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Accuracy of magnetic resonance imaging (MRI) for subscapularis tear: a systematic review and meta-analysis of diagnostic studies

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Abstract

Introduction The accuracy of MRI for subscapularis tear is lower than that of overall rotator cuff tears. Until now, no systematic reviews and meta-analysis have been conducted to compile these data. The purpose of this study was to determine, through a systematic review and meta-analysis, the diagnostic accuracy of MRI in the detection of subscapularis tendon tears.

Materials and methods A systematic review of PubMed, EMBASE, and MEDLINE databases up to April 2017 was performed. All studies assessing the sensitivity and specificity of the MRI (index test) compared to arthroscopic surgical findings (reference test) for subscapularis tendon tear were included. A meta-analysis was performed to calculate pooled sensitivity, specificity, sROC curve, and diagnostic odds ratio values.

Results A total of 497 citations were identified. After applying the eligibility criteria, 14 articles were included, including 1858 shoulders with 613 subscapularis tears. For overall subscapularis tears, sensitivity was 0.68 (95% CI 0.64–0.72) and specificity was 0.90 (95% CI 0.89–0.92). Sensitivity was 0.93 (95% CI 0.83–0.98) for full-thickness tears and 0.74 (95% CI 0.66–0.82) for partial tears. Specificity was 0.97 (95% CI 0.94–0.98) for full-thickness tears and 0.88 (95% CI 0.85–0.91) for partial tears. Analyzing only studies with field of strength ≥ 1.5 T, sensitivity was 0.80 (95% CI 0.76–0.84) and specificity 0.84 (95% CI 0.81–0.87).

Conclusion MRI is an accurate method for diagnosing subscapularis tendon tears; however, its accuracy is lower than that of overall rotator cuff tears, due to its lower sensitivity.

Level of evidence III, systematic review of Level II and III studies.

Keywords Rotator cuff tear · MR imaging · Subscapularis tendon · Accuracy · Sensitivity · Specificity

Introduction

Rotator cuff tears are a common cause of shoulder pain and dysfunction [1]. The frequency of rotator cuff repairs increased 141% from 1996 to 2006 [2]. In 1999, Pfirrmann [3] reported that among rotator cuff tears, the subscapularis tendon has received significantly less attention in the medical imaging and orthopedic literature. Lo and Burkhart [4] described the subscapularis tendon as the "forgotten tendon" as it is largely ignored in the literature, despite its importance. The prevalence of subscapularis tears is reported in 12–50% [5–7] of all patients undergoing arthroscopic evaluation.

The subscapularis is important in shoulder biomechanics, contributing to internal rotation strength, anterior stability, and glenohumeral coaptation [4, 8]. Subscapularis tendon tears have an impact on treatment, surgical approach, and post-surgical prognosis [4, 8–10].

The diagnostic accuracy of magnetic resonance imaging (MRI) for the subscapularis tears varies widely, with sensitivity ranging from 25 to 94% [5, 11] and specificity from 64 to 100% [12–14]. However, no systematic reviews and meta-analysis have been conducted to compile these data. Previously meta-analysis has shown higher accuracy of MRI when evaluating overall rotator cuff lesions. De Jesus et al. [9] reported sensitivity of 91.7% and specificity of 96.5% for MR arthrography (MRA) and sensitivity of 85.5% and specificity of 90.4% for MRI in the diagnosis of rotator cuff

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tears. Smith et al. [15] found sensitivity and specificity of 80% and 95%, respectively, for partial-thickness rotator cuff tears and 91% and 97%, respectively, for full-thickness tears. Both of these studies refer to overall rotator cuff tears, not specifically supraspinatus, infraspinatus, or subscapularis tendon tears.

Therefore, the purpose of this study was to determine, through a systematic review and meta-analysis, the diagnostic accuracy of MRI in the detection of subscapularis tendon tears in the adult population.

Materials and methods

Protocol and registration

This systematic review was reported in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) statement [16]. The review was recorded under the Prospero International Prospective Register of Systematic Reviews (CRD42014009519).

Eligibility criteria

All diagnostic accuracy studies that directly compared the accuracy of a MRI (index test) to arthroscopic surgical findings (reference test) for subscapularis tendon tear were included. Inclusion criteria for these studies were: absolute (raw) data on subscapularis tears (full or partial thickness, or both) in the form of true positives (TPs), true negatives (TNs), false positives (FPs), and false negatives (FNs), either provided or extractable; arthroscopy surgical reference standards; and diagnostic imaging studies interpreted by radiologists or orthopedic surgeons. Both prospective and retrospective studies were included, even when the analysis was performed after surgery. Cadaver, animal, and pediatric subject studies were excluded. We also excluded studies that presented data on rotator cuff tears, but had no adequate data on subscapularis tears for meta-analysis. Studies that primarily investigated the rotator cuff but presented data on subscapularis tears as a secondary outcome were included. The available data had to be precisely related to the subscapularis tendon tear; articles evaluating adjacent lesions such as cysts or indirect radiological signs related to subscapularis lesion were therefore excluded.

Information sources

The search was conducted in accordance with the PRISMA recommendations [16]. We searched the following electronic databases up to April 24 2017: PubMed, EMBASE, and MEDLINE. Additionally, we manually searched the references and conducted a citation analysis of the included studies.

Search

The search strategy was performed using the following keywords: rotator cuff [MeSH Terms] OR "rotator cuff" OR "subscapular" OR "subscapularis" AND magnetic resonance imaging[MeSH Terms] OR "magnetic resonance imaging" OR "MRI" AND arthroscopy [MeSH Terms] OR "arthroscopy" AND sensitivity OR specificity OR accuracy, applying a filter to human studies.

Study selection

Three reviewers (EAM, JHA, and MECG) independently reviewed the titles and abstracts from the search strategy. Abstracts that did not provide enough information regarding the eligibility criteria were selected for further evaluation through inspection of the full-text versions. The full texts of each potentially eligible study were retrieved and independently reviewed a second time by the same reviewers for inclusion in the final review. Disagreements were resolved by consensus.

Risk of bias across studies

The methodological quality of each included study was assessed using the QUADAS-2 form [17], through consensus.

Data extraction

Three reviewers (EAM, JHA, and MECG) independently extracted all data. Disagreements in data collected between the reviewers were resolved through consensus. The presence of either partial- or full-thickness tears was considered positive, and their absence, negative. The data extracted included sample size, cohort gender, mean age, number of subscapularis tears, use of intraarticular or intravenous contrast, MRI field of strength, days between MRI and surgery, number of reviewers, type of reviewers, MRI protocol, and the frequency of true positives, true negatives, false positives, and false negatives for the index to reference test analysis. When insufficient data were available, attempts were made to calculate these using summary estimates.

Data analysis

The datasheet detailing true-positive, false-positive, false-negative and true-negative values was used to calculate sensitivity, specificity, and diagnostic odds ratio (DOR) with 95% confidence intervals (CI) for each included

study. We showed accuracy measures from each individual study in forest plots for sensitivities, specificities, and DOR. The pooled accuracy measures of all studies included were obtained, and statistical heterogeneity was assessed using the I^2 statistical test. We constructed the summary receiver operating characteristics (sROC) curve for all studies included in the systematic review.

Possible sources of heterogeneity across the studies were explored using meta-regression analysis with the following covariates as predictor variables: use of intraarticular or intravenous contrast, MRI field of strength, and experience of MRI evaluators (musculoskeletal radiologists vs others). For the variables that were strongly associated with accuracy, we performed a subgroup analysis, including only studies with homogeneous interpretation data or image acquisition methods.

We also performed a subanalysis of the diagnostic accuracy of MRI in partial- and full-thickness subscapularis tears. All analyses were performed through the Meta-DiSc 1.4 (Hospital Ramon y Cajal and Universidad Complutense de Madrid, Madrid, Spain).

Results

Study selection

Based on the search strategy, a total of 497 citations were identified. After reviewing these against the predefined eligibility criteria, a total of 14 articles were included in the full review (Fig. 1).

Studies' characteristics

The study characteristics for each eligible paper are presented in Table 1. In total, 1856 patients (1858 shoulders) with 613 subscapularis tears were reviewed from the 14 papers [5, 6, 11–14, 18–25]. The partial tear analysis included six articles [13, 14, 20, 21, 23, 24], assessing 589

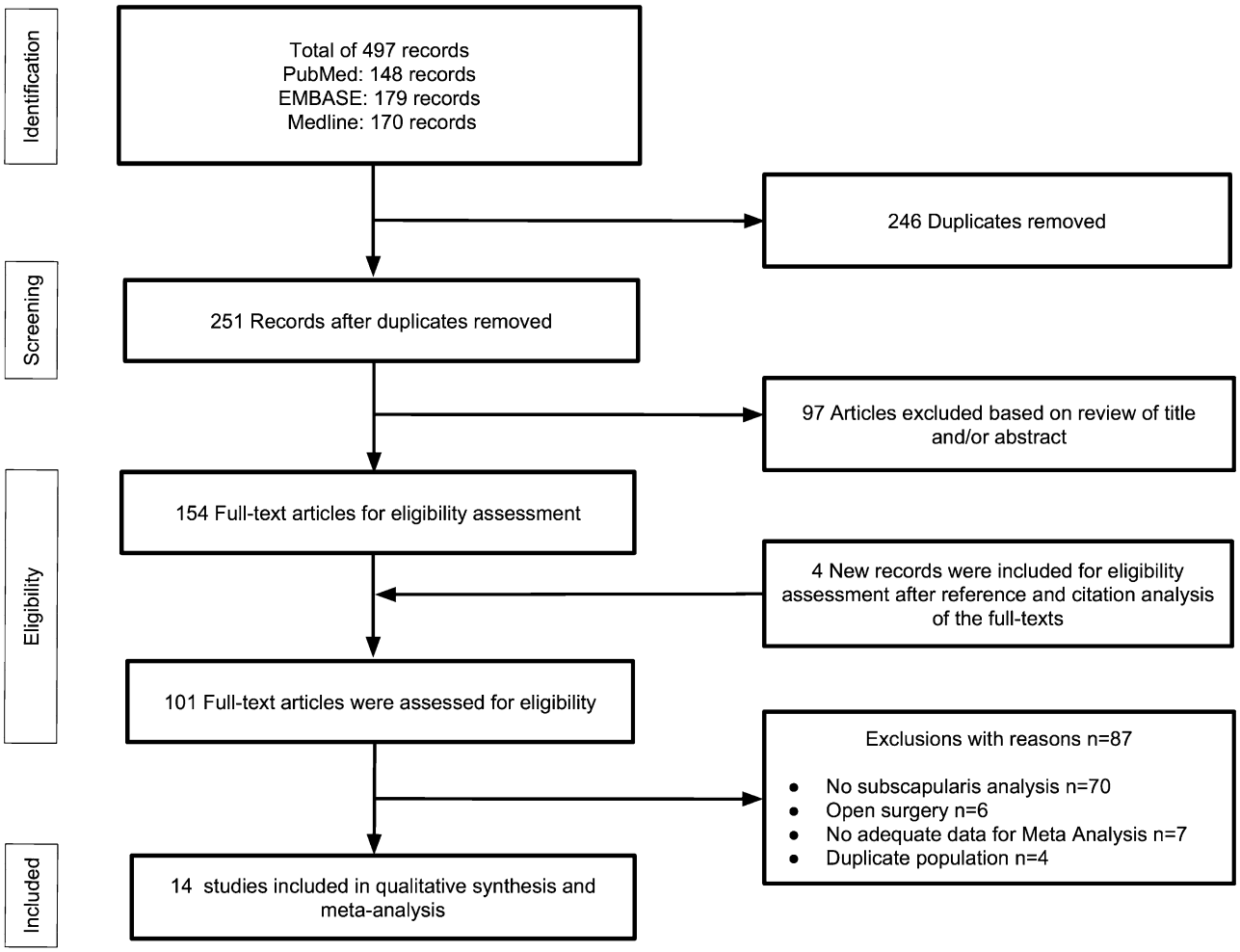

Fig. 1 Flow diagram of the selection process

Table 1 Baseline of study characteristics

References	Year	Shoulders	Contrast	Field of strength	Mean age (years)	Time interval[a]	MRI evaluators[b]
Adams [19]	2012	202	MRI	≤ 1.5	53	< 6 months	1 Radio/1 surgeon
Adams [12]	2010	90	MRI	Not reported	56	< 6 months	1 Radio
Choo [14]	2012	49	MRA/indirect MRA	3.0	53 (M), 58 (F)	< 2 months	2 MSK radio
Furukawa [13]	2014	55	MRI	3.0	63	Not reported	2 Surgeon
Garavaglia [11]	2011	213	Not reported	Not reported	Not reported	Not reported	1 Radio
Gyftopoulos [21]	2013	244	MRI	1.5 + 3.0	48	< 6 months	2 MSK radio
Jung [25]	2017	167	MRA	3.0	56	< 3 months	2 MSK radio
Lee [6]	2014	206	Indirect MRA	3.0	51 (M), 62 (F)	< 5 days	1 Radio/1 MSK radio
Malavolta [23]	2016	93	MRI	1.5	Not reported	Not reported	1 MSK radio
Meyer [24]	2016	92	MRA	1.5	56	3 months	1 MSK radio
Momenzahed [22]	2015	80	MRI	≤ 1.5	Not reported	< 1 month	1 Radio
Oh [18]	2009	36	Indirect MRA	3.0	47 (M), 59 (F)	1 day	2 MSK Radio
Omoumi [20]	2012	56	MRA	1.5	46	1 month	2 MSK radio
Waldt [5]	2007	275	MRA	1.0	39	< 6 months	2 MSK radio

MRI magnetic resonance imaging, *MRA* magnetic resonance arthrography

[a]Time interval between MRI and arthroscopy

[b]Evaluators per MRI

patients (590 shoulders) with 126 tears. The full-thickness tear analysis included four articles [13, 14, 21, 23], assessing 441 patients (442 shoulders) with 44 tears.

Of the 14 articles, 10 (71.4%) were retrospective [5, 6, 11, 12, 14, 19, 21, 23–25], 2 (14.3%) were prospective [17, 19] and in 2 (14.3) it was not clear [13, 22]. The evaluated population comprised rotator cuff tears in four articles [11–13, 23] and several diseases in the rest. The mean age of the patients ranged from 38.9 [5] to 62.7 years [13]. The time interval between MRI and arthroscopy was documented in 12 papers [5, 6, 11, 12, 14, 18–22, 24, 25] and ranged from 1 day [18] to a maximum of 190 days [12]. Five studies used a 3.0 T MRI [6, 13, 14, 18, 19, 25], three a 1.5 T [20, 23, 24] and one both 1.5 T and 3.0 T [21]; the remaining studies used various field strengths within the sample or did not report it. Of 1856 patients, 996 (998 shoulders) were evaluated with MRI field strength ≥ 1.5 T. The MRI images of nine studies [5, 6, 14, 18, 20, 21, 23–25] were reviewed by one or more musculoskeletal radiologists, while the others reported that their images were reviewed by general radiologists or orthopedic surgeons [11–13, 19, 22].

Risk of bias

The results of the QUADAS-2 assessment process are described in Table 2, which shows that only one parameter presented a low risk assessment in all studies. The studies presented two or more specific limitations. None reported that the arthroscopies were interpreted without the knowledge of the MRI result (index test result not blinded). Also, in only 21.4% of the studies, it was clear that the sample was composed specifically of rotator cuff tears with surgical treatment indication [11, 12, 23] and in 50%, it was unclear whether the MRI was interpreted with or without the knowledge of arthroscopy results [11, 12, 18, 19, 21, 22, 25].

Synthesis of results

Overall subscapularis tears

For overall subscapularis tears [5, 6, 11–14, 18–25], pooled sensitivity for MRI was 0.68 (95% CI 0.64–0.72), with 90% inconsistency (Fig. 2). Specificity was 0.90 (95% CI 0.89–0.92), with 87.3% inconsistency (Fig. 3). The sROC plot indicated 0.90% accuracy (Fig. 4). The DOR was 27.22 (CI 17.52–42.29), with 39.8% inconsistency.

Full-thickness subscapularis tears

For full-thickness tears analysis, four papers were available [13, 14, 21, 23]. Sensitivity was 0.93 (95% CI 0.83–0.98), with 37.3% inconsistency. Specificity was 0.97 (95% CI 0.94–0.98), with 89.1% inconsistency. The sROC plot indicated 0.99% accuracy. The DOR was 482.41 (CI 108.11–2152.55), with 0.0% inconsistency.

Partial subscapularis tears

For partial tear analysis, six articles were available [13, 14, 20, 21, 23, 24]. Sensitivity was 0.74 (95% CI 0.66–0.82), with 45.4% inconsistency. Specificity was 0.88 (95%

Table 2 QUADAS-2 assessment

References	Year	Risk of bias				Applicability concerns		
		Patient selection	Index test	Reference standard	Flow and timing	Patient selection	Index test	Reference standard
Adams [19]	2012	L	?	?	L	H	H	L
Adams [12]	2010	L	?	?	L	L	?	L
Choo [14]	2012	L	L	H	L	H	L	L
Furukawa [13]	2014	?	L	?	?	H	L	L
Garavaglia [11]	2011	H	?	?	?	L	?	L
Gyftopoulos [21]	2013	L	?	?	L	?	L	L
Jung [25]	2017	H	?	?	L	?	L	L
Lee [6]	2014	L	L	H	L	H	L	L
Malavolta [23]	2016	H	L	?	?	L	L	L
Meyer [24]	2016	H	L	?	L	H	L	L
Momenzahed [22]	2015	L	?	?	L	H	H	L
Oh [18]	2009	L	?	H	L	H	L	L
Omoumi [20]	2012	L	L	?	L	H	L	L
Waldt [5]	2007	?	L	H	L	H	H	L

L low risk, *H* high risk, ? unclear risk

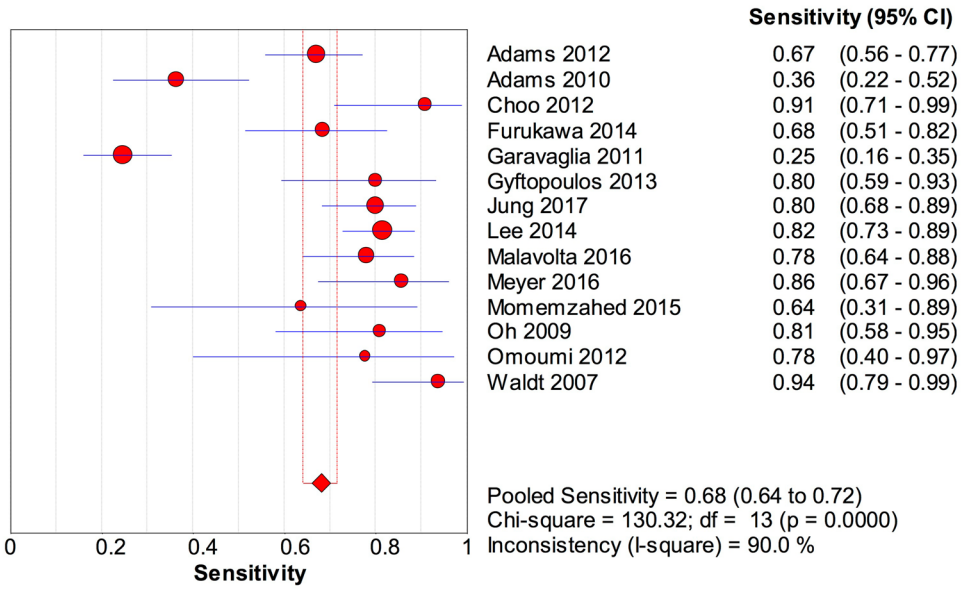

Fig. 2 MRI sensitivity for overall subscapularis tear diagnosis

CI 0.85–0.91), with 84.8% inconsistency. The sROC plot indicated 0.88% accuracy. The DOR was 20.78 (CI 11.79–36.61), with 0.0% of inconsistency.

Meta-regression

Meta-regression showed that the MRI field of strength was a confounder ($p = 0.017$). The use of contrast (either intravenous or intraarticular) or the experience of MRI evaluators (musculoskeletal radiologists vs others) did not influence the results (Table 3).

Subgroup analysis of source of heterogeneity (MRI field of strength)

Analyzing only studies with field of strength ≥ 1.5 T [6, 13, 14, 18, 20, 21, 23–25], sensitivity was 0.80 (95% CI 0.76–0.84) and specificity 0.84 (95% CI 0.81–0.87). The DOR was 21.06 (95% CI 14.48–30.63), with 0.0% inconsistency. The sROC plot indicated 0.89 accuracy.

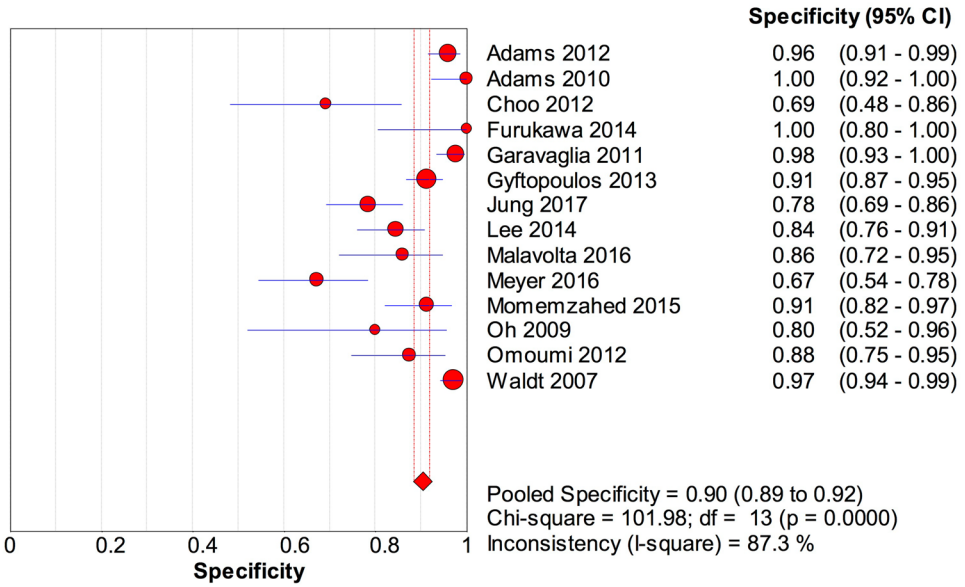

Fig. 3 MRI specificity for overall subscapularis tear diagnosis

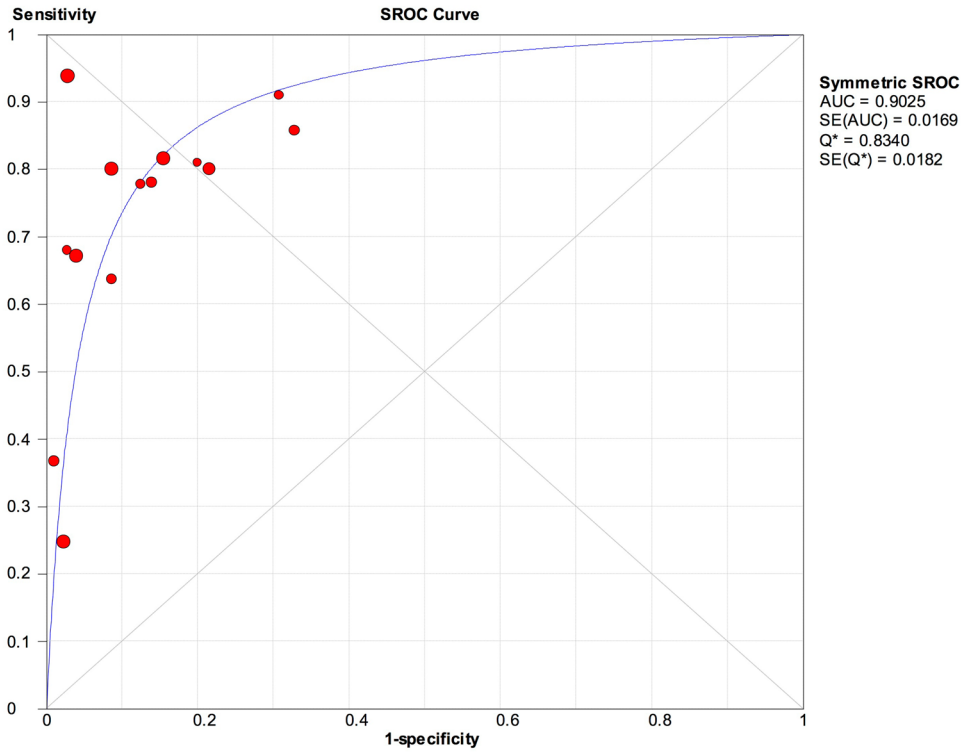

Fig. 4 sROC plot for overall subscapularis tear diagnosis

Discussion

To our knowledge, this is the first systematic review and meta-analysis of the diagnostic accuracy of MRI in subscapularis lesions. As expected, our study included only 14 papers [5, 6, 11–14, 18–25], compared to previous diagnostic systematic review and meta-analysis of rotator cuff tears that included 44 and 65 publications [9, 15].

We observed that the diagnostic accuracy of MRI in the detection of subscapularis tendon tears was 0.90, with a sensitivity and specificity of 0.68 and 0.90, respectively. Other authors have identified a higher sensitivity for the

Table 3 Meta-regression for possible sources of heterogeneity

	Coefficient	Standard error	*p*	RDOR	95% CI	
Constant	3.497	0.822	0.002	–	–	–
S	−0.024	0.221	0.917	–	–	–
Field of strength[a]	−2.194	0.753	0.017	0.11	0.02	0.61
Evaluator[b]	2.152	0.986	0.057	8.60	0.92	80.07
Contrast[c]	−0.214	0.423	0.625	0.81	0.31	2.10

[a]≥ 1.5 T vs < 1.5 T

[b]Radiologist MSK vs radiologist or orthopedic surgeon

[c]MRI vs MRA or indirect MRA

subscapular diagnosis. Pfirrmann et al. [3] describe sensitivity of 0.91, while Fotiadou et al. [26] describe 100% accuracy in full-thickness and 0.90 for partial tears. However, these authors include open surgeries as the gold standard diagnostic in their methodology, which may decrease the ability to detect some lesions, particularly involving the partial articular side. Therefore, their data were not included in our meta-analysis. Arthroscopy is ideal for the detection of subscapularis tears due to the fact that most of them originate from the articular side [11]. In some cases, partial lesions may possibly not even be seen on arthroscopy, if it is not well standardized.

Our results were lower than that founded by de Jesus et al. [9], who evaluated MRI and MRA accuracy for overall rotator cuff tears, including posterosuperior tears; these authors reported an MRI and MRA sensitivity of 0.86 and 0.92, respectively. The specificity found by us, 0.90, is slightly lower than the results described by the same authors [9]. Analyzing only subscapularis full-thickness tears, the values of sensitivity and specificity found by us (0.93 and 0.97, respectively) were similar to those described by authors, who evaluated the MRI accuracy for overall rotator cuff tears, including posterosuperior tears. Smith et al. [15] reported values of 0.91 and 0.97, respectively. De Jesus et al. [9] found values of 0.92 and 0.93 for the MRI and 0.95 and 0.99 for the MRA. Regarding partial tears, our findings of sensitivity and specificity (0.74 and 0.88, respectively) were lower than those described by other authors. Smith et al. [15] reported values of 0.80 and 0.95, respectively, whereas de Jesus et al. [9] 0.86 and 0.96 for MRA and 0.64 and 0.92 for MRI. This shows that the MRI has a lower accuracy in the diagnosis of the subscapularis tears in comparison to tears in general, mainly due to partial tears. The reliable diagnosis of partial-thickness tears of the rotator cuff remains challenging, as the MRI diagnostic accuracy is still limited [27].

It should be noted that the overall sensitivity was lower than that found for both partial- and full-thickness tears. This apparent inconsistency is due to the fact that the number of articles studied in the subanalysis differs from the overall analysis. The overall sensitivity was calculated based on 14 articles [5, 6, 11–14, 18–25], whereas in the subanalysis it was possible to use only 4 articles for full thickness [13, 14, 21, 23] and six for partial tears [13, 14, 20, 21, 23, 24].

The difficulty in properly assessing tears of the subscapularis MRI is consistent with other studies [12, 13, 19, 23], and the reported values of sensitivity and specificity are generally lower than those obtained when the analysis includes the supraspinatus [9, 15]. The lower accuracy for diagnosis of subscapularis tendon tears compared to the other rotator cuff tears may be due to several factors. The first reason could be acquisition protocols and tendon analysis. It has already been shown [3] that the evaluation of the tendon in two imaging planes (axial and sagittal planes) has higher sensitivity and specificity values compared to evaluation in only the axial plane. Second, recognition of specific imaging pitfalls, especially volume averaging with the rotator interval at the superior portion of the subscapularis, may result in an overestimation of tendon tears [21]. Third, some portions of the subscapularis tendon and intrasubstance tears on an MRI may not be seen during routine arthroscopy [28], resulting in a false-positive MR evaluation. Therefore, we believe that the MRI has a lower capacity to find subscapularis tears than in other rotator cuff tendons.

The confounding factor analysis by meta-regression demonstrated that the MRI field of strength was one of the determinants for the diagnostic accuracy. We show that the sensitivity goes from 0.68 to 0.80 when only 1.5 T or higher field of strength was analyzed. Increased sensitivity in tests with a greater field of strength is also reported by Smith et al. [15]. However, we noticed that examinations with a greater field of strength led to a decrease in specificity, from 0.90 to 0.84, differently from that reported previously [15]. This may be due to a greater inconsistency of the data for specificity (0.0% for sensitivity and 76.1% for specificity) or difficulties inherent to the visualization of subscapularis in MRI, which may increase false positives. In our review, the use of contrast was not a potentially source of heterogeneity for the diagnostic accuracy. This result is inconsistent with results found in the review by de Jesus et al. [9] which demonstrated a better performance of MRA in relation to MRI for detection of rotator cuff tears in general, including

posterosuperior tears. The small number of articles included may be a possible cause, leading to a beta error.

Regarding the analysis according to the criteria of QUADAS-2 [17], there were two main limitations of the articles. First, there was a lack of blinding of the surgeon as to the results of preoperative MRI (in 33.3% it was not blinded and in 66.7% it was unclear). Secondly, in only 21.4% of the studies was it clear that the sample was composed specifically of rotator cuff lesions with surgical treatment indication. Smith et al. [15] also noted that the lack of blinding was the biggest problem found; he discovered that in 56.8% of studies, the radiologists' analyses were blinded to the surgery findings, while only 4.5% of studies reported that the surgeon was blinded to the MRI analysis.

Our study has several limitations. The number of included studies is relatively small when compared to systematic reviews evaluating the rotator cuff tears in general, including posterosuperior tears. Most studies included have a retrospective design, and none describe surgeon blinding, which increases the risk of collection bias. The group of patients studied is not standardized, and some articles evaluate only patients with rotator cuff disorders, while others evaluate all types of arthroscopy. The time between MRI and arthroscopy, which ranged from 1 day to 6 months, may also be a possible criticism.

Our findings have practical implications for both the orthopedic surgeon and the radiologist. For the surgeon, it seems necessary to perform a systematic inspection during a rotator cuff surgery, seeking subscapularis tear, even in the absence of findings on imaging, given the high rate of false negatives. Maneuvers such as lever push, which facilitates the visualization of articular tears of the subscapularis, and the use of optics with 70° angulation are possible tools for better intraoperative evaluation [29]. Furthermore, the preoperative physical examination should look objectively for symptoms and signs related to the subscapularis. For the radiologist, in addition to careful consideration of this tendon, it is interesting to discuss new protocols for image acquisition.

Conclusion

The MRI is an accurate method for diagnosing subscapularis tendon tears; however, its accuracy is lower than for overall rotator cuff tears, due to its lower sensitivity.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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