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Evaluation of Magnetic Resonance Imaging (MRI) Versus Knee Arthroscopy in Diagnosing Anterior Cruciate Ligament (ACL) Tears: Systematic Review

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Abstract

The most frequently injured ligament in the knee is the ACL, and while this condition can be treated through surgery, it cannot be naturally cured. The knee is prone to frequent joint injuries due to its involvement in various movements. Currently, the gold standard for diagnosing ACL tears is arthroscopy, which is claimed to have a 100% accuracy rate. However, arthroscopy is an invasive procedure with potential complications for patients, causing many to be apprehensive about undergoing this diagnostic method. Therefore, the purpose of this study is to compare the diagnostic accuracy between MRI and knee arthroscopy, explore the advantages of MRI over knee arthroscopy, and assess the role of different MRI sequences in the diagnosis of ACL tears. A systematic review was conducted by searching reliable databases. The study adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The risk of bias was assessed using QUADAS-2 and its associated signalling questions. A total of 17 articles were included in this review, all of which were accessed through the PubMed database. The diagnostic accuracy of MRI in detecting ACL tears is notably high, with sensitivity ranging from 81% to 98.60%, specificity ranging from 79% to 100%, PPV falling within 80.55% to 100%, NPV within the range of 74.50% to 100%, and AUC value exceeding 0.9. Each study's risk of bias and applicability concerns were assessed. In conclusion, the diagnosis of ACL injuries using MRI demonstrates high diagnostic accuracy, but knee arthroscopy remains the established gold standard for evaluating ACL tears. MRI offers advantages such as being non-invasive, radiation-free, cost-effective, rapid, and free from the risk of complications. However, there is no definitive conclusion regarding the most effective MRI sequences for detecting ACL tears, although T2-weighted images are commonly used. Additional sequences, such as volume sequences of DESS and FLASH, may also be employed.

Keywords

Magnetic Resonance Imaging (MRI), Knee Arthroscopy, ACL tears.

Introduction

The anterior cruciate ligament (ACL) is an essential element of the knee joint, serving vital roles in preserving joint stability [1]. ACL injuries often occur when there is a forceful impact on the upper back of the calf, leading to damage. These injuries have become increasingly prevalent in clinical practice [2, 3]. An ACL injury can have detrimental effects on the meniscus and articular cartilage, potentially leading to the development of osteoarthritis [4]. The primary cause of ACL injury is a sudden change in direction, which can result in the partial destruction of the ligament's fiber bundles. Such injuries can occur on their own or in conjunction with damage to other ligaments and menisci [5].

Arthroscopy, a traditional diagnostic method, has demonstrated high sensitivity in detecting ACL damage, but it is an invasive procedure [6]. MRI examinations are now widely recognized as a safe and valuable diagnostic approach in clinical settings to confirm ACL injuries. Additionally, they can reveal various joint abnormalities and assess the location and extent of ligament ruptures [7]. Arthroscopy remains the most recent gold standard for evaluating ACL injuries, boasting a 100% accuracy rate [8]. However, it is an invasive procedure with potential complications, which has led to patient reluctance in opting for this diagnostic method [9].

Previous research in the field of ACL injuries and diagnostic methods has encountered challenges, particularly in balancing accuracy with invasiveness. While arthroscopy has been considered the gold standard with 100% accuracy, its invasive nature raises concerns and contributes to patient hesitancy. Additionally, reliance solely on arthroscopy may lead to missed opportunities for early diagnosis and intervention. On the other hand, while MRI examinations are increasingly recognized for their safety and effectiveness in diagnosing ACL injuries, there is a need to explore the nuances of different MRI sequences to enhance diagnostic precision. Some studies may not have delved deeply into the comparative advantages of MRI versus arthroscopy, potentially leaving gaps in understanding the full diagnostic landscape. This study aims to address these issues by conducting a comprehensive comparison of the diagnostic accuracy of MRI and knee arthroscopy, shedding light on the specific strengths and limitations of each method. Furthermore, the investigation into the best MRI sequences will provide valuable insights into optimizing non-invasive diagnostic approaches for ACL injuries, potentially paving the way for improved patient outcomes and increased diagnostic confidence.

Materials and Methods

Study design

The type of study for this research is a systematic review (SR). The primary objective of this SR is to assess the diagnostic accuracy of MRI versus knee arthroscopy in diagnosing ACL tears.

Ethical Approval

Systematic review (SR) is indeed a form of secondary research that compiles information from various sources, including research papers found in different sites and sources. Unlike primary research, which involves data collection directly from the targeted population and often requires ethical approval, SR are typically exempt from the need for ethical approval, as they do not involve direct interaction with human subjects.

Population

The population under consideration for this review included individuals aged 15 years and above who either had ACL tears or were suspected of having ACL tears. There were no specific restrictions based on gender and ethnicity. However, individuals with a history of knee surgery, contraindications for MRI, those who did not undergo arthroscopy, and those with a history of potential presence of tumors, synovial disorders, arthropathy, or multiple traumas were excluded from the study.

Intervention

The study's intervention focused on the examination of MRI and knee arthroscopy as diagnostic methods for ACL tear detection. Through this comparative analysis, the review sought to assess the diagnostic accuracy, advantages, limitations, and practical implications for the management of ACL tears.

Comparison

In this study, the comparison group consisted of MRI and knee arthroscopy. Through the examination of the advantages and limitations of these two diagnostic methods, the review aimed to offer valuable guidance to clinicians and researchers in choosing the most suitable diagnostic approach for patients who may have ACL tears.

Outcomes

The primary objective of this study was to deliver information on the diagnostic precision of MRI in relation to knee arthroscopy, the advantages of MRI, and the optimal MRI sequences for the detection of ACL tears.

Time

No time restriction for the selected articles for this study.

Types of Studies

This study was primarily centered on cohort studies, including retrospective and prospective cohort studies.

Inclusion and Exclusion Criteria

The articles included in this study targeted patients aged 15 years and older who had not undergone previous knee surgeries. These articles specifically explored the pre-operative evaluation of ACL tears using both MRI and knee arthroscopy, along with an examination of the benefits of both methods, MRI sequences, and were required to be in the English language.

This study excluded articles that centered on pediatric patients, ACL tear reconstruction procedures, individuals with a history of knee surgery, and those with MRI contraindications, as well as patients with tumors, synovial disorders, arthropathy, multiple traumas, and articles in foreign languages.

Search Strategy

The research was carried out employing a systematic search approach per the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. The database utilized for the study was PubMed. To retrieve relevant articles, the following keywords were input: "ACL tear", "MRI", and "knee arthroscopy", with specific exclusion criteria to filter out articles related to "reconstruction", "review", "animal studies", and "reports".

Data Extraction

Data extraction in this study will be carried out using a structured data extraction form. This form includes a field for the article title, study objective, study design, criteria for inclusion and exclusion, sample size, the age range of participants, advantages of MRI, details of MRI sequences, as well as sensitivity, specificity, accuracy, PPV, NPV, AUC, reference standard and the study's conclusions. The collected data will be organized, evaluated, and analyzed using Microsoft Excel.

Quality Assessment

To assess the quality of diagnostic accuracy studies included in a systematic review, the QUADAS-2 tool was employed.

Results

Selection of Study

The initial database search yielded 114 studies, but after removing duplicate articles, there were 72 unique records. These 72 studies underwent a screening process where their titles and abstracts were evaluated. Following this screening, 30 studies were deemed eligible for inclusion, while the remaining 42 studies were excluded because they were unrelated to the research topic and did not align with the research questions and objectives. The excluded studies encompassed therapeutic and post-operative investigations, studies involving pediatric patients, those focused on MRI positioning rather than techniques, and those addressing different knee ligament pathologies. Additionally, any review, report, and animal studies were also excluded during the screening phase.

Subsequently, the full text of the 30 studies selected during the screening phase were thoroughly evaluated for eligibility. Out of these, 13 articles were excluded for various reasons. One article could not be assessed due to its publication in a foreign language, 1 article focused on using positioning modifications to detect ACL tears, 7 articles did not establish a correlation between MRI and knee arthroscopy, and 4 articles dealt with other knee pathologies, such as knee lesions, knee cartilage injuries, and meniscus tears.

In the final stage of the review process, a total of 17 studies were deemed suitable for inclusion in this review, as they satisfied the specified inclusion criteria and aligned with the research questions and objectives.

Data Extraction

There is a notable range in the sample sizes among the 17 studies included, spanning from 30 to 377 participants. The study with the largest sample size was carried out by Xu et al. [10], involving a total of 377 patients. Conversely, the study with the smallest sample size, conducted by Li et al. [11], included only 30 patients. Of the 17 selected studies, 4 studies were retrospective in nature and were authored by Li et al. [12], Shin et al. [13], Yaqoob et al. [14], and Xu et al. [10]. The remaining 13 studies were prospective in design.

In the included studies, there was a relatively consistent choice of index tests. The majority of the studies relied on MRI as their index test, with only 2 studies employing slightly different approaches. Björkman et al. [15] used both MRI and DECT as index tests for their research, while Shin et al. [13] utilized the MRI-CNN model as their index test. Moreover, in 16 out of the 17 studies, knee arthroscopy was the selected reference standard diagnosis. The exception was the study conducted by Shin et al. [13], where the diagnosis results were solely dependent on the radiologist's assessment.

The majority of the authors of the selected studies reached a consistent conclusion that MRI demonstrates a high level of accuracy in the detection of ACL tears, making it a valuable imaging method for assessing the ligaments of the knee joint and surrounding tissue. However, a few studies presented differing viewpoints. Rayan et al. [16] suggested that while MRI is useful for ruling ACL tears, it may not be as effective for diagnosis, as its negative predictive value (NPV) surpasses its positive predictive value (PPV). Orlando Júnior et al. [17] recommended that MRI should be employed to supplement findings in cases where clinical examinations are inconclusive or when doubts exist.

Quality Assessment

The assessment using QUADAS-2 involved 4 key domains: patient selection, index test, reference standard, and flow and timing. In each domain, the risk of bias was evaluated, and the first 3 were further analyzed for concerns about applicability. Among the 11 studies, no bias or applicability concerns were identified. Unfortunately, 5 studies exhibited some issues related to bias and applicability. These studies were conducted by Bjorkman et al. [15], Shin et al. [13], Halinen et al. [18], Behairy et al. [19], and Orlando Junior et al. [17]. Additionally, Kostov et al. [20] had concerns about the applicability but were free of bias. Nevertheless, these articles can still be considered for further study.

Diagnostic Accuracy of MRI in Detecting ACL Tears

In this review, the focus of diagnostic accuracy centered on several key parameters, including sensitivity, specificity, accuracy, PPV, NPV, and AUC.

The data on diagnostic accuracy from the 17 selected articles were organized into Table 1. Nevertheless, it's important to note that not all studies provided data for all these diagnostic accuracy elements. Specifically, when it comes to sensitivity, 3 studies did not calculate this metric. These studies were conducted by Shin et al., [13]; Xu et al. [10]; Zairul-Nizam et al. [21]. The highest sensitivity recorded across the studies was 98.60% [22], while the lowest sensitivity was reported by Rayan et al. [16] which stood at 81%. Regarding specificity, highest values were reported by Shantanu et al. [23] and Behairy et al. [19] both at 100%, whereas the lowest specificity was found in the study conducted by Orlando Júnior et al. [17], which was at 73.68%. Notably, specificity data were unavailable in 6 of the studies.

In the selected studies, the accuracy of MRI in detecting ACL tears ranged from 80.80% to 98.3%. Zairul-Nizam et al. [21] reported the lowest accuracy of MRI, which was 80.80%, while the highest accuracy, reaching 98.3%, was achieved in the study conducted by Shantanu et al. [23]. It's worth noting that 5 articles did not provide accuracy calculations. PPV was reported in 9 articles, while the remaining articles did not include this metric. Among those reported PPV, the highest of 100% was observed in studies conducted by Shantanu et al. [23] and Behairy et al. [19], while the lowest reported PPV was 80.55% [24].

Out of the 17 selected studies, 8 provided data on NPV. The highest NPV, recorded at 97.60% was reported by Navali et al., [22] in 2013, while the lowest NPV, at 74.50%, was found in the study conducted by Kostov et al., [20] in 2014. Among the 17 studies, only 2 studies, namely Li et al., [12] and Shin et al., [13] included data on AUC, with values of 0.906 and 0.941 respectively.

Table 1: Diagnostic accuracy of MRI in detecting ACL tears.

Studies	Sample Size	Diagnostic Accuracy					AUC
		Sensitivity	Specificity	Accuracy	PPV	NPV	
Björkman et al. [15]	50 patients	86.8%	N/A	N/A	91.67%	N/A	N/A
Shantanu et al. [23]	60 patients	98.1	100%	98.3%	100%	88.9%	N/A
Bari et al. [24]	230 patients	87.87%	81.57%	N/A	80.55%	88.57%	N/A
Li et al. [11]	30 patients	96.78%	90.62%	92.17%	N/A	N/A	N/A
Li et al. [12]	120 patients	90%	79%	N/A	N/A	N/A	0.906

Zhao et al. [9]	78 patients	95.45%	91.67%	94.87%	98.3%	78.57%	N/A
Shin et al. [13]	164 patients	N/A	N/A	94.12%	N/A	N/A	0.941
Yaqoob et al. [14]	54 patients	91.60%	95.20%	94.40%	84.60%	97.50%	N/A
Kostov et al. [20]	103 patients	83%	88.37%	82.50%	93%	74.50%	N/A
Richards et al. [25]	231 patients	86.40%	95.20%	94.70%	N/A	N/A	N/A
Halinen et al. [18]	44 patients	93.20%	N/A	93.20%	N/A	N/A	N/A
Xu et al. [10]	377 patients	N/A	N/A	N/A	N/A	N/A	N/A
Behairy et al. [19]	70 Patients	92.3%	100%	97%	100%	95%	N/A
Navali et al. [22]	120 patients	98.60%	83.30%	92.50%	89.90%	97.60%	N/A
Zairul-Nizam et al. [21]	55 patients	N/A	N/A	80.80%	N/A	N/A	N/A
Rayan et al. [16]	131 patients	81%	96%	93%	81%	95%	N/A
Orlando Júnior et al. [17]	32 patients	86.79%	73.68%	83.33%	N/A	N/A	N/A

N/A = Not Available, PPV = Positive Predictive Value, NPV = Negative Predictive Value, AUC = Area Under Curve

Advantages of MRI in Detecting ACL Tears

Among the selected studies, 5 articles did not discuss the advantages of MRI. These articles were authored by Björkman et al. [15]; Li et al. [12]; Shin et al. [13]; Richards et al. [25]; Halinen et al. [18].

Among the 12 articles that did mention the advantages, 8 highlighted that MRI is a non-invasive modality or technique. Four articles emphasized that MRI can offer cost-effectiveness when compared to arthroscopy. The advantages of MRI were further detailed, including its ability to provide detailed insights, high contrast, high resolution, radiation-free imaging, high-quality image production, and accurate results. Li et al. [11] in their 2021 study mentioned that MRI not only reveals the normal structure of the ACL but also provides information on the location and extent of pathologies, meniscus tears, and other knee injuries. Xu et al. [10] stated that MRI is a favored imaging method for assessing the normal, ruptured, or healed ACL and is reliable in the detection of acute ACL tears.

Navali et al. [22] pointed out that MRI exhibited a slightly higher proficiency in detecting complex injuries compared to single injuries. Furthermore, Rayan et al. [16] highlighted MRI had a significantly better NPV than PPV in diagnosing ACL injuries. In conclusion, Table 2 provides a summarized overview of the advantages of MRI as reported in each of the reviewed articles.

Table 2: The advantages of MRI in detecting ACL tears referring to the selected study

Studies	Advantages of MRI
Björkman et al. [15]	N/A
Shantanu et al. [23]	• Non-invasive screening modality. • Provides details insight. • Essential tool in decision making before the therapeutic procedure.
Bari et al. [24]	• Non-invasive technique • Not operator dependent • Radiation free • Cost-effective • Good in evaluating ligaments of the knee joints and surrounding soft tissue.
Li et al. [11]	• Non-invasive • High contrast and high resolution • Multipart imaging • Not only shows the normal form of ACL clearly but also shows the location, extent of the fracture, tear of the meniscus, and other knee injuries.
Li et al. [12]	N/A
Zhao et al. [9]	• Non-invasive • High spatial resolution • High soft tissue resolution • High specificity • High sensitivity
Shin et al. [13]	N/A
Yaqoob et al. [14]	• Non-invasive • Quick • High quality images
Kostov et al. [20]	• Non-invasive • Accurate • Can be used as a first line investigation in patients with soft tissue trauma to the knee.
Richards et al. [25]	N/A
Halinen et al. [18]	N/A
Xu et al. [10]	• Preferred imaging technique to evaluate intact, ruptured, or healed ACL. • Reliable in the evaluation of acute ACL tears.
Behairy et al. [19]	• Non-invasive • Cheaper compared to arthroscopy • Do not need hospitalization
Navali et al. [22]	• MRI is slightly better at detecting complex injuries compared with single injuries
Zairul-Nizam et al. [21]	• Non-invasive • Cost effective

Rayan et al. [16]	● May be used to rule out the injuries rather than diagnose them ● Has a much better negative predictive value than the positive predictive value in ACL injury diagnosis.
Orlando Júnior et al. [17]	● Non-invasive ● Quick ● Cheaper than arthroscopy

ACL: Anterior Cruciate Ligament; MRI: Magnetic Resonance Imaging; N/A = Not Available

MRI Sequences Used in Detecting ACL Tears

In this review, various sequence parameters were considered, including echo time (TE), repetition time (TR), inversion time (TI), echo train length, matrix size, slice thickness, slice spaces, field of view (FOV), and scan time. Table 3 provides a comprehensive overview of the sequences employed in each study, along with their specific parameters. It's worth noting that 3 studies did not specify the sequences and parameters used in their study. Additionally, the study conducted by Zairul-Nizam et al. [21] did not mention the sequences they used but did provide information on the slice thickness (4.0mm), spacing (0.4 mm) and FOV (180 mm).

Richards et al. [25] utilized a total of 7 sequences, which represented the highest number of used in detecting ACL tears in the reviewed studies. They provided details for all parameters except for the echo train length. In the case of Halinen et al. [18], their study involved the use of two different field strengths for MRI, which were 0.23T and 1.5T. Consequently, not all patients in their study underwent the same sequences. Some patients were subjected to 0.23T MRI with the specific sequences including coronal STIR, coronal T1 SE, axial T2, sagittal DE, and oblique coronal T2 SE. Others underwent 1.5T MRI and had sequences such as coronal T2FSE FS, axial PD FSE FS, sagittal DE, sagittal PD SE, and oblique coronal T2 FSE. Both the 0.23T and 1.5T field strengths were described in terms of their TE and TR values applied in each sequence. However, only the coronal STIR sequence at 0.23T had information on the TI TI which was set at 90ms, while details for the other parameters used in their study were not available.

The sequences used by Shin et al. [13] mark as the least sequences used in detecting ACL tears which were oblique T2WI FS and sagittal T2WI FS. Nonetheless, Li et al. [12] did not state the sequences they used in much detail as they only mentioned axial, coronal, and sagittal planes with slice thicknesses of 3mm for each plane.

Table 3: MRI sequences used in detecting ACL tears

Studies	Sequences	Echo Time (TE), ms	Repetition Time (TR), ms	Slice Thickness (mm) /Space
Björkman et al. [15]	Sagittal PD, 3.0T	20	1800	3/0.3
	Axial PD Fat Sat, 3.0T	35	3981	3/0.3
	Sagittal PD Fat Sat, 3.0T	30	3400	3/0.3
	Coronal PD Fat Sat, 3.0T	30	3572	3/0.3
	3D PD Fat Sat, 3.0T	185	1300	0.63/-
Shantanu et al. [23]	Sagittal T1, 1.5T	N/A	N/A	N/A
	Coronal T1, 1.5T			
	Sagittal T2- weighted, 1.5T			
	Coronal T2-weighted, 1.5T			

	Sagittal PD, 1.5T			
	Coronal PD, 1.5T			
Bari et al. [24]	Sagittal T2 FSE, 1.5T	120	4290	3.0/1.0
	Sagittal PD Fat Sat, 1.5T	45.1	2200	3.0/1.0
	Sagittal STIR, 1.5T	42.9	6258	3.0/1.0
	Sagittal T2 FRFSE Fat Sat, 1.5T	82.6	2281	3.0/1.0
	Coronal PD Fat Sat, 1.5T	47.7	2243	3.0/1.5
	Axial STIR, 1.5T	47.3	6620	3.0/1.0
Li et al. [11]	Oblique coronal	N/A	N/A	0.4/-
	Cross sectional multiplane recombination			N/A
	T2WI-SPAIR sagittal			
	T2WI cross sectional			
Li et al. [12]	Axial, coronal, sagittal planes, 1.5T	N/A	N/A	3mm for each plane/ N/A
Zhao et al. [9]	Sagittal PDWI-FS, 1.5T	31	3000	4.0/0.8
	Coronal PDWI-FS, 1.5T	31	3000	4.0/0.8
	Sagittal T1WI, 1.5T	31	400	4.0/0.8
	Axial T2WI-FS, 1.5T	79	3770	5.0/1.0
	3D MEDIC, 1.5T	22	40	1.5/-
Shin et al. [13]	Oblique T2WI FS, 1.5T	19-25	2480-5000	4.0/-
	Sagittal T2WI FS, 1.5T			
Yaqoob et al. [14]	Sagittal T1, 1.5T	N/A	N/A	3.0/1
	Sagittal T2, 1.5T			
	Sagittal GRE, 1.5T			
	Coronal T2, 1.5T			
	Coronal PD, 1.5T			
	Axial T2*GRE, 1.5T			
Kostov et al. [20]	Sagittal, 1.0T	N/A	N/A	3-5mm/-
	Coronal, 1.0T			
	Axial, 1.0T			
Richards et al. [25]	Sagittal T1, 1.0T	15	532	4/-
	Sagittal T2*, 1.0T	18	608	4/-
	Axial FS DE, 1.0T	22/90	3500	5/-
	Coronal STIR, 1.0T	30	4300	4/-
	Sagittal FS 3D, 1.0T	11	58	2/-
	Sagittal DESS, 1.0T	9	26.8	1.6/-
	Oblique T1, 1.0T	15	400	3/-
Halinen et al. [18]	Coronal STIR, 0.23T	16	1000	N/A
	Coronal T1 SE, 0.23T	25	380	
	Axial T2 FSE, 0.23T	80	1900	
	Sagittal DE, 0.23T	22/80	2400	
	Oblique coronal T2 SE, 0.23T	81	1600	
	Coronal T2FSE FS, 1.5T	40	4740	
	Axial PD FSE FS, 1.5T	26	2640	
	Sagittal DE,1.5T	20/90	2340	
	Sagittal PD SE, 1.5T	20	1800-2700	
	Oblique coronal T2 FSE, 1.5T	96	3500-5200	

Xu et al. [10]	Sagittal T1WI, 3.0T	10	460	4.0/1.0
	Sagittal T2WI, 3.0T	45	2000	
	Sagittal STIR, 3.0T	30	2000	
Behairy et al. [19]	Sagittal SE T1WI, 0.5T	22	500	4.0/0.5
	Sagittal T2WI, 0.5T	100	3600	
	Sagittal PD, 0.5T	17	2200	
	Coronal STIR, 0.5T	60	2300	
	Axial T2WI, 0.5T	100	3600	

Discussion

Diagnostic Accuracy of MRI in Detecting ACL Tears

The selected articles consistently reported that MRI exhibited notably high sensitivity and specificity in the detection of ACL tears. The specificity ranged from 81% to 98.60%, while the sensitivity ranged from 73.68% to 100%. Additionally, PPV fell within the range of 80.55% to 100%, and the NPV varied from 74.50% to 97.60%. Moreover, the accuracy recorded across the 17 selected studies was notably high, with the majority achieving a score of over 90%. These findings underline the high diagnostic accuracy of MRI in the assessment of ACL tears, a conclusion supported by the analysis of the was ROC curve in the selected studies.

The ROC curve is a valuable tool used to evaluate the overall diagnostic accuracy of a test and to make comparisons between the results of two or more diagnostic procedures [26]. In the assessment of diagnostic testing, the AUC is often used to gauge accuracy. Therefore, for any diagnostic procedure to be considered meaningful, its AUC must exceed 0.5, and typically, it should surpass 0.8 to be considered acceptable. Furthermore, when comparing the performance of two or more diagnostic tests, the ROC curve with the highest AUC is generally considered to have superior diagnostic performance [26]. The interpretation of AUC values can be found in Table 4.

Table 4: AUC range interpretation

AUC Range	Diagnostic Accuracy
≤ 0.6	Excellent
0.8-0.9	Good
0.7-0.8	Acceptable
0.6-0.7	Poor
≤ 0.6	Fail

This review was able to collect only 2 values of the AUC among the selected studies. The first study, conducted by Li et al. [12], reported an AUC of 0.906, while the second study by Shin et al. [13] recorded and AUC of 0.941. The remaining studies did not include information about the AUC values. It is noteworthy that both of these studies demonstrated outstanding accuracy for MRI in detection of ACL tears when compared to arthroscopy, as they both achieved AUC values exceeding 0.9.

Shantanu et al. [23] achieved a specificity and PPV value of 100% because their MRI results did not include any false-positive cases. Their study reported higher rates of sensitivity, specificity, and PPV for MRI compared to prior studies, which may be attributed to the smaller sample sizes and the inclusion of more adolescent patients in their study [23]. In the study conducted by Zhao et al. [9], out of the 66 patients with ACL damage identified by arthroscopy, MRI successfully detected 63 cases of ACL injury. They noted that both MRI examination and arthroscopic investigation demonstrated similar effectiveness in diagnosing ACL tears, suggesting that the diagnostic outcomes were comparable between the two approaches based on their findings. They further stated that the accuracy of MRI in diagnosing both incomplete and complete ACL tears reached as high as 90% when compared to arthroscopic detection.

The MRI examination for ACL injuries yielded 60 cases that were positives (meaning they were also detected through arthroscopy), 25 true-negatives (indicating the absence of an ACL injury), 5 false positives (incorrectly identified as having an ACL injury), and 13 false negatives (those not clinically diagnosed) [20].

In the MRI examination, 28 tears were detected in the proximal region, 2 were found in both the proximal and midsubstance regions, 12 were identified in the midsubstance area, 1 was in distal region, and 1 was detected in both proximal and distal regions. In contrast, during arthroscopy, 40 tears were observed in the proximal region, while 4 were located in the midsubstance area [18].

In 1 study [19] MRI identified 44 healthy ACLs, 18 complete ACL injuries, and 8 partial ACL injuries. During arthroscopy, 14 complete ACL tears, 10 partial ACL tears, and 46 normal ACLs were observed.

Furthermore, when comparing MRI findings to arthroscopic results, it was revealed that 78% of the complete ACL tears identified by MRI were also confirmed as complete ACL tears by arthroscopy, while remaining 22% were classified as partial ACL tears. Additionally, arthroscopy validated 50% of the partial tears detected by MRI, with the other 50% appearing as normal [19]. In a separate study conducted by Rayan et al. [16], out of 26 cases where the ACL was determined to be injured based on MRI examination, 22 cases (84.6%) were confirmed to have a ruptured ACL through arthroscopy. This study highlighted a higher sensitivity of MRI in ACL tear diagnosis and suggested that in the future, MRI could potentially reduce the need for diagnostic arthroscopic procedures by 22% [16]. Contrastingly, a prior study by Rangger et al. [27] involved 121 individuals and concluded that MRI should be an essential evaluation method for detecting ACL tears before resorting to arthroscopy. However, Rayan et al. [16] cautioned against relying solely on MRI as the primary diagnostic modality for ACL issues. Instead, they recommended using MRI to assess high-risk cases in order to facilitate early disease intervention and potentially avoid MRI examinations when conducting arthroscopic examinations in such cases would be more beneficial.

According to the study by Navali et al. [22], MRI demonstrated slightly superior performance in diagnosing complex injuries compared to single injuries. They suggested that MRI should be employed when there is a strong clinical suspicion of injury, especially in cases of complex injuries. The presence of multiple injuries in the knee, coupled with the technical challenges in interpreting MRI results, might enhance the diagnostic accuracy of the scan [28].

The results obtained from the selected studies were consistent with prior research. Previous studies also revealed similar findings regarding the sensitivity of MRI in the range of 66-100% [29, 30, 31], specificity ranging from 67-98% [29, 30, 32], PPV in the range of 75-93% [29, 30], NPV spanning 79-100% [29, 30, 34] and accuracy falling between 78-98% [29, 30, 33] in the context of detecting ACL tears using MRI, aligning with the results through knee arthroscopy.

There is not much information about the true values of sensitivity, specificity, accuracy, PPV, NPV, and AUC for the diagnosis of ACL tears through knee arthroscopy in the selected studies. It's worth noting that all the selected studies utilized arthroscopy as the benchmark method, given its reputation as the most reliable approach for detecting ACL tears. In most of these studies, arthroscopy served as the gold standard when

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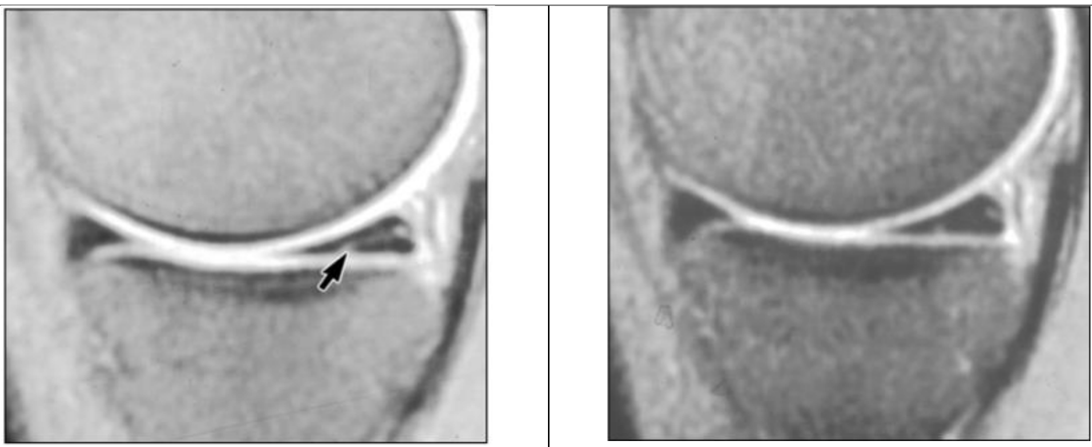
evaluating knee MRI [22, 28]. For instance, one of the selected studies conducted by Kostov et al. [20], presumed that arthroscopy is infallible with a 100% accurate rate in diagnosing any possible knee condition, using it as their reference standard.

Several factors may have contributed to the variation in diagnostic accuracy parameters within this review. One significant factor that could lead influence the diagnostic accuracy of MRI is the differences in sample sizes. Variance in sample size can impact the prevalence of ACL tears, and this, in turn, can affect the accuracy, PPV, and NPV. Higher disease prevalence can lead to lower the accuracy, and the predictive values of a diagnostic test can vary based on the specific population being examined and the disease's prevalence, particularly in individuals with ACL tears. A decrease in population with ACL tears would result in an increase in the disease’s NPV, while the PPV would rise with a larger population of individuals with ACL tears [36]. For instance, Björkman et al. [15] did not report NPV in their study due to a low number of true negatives, and the study by Bari et al. [24] had a small number of false positives and false negatives, which could introduce inaccuracies into NPV and PPV calculations.

Moreover, variations in diagnostic accuracy could be attributed to differences in the time gap between MRI and knee arthroscopy procedures performed on the patient. The duration between arthroscopy and MRI could be a contributing factor to the observed rates of imaging inaccuracies, as it might allow for the healing of the lesion during this interval [35]. It’s worth noting that Orlando Júnior et al. [17] acknowledge that they did not take into account the time elapsed between injury development, patient's admission to the outpatient clinic, and subsequent surgery procedures, and this time frame could potentially lead to additional injuries [17].

Furthermore, the precision of ACL diagnosis is contingent upon the quality and state of the imaging modality, as well as the expertise of the radiologist and arthroscopists involved [28]. Technical factors, including imaging parameters, coil strength, the use of surface coils, and the selection of imaging planes, can all have an impact on the varying accuracy values [24]. In addition, various publications have highlighted that specific imaging sequences can enhance both sensitivity and specificity in the detection of ligament tears [37]. As shown in Figure 1, the sagittal proton density-weighted MR image obtained through the medial meniscus shows an oblique tear (arrow) of the posterior horn while the sagittal fast spin-echo MR image does not show a meniscal tear. Additionally, different scanning angles can lead to incorrect diagnoses.

Incorrect MRI interpretations can stem from a broad spectrum of technical and anatomical factors [18]. Some of the errors in MRI analysis and interpretation might be linked to the challenges posed by using arthroscopy results as the gold standard reference, including difficulties in imaging certain injuries located beneath the surface of the posterior horn, reliance on probing or compression for tear identification, and variations in the terminology used to describe ligament-related conditions or damage [38]. Additionally, variations of the expertise of professionals involved in MRI analysis and arthroscopy played a significant role in the discrepancies observed in the results [22]. Previous research has emphasized that the accuracy of examinations is contingent on the proficiency of the technician performing them [39, 40].



(A) (B)

Figure 1: Conventional spin-echo vs. fast spin echo imaging for meniscal tear. (A) Sagittal proton density (TR/TE, 2000/20) shows an oblique tear (arrow) of the posterior horn. (B) Sagittal fast spin-echo (3000/18) does not show a meniscal tear.

Advantages of MRI in Detecting ACL Tears

Arthroscopy is a sophisticated surgical procedure that provides a means to confirm diagnoses [19, 20]. Unfortunately, it is an invasive surgery that carries inherent risks and potential complications for the patients [14]. Excessive utilization of arthroscopy can result in unwarranted issues, including pulmonary embolism, infections at superficial and deep levels, vascular damage, and injuries to the saphenous and peroneal nerves [41]. As per the findings of Zhao et al. [9], they similarly noted that arthroscopy is an invasive procedure entailing multiple risks for patients.

Bari et al. [24] also pointed out that arthroscopy faces challenges in diagnosing knee ligamentous conditions due to its invasiveness, high cost, and relatively uncommon but associated risks of complications. The effectiveness of the procedures can also vary depending on the surgeon's expertise, particularly in complex cases [19, 20]. Arthroscopy is a more costly and time-consuming procedure compared to MRI, [17] requiring hospitalization, anesthesia, and a skilled surgeon [42, 43]. Consequently, many patients are hesitant to opt for this method for diagnosing ACL tears.

On the other hand, MRI provides a clear and comprehensive visualization of ACL injuries, including their normal typical appearance, location, extent, the presence of fractures, meniscus tears, and other knee joint conditions. Prior research underscores the numerous advantages of MRI, such as its high spatial resolution and exceptional soft tissue resolution, which allow for a detailed examination of the knee joint's entire anatomy, facilitating the detection of ACL tears in a clinical setting [44]. With its merits of high contrast, outstanding resolution, non-invasive nature, and multiplanar imaging, MRI has firmly established itself as the most effective diagnostic tool for identifying cruciate ligament injuries in the knee [11]. These findings align with earlier research by Boeree et al. [45], who also concurred that MRI has become a widely utilized and valuable method for assessing ACL injuries due to its well-documented accuracy and sensitivity in the literature.

Furthermore, when factoring in the surgical and anaesthesia-related risks, the cost of an additional non-invasive examination appears justifiable. MRI alone has the capability to detect "simple" injuries, such as partial ACL tears that may not necessitate surgery [21]. This means that patients who might not require surgery can avoid the potential negative outcomes and perceived expenses associated with arthroscopy [46]. This underscores the cost-effectiveness in the expected economics of patient care, particularly when considering the likelihood of complications like tool breakage, compartment syndrome, nerve damage, and infections, among others [47]. Zairul- Nizam et al. [21] have emphasized that expenses related to operating theatre costs, instrument maintenance, working hours, and more can be reduced based on MRI findings of injuries or their absence. They believe that MRI serves as a first-line, non-invasive, and cost-effective diagnostic approach for patients with internal knee derangement.

Additionally, MRI can generate images without requiring the injection of a radioisotope [9], making it a radiation-free imaging procedure [24]. The main distinction between MRI and arthroscopy procedures is that MRI is a non-invasive method with excellent image quality, high sensitivity, and specificity for detecting ACL injuries [9]. It offers a high level of accuracy and consistency when compared to arthroscopic diagnosis. In cases of knee soft tissue injuries, it is often used as the initial diagnostic tool [20]. In fact, MRI is now commonly employed before considering diagnostic arthroscopy, as it is faster, non-invasive, and avoids the potential complications associated with arthroscopy.

MRI Sequences Used in Detecting ACL Tears

The usual positioning of the ACL is superolateral to inferomedial orientation [48]. When conducting a knee MRI in the sagittal plane, the angle is adjusted to provide the best possible view of the ACL. In a T1 sagittal image, the ACL should appear as a well-defined and dark structure. The ACL crosses the knee joint at a somewhat diagonal angle and is not completely straight (Figure 2). As a result, a single MRI taken in the true sagittal view often shows the entire ligament [20].

As per Young et al's comprehensive literature. [49], they have established MRI diagnostic criteria for assessing ACL injuries. They have categorized MRI indicators of ACL tears into four distinct grades; Grade 0: no observable changes in the initial appearance, structure, or signal of the ligament, Grade I: the ligament retains its continuity and overall shape, showing minimal swelling or slight thickening and extension. There may be small areas or streaks of signal changes, with the injury affecting less than 50% of the ligament, Grade II: the ligament continuity is compromised, but some continuous fibers are still visible.

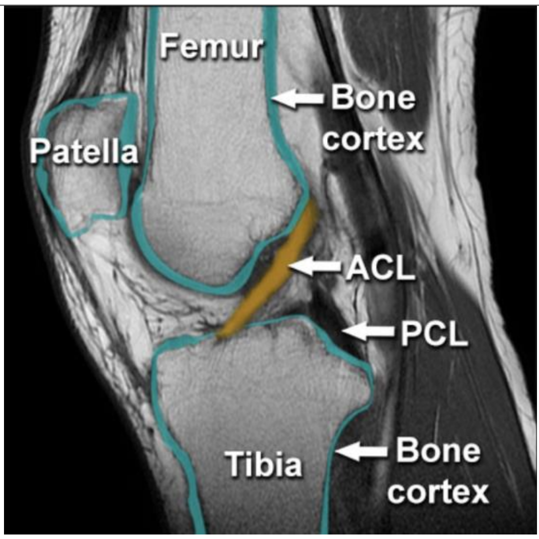


Figure 2: Normal ACL in sagittal T1 MRI knee

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There may be regional thickening or dispersion of the ligament, incomplete or clearly defined edges at the site of ligament damage or evidence of localized notched areas. The affected region exhibits significant signal changes, with the injury affecting 50% or more of the ligament, Grade III: the ligament is completely torn, with no continuity, and there is the displacement of the torn or bent ends, clumping of ligament fibres, elevated signal intensity, and an indistinct border at the injury site.

An appreciable broadening is observed at the site of the torn ACL segment, accompanied by a pronounced signal intensity on T2-weighted MRI. Additionally, a substantial presence of fluid is evident in the joint space, with a reduced signal on T1-weighted images and an increased signal on T2-weighted images. In the case of incomplete ACL tears, the injuries tend to exhibit enlargement, and some may not be readily visible, with an elevated signal on T2-weighted MRI images compared to the previous scan [9].

Xu et al. [10] and Yaqoob et al. [14] conquered that T2-weighted MRI images offer a high level of accuracy in the detection of ACL tears. Yaqoob et al. [14] specifically noted that sagittal images using T2-weighting proved highly precise in identifying ACL abnormalities. Additionally, they found that coronal T2-weighted and PD sequences were valuable for determining both the proximal and distal adherence sites of the ACL. In a study conducted by Xu et al. [10], the research focused on evaluating the direct and indirect MRI indicators for patients with acute and chronic ACL tears. Direct evidence of an ACL tear on T2-weighted images included features such as increased diffuse high signal, reduced low signal, and localized high signal within the ACL substance, along with disruptions to fascicles, interruptions, expansion, or localized masses within the ACL material as observed on T1-weighted images. They discovered that acute ACL tears were more likely to exhibit diffuse high signals of T2-weighted images compared to chronic ACL tears. Notably, among the direct indicators on both T1-weighted and T2-weighted images, a diffuse high signal on the T2-weighted image was identified as the most significant predictor for distinguishing acute ACL tears from chronic ACL with percentages of 55% and 3.2% respectively. These findings align with a study by Dimond et al. [50], which reported similar proportions of diffuse high signal intensity for acute and chronic ACL injuries, at 58% and 15%, respectively.

In contrast, Richards et al. [25] conducted a study focusing on the diagnostic accuracy of two volumetric MRI sequences, namely DESS and FLASH, along with a narrow oblique T1 section within the intercondylar notch of the ACL, in comparison to arthroscopy. They observed that the use of volumetric sequences for generating ultra-thin slices led to improvements in sensitivity, specificity, accuracy, and positive predictive value. This enhancement was attributed to the reduced impact of partial volume effects in volumetric sequences [51, 52]. The volume allowed for the creation of 1.6 mm DESS or 2 mm FLASH reconstructions, while the oblique T1 slices were limited to 3 mm thickness. It's worth noting that some of the observed differences in diagnostic accuracy may stem from variations in slice thickness rather than the choice of imaging sequence.

The hypothesis that performance metrics would be enhanced compared to narrow oblique T1 sequences is substantiated by the advantages of thin slices and reduced volume averaging in volume sequences. Although fast spin echo sequences at 2T magnetic field strength show improved diagnostic capabilities for partial ACL tears but not for complete ACL tears [53, 54], it's important to note that these high-field 2T magnets are costly and not commonly used. In their conclusion, it was found that the choice between the volume sequences had no impact since both demonstrated strong diagnostic performance and acceptable reliability among different observers, whereas the narrow oblique T1 sequence was found to be unreliable. Furthermore, it was noted that coronal STIR sequences exhibited inferior spatial resolution compared to SE or GE T2 sequences [25].

Behairy et al. [19] stated that their study did not introduce any novel MRI sequences but relied on the sequences typically employed by the centres for routine examinations. Because the selected studies did not provide details about variations in sequences or offer direct comparisons of the same sequences, there was no definitive conclusion regarding the most effective sequences for detecting ACL tears. However, the majority of the authors in the studies visualized ACL tears using the T2-weighted imaging sequence, whether for partial or complete tears. Furthermore, they suggested that the volume sequences like DESS and FLASH could enhance the diagnostic accuracy of MRI in detecting ACL tears.

Several limitations should be considered when interpreting the findings of this systematic review. Firstly, the inclusion of only published studies may introduce publication bias, as studies with positive or significant results are more likely to be published. Additionally, the quality of the included studies varies, and some may have inherent biases or methodological limitations. Lastly, the diversity in MRI techniques, equipment, and protocols across the selected studies may introduce heterogeneity in the results, making it challenging to establish a single definitive set of best practices for ACL tear detection using MRI.

Conclusion

The diagnosis of ACL injury using MRI has high diagnostic accuracy and good consistency with arthroscopic diagnosis. MRI offers distinct advantages as a non-invasive procedure, radiation-free, cost-effective, quick, and low-risk imaging modality for patients. While the optimal MRI for detecting ACL tears remains inconclusive, the selected articles commonly rely on T2-weighted images due to their excellent visualization of both partial and complete ACL tears. Additionally, the inclusion of supplementary sequences, such as DESS and FLASH volume sequences, can enhance diagnostic accuracy, whereas oblique T1 sequences are deemed unreliable.

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Conflict of Interest Disclosure

None to declare

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List of Abbreviation

2D	Two Dimension
3D	Three Dimension
3T MRI	3 Tesla Magnetic Resonance Imaging
ACL	Anterior Cruciate Ligament
AM	Anteromedial
AMB	Anteromedial Band
AUC	Area Under the Curve
CNN	Convolutional Neural Network

DECT	Dual Energy Computed Tomography
DESS	Double Echo Steady State
DL	Deep Learning
FLASH	Fast Low Angle SHot
FOV	Field of View
FRFSE	Fast Recovery Fast Spin Echo
FSE	Fast Spin Echo
FTA	Femur-Tibia Angle
GE	Gradient Echo
GRE	Gradient Echo
MCL	Medial Collateral Ligaments
ML	Machine Learning
MR	Magnetic Resonance
MRI	Magnetic Resonance Imaging
N/A	Not Available
NPV	Negative Predictive Value
OT	Operation Theatre
PCL	Posterior Cruciate Ligament
PD	Proton Density
PDWI-FS	Proton Density Weighted Image-Fat Sat
PL	Posterolateral
PLB	Posterolateral Band
PPV	Positive Predictive Value
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
PTA	Patella-Tibia Angle
QUADAS-2	Quality Assessment for Diagnostic Accuracy Studies 2
ROC curve	Receiver Operating Characteristic curve
SE	Spin Echo
SLR	Systematic Literature Review
SPAIR	SPectral Attenuated Inversion Recovery
STIR	Short Tau Inversion Recovery
T1WI	T1 Weighted Image
T2WI	T2 Weighted Image
TE	Echo Time
TI	Inversion Time
TR	Repetition Time