed that a considerable number of systematic reviews on the topic, published between 2003 and 2012, were already available. Additionally, it was observed that diagnostic accuracy studies using low-field MRI systems were published mainly in the 1990s. We decided to rely primarily on the available systematic reviews to answer our research question provided that they met our inclusion criteria. In case those systematic reviews did not fully meet our needs, additional primary studies were to be considered. Otherwise, we used the recommended methods for systematic reviews of diagnostic accuracy studies [7, 8] and formulated the inclusion and exclusion criteria displayed in Table 1.

For the systematic literature search in the databases Medline, Cochrane Database of Systematic Reviews, and Scopus, combinations of the following search terms were used: magnetic resonance imaging, MR imaging, MRI, MRT, knee, meniscus, cruciate ligament, cartilage, chondral, and arthroscopy. The search was limited to papers published between 1990 and 2013 and not restricted to specific languages. Additionally, we screened the reference lists of the original articles for work that was not found with the described literature search.

All articles that could not be excluded on the basis of the title or abstract of the article were retrieved in full text. One author decided whether the selected studies met the inclusion and exclusion criteria for this review, while two other authors checked whether the selection process was correct.

The literature search revealed 11,987 references, of which 2347 were duplicates and 8042 could be excluded based on the title. Of the remaining 1598 articles, the abstracts were reviewed. Out of these, 87 full-text articles were retrieved. Primary studies that were retrieved in full text but were included in one of the presented systematic reviews were later excluded. This resulted in the final inclusion of four systematic reviews (of totally 94 diagnostic primary studies) and six primary studies. The flowchart of study selection, retrieval, and inclusion is displayed in Fig. 1.

Data were abstracted by the first author (SP) and checked for accuracy and completeness independently by the two co-authors (YCKK, LE). Any disagreements were resolved

through discussion. For calculation of pooled sensitivity and specificity values, the absolute numbers of true-positive, false-positive, true-negative, and false-negative cases per study and type of injury or pathology were considered.

## Results

### Quality assessment

We found four systematic reviews referring to the diagnostic performance of MRI in knee pathologies that met both the inclusion and exclusion criteria. One was published in 2003, one in 2011, and two in 2012. Two included both low- and high-field MRT studies [2, 9], and the other two [10, 11] had used a minimum field strength of 1.5 T as an inclusion criteria.

Oei et al. [2] displayed a meta-analysis of 29 articles in their systematic review study to determine the diagnostic performance of all-strength MRI of the *menisci and cruciate ligaments* and to assess the effect of study design characteristics and magnetic field strength on diagnostic performance. In this work, the eligibility criteria for including articles were clearly specified, data extraction had been performed by two authors independently, publication bias was addressed and determined to be very unlikely because of almost perfectly shaped funnel plots, reasons for excluding full text articles were given, and a check for possibility of verification bias was performed for each article.

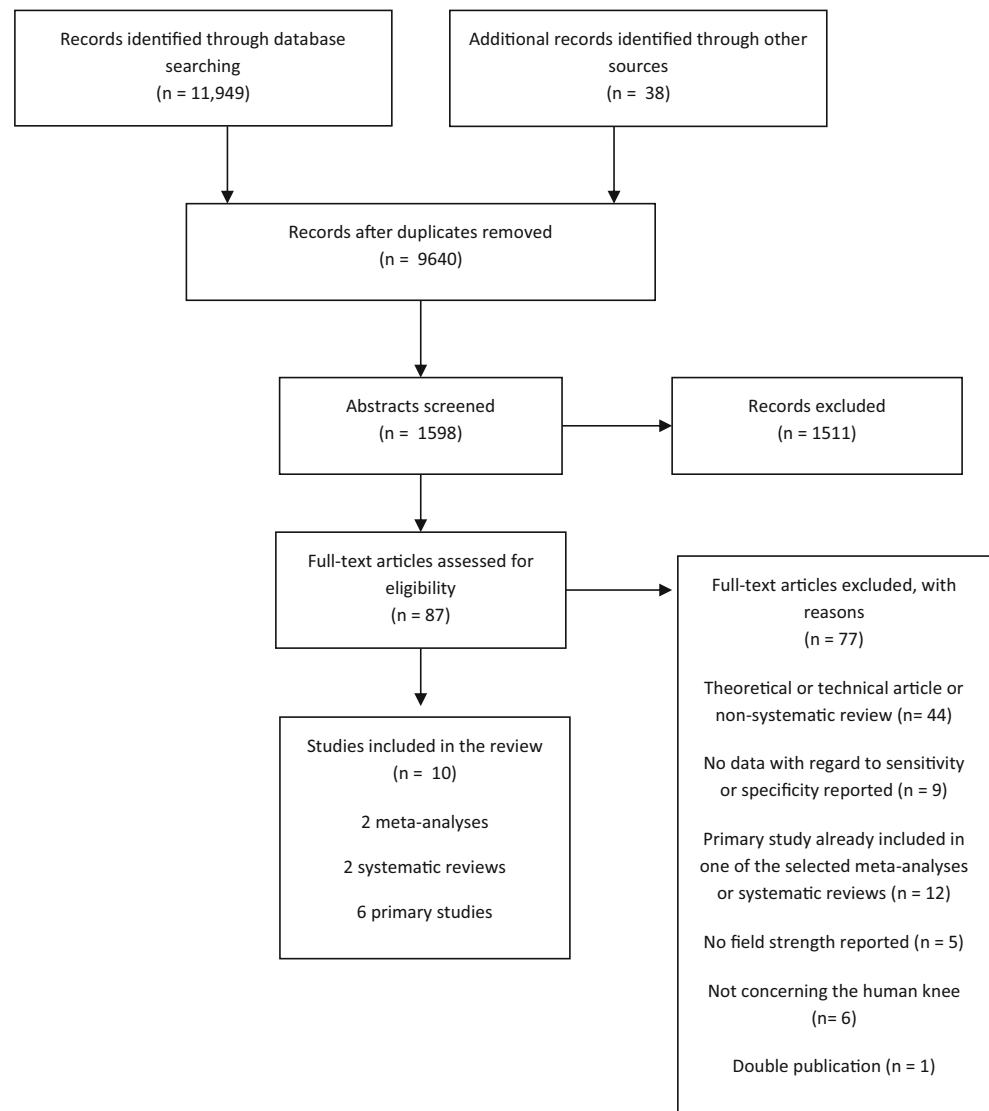
Smith et al. [9] evaluated the diagnostic accuracy of *anterior cruciate ligament (ACL) rupture* using all-strength MRI by performing a pooled meta-analysis. They included 53 articles of which 16 had already been referred to by Oei et al. [2]. The same quality assurance tasks as described in the previous paragraph for the paper of Oei et al. [2] had been performed by these authors; additionally, they had used the QUADAS checklist [12] to assess each study's methodological quality.

Quatman et al. [11] aimed to reveal the clinical utility and diagnostic performance of MRI for the identification of *knee osteoarthritis*. They found 27 studies of varying quality that met their inclusion criteria including a minimum field strength

**Table 1** Criteria for inclusion and exclusion of systematic reviews and primary studies

Inclusion criteria	Article published in English, German, Spanish, Turkish, French, or Italian language
	Depicting lesions of the collateral ligaments, retinacula, or cartilage of the human knee
	Magnetic field strength reported
	Findings at arthroscopy or surgery or histological workup used as a reference standard
	Sensitivity and specificity of MRI and/or rates of true-positive, true negative, false-positive, or false-negative results reported
Exclusion criteria	MRI used for postoperative evaluation
	Only the diagnostic value of specific features or indirect signs of knee pathologies at MRI, such as the empty notch sign, anterior tibial subluxation, or bone bruise, assessed

**Fig. 1** PRISMA flowchart of study selection, retrieval, and inclusion



of 1.5 T. The diagnostic performance of MRI demonstrated a wide range, and there were large inconsistencies between imaging techniques, specifically in the heterogeneity of MRI sequences.

Harris et al. [10] presented a systematic review on the sensitivity of MRI for detection of *patellofemoral articular cartilage defects*. Inclusion criteria were that patients underwent both MRI and arthroscopy and that the minimum field strength was 1.5 T. Thirteen studies were considered in this review, but significant heterogeneity across studies precluded meta-analysis. The quality of the included studies was rather diverse.

The available meta-analyses and systematic reviews did not include low-field MRI studies for the detection of *cartilage defects and osteoarthritis of the knee*. Therefore, relevant primary studies were assessed. Actually, only a handful of studies that used a reference standard to determine the sensitivity and specificity of low-field MRI was performed or could be identified, respectively. They are displayed in Table 2.

Furthermore, these studies were published between 1995 and 2003, at a time when quality standards for the performance of diagnostic accuracy studies were not yet widely spread. Nevertheless, we tried to describe the methodological strengths and weaknesses of the individual studies considering the questions contained in the QUADAS checklist [12] and summarised those in the “Strengths and weaknesses of the study”.

### Diagnostic performance

Data were extracted from two high-quality meta-analyses dealing with the diagnostic accuracy of MRI in knee injuries related to the *menisci and the cruciate ligaments* [2, 9]. Table 3 details the number and content of included articles, publication period of included articles, inclusion criteria, and results with regard to differences in diagnostic performance between low- and high-field MRI.

**Table 2** Methodological strengths and weaknesses of identified studies evaluating low-field MR imaging of knee cartilage defects [13–18]

First author (year of publication)	Specialisation of authors	Strengths of study	Weaknesses of study
Ahn (1998)	Radiology, orthopaedic surgery, pathology	Macroscopic findings used as reference; grading of cartilage lesions considered; relevance of MRI sequences considered	Only 10 patellae from human cadavers evaluated; all cadavers from patients >78 years.; double reading of MRI images, but single reading of macroscopic examinations; wide range of sensitivity and specificity
Bredella (2001)	Radiology	Consecutive patients; grading of cartilage lesions considered; exact numbers of TP, TN, FP, and FN results can be derived	Only 20 patients; arthroscopers not blinded to MRI results; MRI interpretation performed by consensus of two readers, not independently
Harman (2003)	Radiology, orthopaedic surgery	50 knees of 42 patients; grading of cartilage lesions considered; arthroscope blinded to MRI results	No confidence intervals for diagnostic parameters calculated; MRI interpretation performed by consensus of two readers, not independently
Kladny (1995)	Orthopaedic rheumatology	Directly comparing 0.2- vs. 1.5-T MRI and using arthroscopy as a reference for both; all patients gave informed consent; wide age range of patients (14–70 years); short interval between MR imaging and arthroscopy; grading of cartilage lesions considered	Only 22 patients examined, cartilage defects detected only in 6/22 patients; no sensitivity and specificity values for knee cartilage lesions displayed; arthroscopers not blinded to MR imaging results
Kreitner (1999)	Radiology, orthopaedic surgery, statistics	75 patients prospectively examined with MRI and arthroscopy, with 31 patients showing cartilage lesions; confidence intervals for sensitivity and specificity intervals calculated; reading independently performed by an experienced and a less experienced radiologist	Low number of patients with cartilage defects, and large confidence intervals for sensitivity values; arthroscopers not blinded to MRI results
Riel (1999)	Sports orthopaedics, radiology	244 consecutive patients prospectively evaluated, 62/244 showed full-thickness cartilage lesions	No confidence intervals for diagnostic parameters calculated; only full-thickness cartilage lesions detected/considered

The conclusions of both meta-analyses regarding our research question were that there are no differences between low- and high-field MRI in the detection of meniscal or cruciate ligament tears. However, since the authors did not provide detailed data and also included studies using a field strength of 1.0 T in their analyses, we decided to recalculate their results. For these recalculations, we included all studies for which an MRI field strength of <1.0 T or  $\geq 1.5$  T was reported. Table 4 contains a summary of these calculations.

Despite expectations that high-field MRI raises the likelihood of detecting those lesions, this was not the case. On the contrary, there were practically no differences in the diagnostic performance of low- versus high-field MRI for the detection of meniscal or cruciate ligament tears detectable (Table 4).

A systematic review in which low- and high-field strength MRI of *cartilage defects or osteoarthritis of the knee* were compared could not be found in the literature. However, we identified two relevant systematic reviews summarising high-field strength MRI results [10, 11]. Details of these reviews are displayed in Table 5.

The identified studies used a large variety of imaging techniques including sequences, slice size, plane of data collection, positioning of patients, and types of scanners. This and the varying qualification and experience of involved radiologists and arthroscopers may have contributed to the wide range of diagnostic performance results. Altogether, the results show that high-field MRI seems to be more specific than sensitive for the detection or grading of cartilage defects of the knee and that the sensitivity is associated with the (severity) grade of the lesions.

We also extracted data from the six identified studies [13–18] that used low-field strength imaging for the evaluation of cartilage defects in the human knee. The findings were diverse and can be summarised as follows: Using low-field MRI, high-grade lesions are detected, but often low-grade lesions are overlooked. The experience of the radiologist plays an important role in the diagnostic process as does the selection of the appropriate examination parameters. The extensive data extraction table can be obtained from the authors upon request. The results suggest that there is insufficient evidence

**Table 3** Meta-analyses that contained MRI studies with different field strengths

	Oei et al. [2]	Smith et al. [9]
No. and content of included articles	29 MR imaging articles, comprising 27 studies on both menisci, 23 studies on ACL tears, and 12 studies on PCL tears	53 MR imaging articles, all comprising studies on complete anterior cruciate ligament (ACL) tears
Articles published in the years	1991–2000	1986–2009
Inclusion criteria for the articles	<p>≥30 patients studied</p> <p>Arthroscopy used as a reference standard</p> <p>Magnetic field strength reported</p> <p>Positivity criteria for MR imaging defined</p> <p>Absolute numbers of true-positive, false-positive, true-negative, and false-negative results available or derivable</p> <p>Only English-language articles</p>	<p>No cadaveric and animal studies</p> <p>Arthroscopy or open surgery findings used as a reference standard</p> <p>No restrictions</p> <p>No arthrogram studies</p> <p>Absolute numbers of true-positive, false-positive, true-negative, and false-negative results available or derivable</p> <p>No restrictions</p>
Results with regard to differences in diagnostic performance between low- and high-field MR imaging	The results of the separate pooled weighted analyses for various categories of magnetic field strengths (not tabulated) suggested a modest trend toward better diagnostic performance for higher field strength categories. None of the differences were found to approach statistical significance, however, and the confidence intervals were all wide	No differences between low- and high-field MR imaging in the detection of ACL tears

for low-field MRI because only a few studies with small samples and equivocal findings have been published.

## Discussion

Several review articles on low-field versus high-field MRI of the extremities agree that low-field strength MRI systems provide the ability to diagnose substantial pathologies within the ligaments and menisci of the knee [3, 9, 19]. This is in accordance with our findings. All pooled sensitivity values were high, except for those values that were observed for the lateral meniscus. But this was not associated with the used MRI field

strength. A reason for the latter result may be that radiologists are undersensitised for recognising lateral meniscal lesions because they are less common than medial meniscal or ACL tears [19].

However, it should be stressed that specialised training is required for quality control and image interpretation in low-field MRI. According to Ghazinoor et al., a reason for insufficient diagnostic accuracy of low-field MRI systems is the use of large FOVs and poor-in-plane resolution [19]. They also recommend the performance of a STIR sequence to further improve the system's diagnostic capabilities. The importance of the radiologist's qualification was shown in an Austrian study [20]: In MRI examinations of knee pathologies, the

**Table 4** Pooled sensitivity and specificity values of MR imaging for the detection of various knee injuries, including 95 % confidence intervals and separated by field strength

Type of injury	Field strength of <1.0 T			Field strength of ≥1.5 T		
	Sensitivity	Specificity	n	Sensitivity	Specificity	n
Medial meniscal tear	0.91 [0.88;0.93]	0.87 [0.85;0.90]	1138	0.94 [0.93;0.95]	0.87 [0.85;0.89]	2173
Lateral meniscal tear	0.76 [0.70;0.81]	0.95 [0.93;0.96]	1155	0.78 [0.75;0.82]	0.95 [0.94;0.96]	2206
PCL complete tear	1.00 [0.80;1.00]	0.98 [0.96;0.99]	555	0.88 [0.62;0.98]	0.98 [0.97;0.99]	961
ACL complete tear	0.92 [0.87;0.95]	0.93 [0.90;0.94]	912	0.94 [0.91;0.96]	0.95 [0.93;0.96]	1514
ACL complete tear*	0.92 [0.89;0.95]	0.93 [0.91;0.95]	1109	0.92 [0.90;0.94]	0.95 [0.94;0.96]	3112

n=number of cases; \*results from the studies included in Smith et al. [9], all other results refer to the studies included in the meta-analysis of Oei et al. [2]

Forest plots can be obtained from the corresponding author upon request

**Table 5** Description of the methodology and results of the two systematic reviews on the diagnostic performance of high-field MRI of cartilage defects and knee osteoarthritis

	Quatman et al. [11]	Harris et al. [10]
No. and content of included articles	27 MRI articles, comprising 27 studies on articular cartilage abnormalities, and 20 studies on knee osteoarthritis	13 MRI articles on articular cartilage defects
Articles published in the years	1988–2010	1994–2009
Inclusion criteria for the articles	Human knee Arthroscopy used as a reference standard Magnetic field strength of $\geq 1.5$ T MRT sequences reported	Human knee Arthroscopy used as a reference standard Magnetic field strength of $\geq 1.5$ T No MRT outcomes after cartilage surgery
<i>Sensitivity</i> of MRI in articular cartilage defects in the various locations	Medial tibial plateau: 0.17–0.96 Lateral tibial plateau: 0.00–0.58 Medial femoral condyle: 0.28–1.00 Lateral femoral condyle: 0.33–1.00 Trochlea: 0.55–1.00 Patella: 0.21–1.00 Patellofemoral compartment: 0.44–0.95 Tibiofemoral compartment: 0.42–0.81	Trochlea: 0.62–1.00 Patella: 0.00–0.95
<i>Specificity</i> of MRI in articular cartilage defects	$>0.85$ in almost all studies and locations, with the exception of two studies (patella: 0.75; lateral femoral condyle: 0.78)	Patella: 0.62–1.00, trochlea: 0.81–0.97
<i>Sensitivity</i> of MRI in early osteoarthritis	0.00–0.86	
<i>Specificity</i> of MRI in early osteoarthritis	0.48–0.95	
<i>Sensitivity</i> of MRI in advanced osteoarthritis	0.47–0.98	
<i>Specificity</i> of MRI in advanced osteoarthritis	0.60–1.00	

number of false reports was dependent on the radiologist rather than on the MRI field strength, and the rate of false interpretations was significantly higher in the less experienced group of radiologists.

Relying on low-field imaging for the detection of meniscal and cruciate ligament injuries may, however, lead to a specific problem in case of equivocal findings: Since most radiologists' level of confidence is superior with high-field MRI, such findings after low-field MRI may increasingly lead to

second examinations on high-field units. Another problem with the use of low-field MR systems is the increasing self-referral rates, e.g. by non-radiologists who install these systems in their offices. It was shown that self-referring physicians used imaging procedures more frequently than those referring to a radiologist, resulting in an increase of imaging charges for self-referring physicians [6].

In contradistinction, accurate diagnosis, and characterisation of articular cartilage lesions are difficult, if not impossible, in the

**Table 6** Take-home table

Conclusions from results displayed in Tables 4 and 5	Evidence
Diagnostic performance of low- and high-field MRI in meniscus and cruciate ligament injuries is equal	Strong
Diagnostic performance of low-field MRI in knee cartilage defects and osteoarthritis is acceptable	Insufficient
Diagnostic performance of low-field MRI in knee cartilage defects and osteoarthritis is good	Limited
Recommendations for use and remuneration of low-field MRI in meniscus and cruciate ligament injuries	
MRI on extremity scanners is best performed by musculoskeletal-trained radiologists with experience in reading images obtained on low-field systems, working closely with the referring clinician	
MRI should not replace clinical diagnosis, but be used in connection with clinical findings and history to provide a more complete picture, especially with complex injuries	
Since the level of confidence in decision-making is reported significantly superior with high-field imaging, equivocal findings with low-field units may lead to an increased number of second examinations on high-field units	
The rates of self-referral, e.g. by non-radiologists who install these systems in their offices, should be controlled	



setting of low-field strength imaging [3, 6, 19]. All in all, the increased noise inherent in low-field MRI seems to affect the detection of cartilage abnormalities when compared to high-field imaging. Full-thickness cartilage defects are easier to appreciate than lower-grade chondral abnormalities.

However, also in high-field strength MRI the results, specifically with regard to sensitivity, are unsatisfactory and often below the usual clinical standard. Recently, Strickland and Kijowski presented a review article in which they discuss the current state of MR cartilage imaging and the existing problems [21]. There is a large variety of MRI techniques available for evaluating articular cartilage. Limited spatial resolution, suboptimal tissue contrast, and artefacts remain major hurdles in the development of clinically useful sequences. The authors believe that the main factor that limits the ability of currently available MRI techniques to identify early cartilage degeneration is suboptimal spatial resolution. Thus, it is expected that MRI systems with higher field strengths (e.g., 3.0 T) will improve cartilage imaging as images are produced with higher spatial resolution and decreased slice thickness without reducing the signal-to-noise ratio or prolonging acquisition time.

Some authors say that the MRI techniques recommended in the literature at present are not able to replace arthroscopy for diagnosis of cartilage damage in the knee [22]. However, according to the results of a randomised controlled trial the use of MRI in patients with chronic knee problems, in whom surgery was being considered, did not increase costs overall, was not associated with worse outcomes, and avoided surgery in a significant proportion of patients [1].

Our review showed that the diagnostic reliability and utility of low-field MRI in detecting meniscus and cruciate ligament tears are comparable to those obtained from conventional units operating at higher magnetic fields (see also Table 6). This is supported by newer primary studies not included in this review, e.g. [23]. The accurate diagnosis and characterisation of cartilage lesions, however, are difficult, if not impossible, in the setting of low-field strength imaging.

Therefore, we can recommend the use and remuneration of low-field strength systems in suspicious meniscus and cruciate ligament injuries with the constraints or specific considerations displayed in Table 6.

Based on the existing evidence, we cannot recommend the use of low-field-strength systems for the diagnosis and grading of knee cartilage defects and osteoarthritis. Since the sensitivity of high-field MRI for chondral lesions is also suboptimal, we recommend referring those patients to specialised centers or well-trained individuals using up-to-date equipment, respectively.

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**Conflicts of interests** None

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