Magnetic resonance imaging criteria for the assessment of the rotator cuff after repair: a systematic review and quality assessment of reliability studies

Abstract

Purpose: To perform a systematic review of the literature on magnetic resonance (MR) criteria for the assessment of rotator cuff after repair and summarize risk of bias and results of intra and interobserver reliability studies.

Methods: Search was performed using major electronic databases from their inception to February 2014. All studies reporting postoperative MR assessment after rotator cuff repair were included. After the identification of avalaible MR criteria, reliability studies were further analyzed. Descriptive statistics were used to summarize findings. Methodological quality was assessed using the Quality Appraisal of Reliability Studies (QAREL) checklist.

Results: One hundred twenty studies were included in the review. Twenty six different criteria were identified. Each criterion was evaluated through presence/absence or a dedicated classification. Ten studies reported interobserver reliability and only two assessed intraobserver reliability of some of the identified criteria. Structural integrity was the most investigated topic. The dichotomization of Sugaya's classification showed the highest correlation (k= 0.80-0.91). All other criteria showed moderate to low interobserver reliability. Tendon signal intensity and footprint coverage showed a complete discordance. Intraobserver agreement was high for the presence of structural integrity; moderate to low for all other criteria. Methodological quality was high only for one study and moderate for 3 studies.

Conclusion: Twenty six different criteria, further described by multiple classification systems, have been identified for the MR assessment of rotator cuff after repair. Reliability of most of them has not been analyzed yet. With the data available, only the presence of structural integrity showed substantial intra and interobserver agreement.

Keywords: magnetic resonance, rotator cuff repair, interobserver and intraobserver reliability

INTRODUCTION

Healing of rotator cuff tendons after surgical repair is problematic, especially for large and massive tears [19, 35]. Although clinical outcome of rotator cuff repair seems not to be predicted by tendon healing, some studies have documented that tendon healing is associated with greater functional improvement than tendon non-healing or re-tear [25, 143].

Several prognostic factors have been identified in rotator cuff surgery that may influence clinical and structural outcome of the repair, some of which can only be assessed with imaging studies. Different imaging modalities are used for the preoperative and postoperative evaluation of the rotator cuff, such as: ultrasounds (US), computed tomography (CT), magnetic resonance (MR), CT-arthrography (CTA) and MR-arthrography (MRA) [89, 125, 136]. Recent studies [36, 54, 141, 155] showed that US and MR are comparable in both sensitivity and specificity for diagnosing a rotator cuff tear. However, US accuracy is still strictly dependent on radiologist experience [116]. CT and CTA are less accurate than MR and are usually recommended only in patients who cannot undergo MR examination [14]. MRA is the most sensitive and specific technique for diagnosing both full- and partial-thickness rotator cuff tears and re-tears [24, 155]. However, as MRA is more expensive, time-consuming and invasive than MR, the latter remains the most commonly used imaging modality for the assessment of rotator cuff before and after surgery.

Although the evaluation of tendon integrity remains the most relevant imaging information at follow-up, MR also allows the evaluation of some other outcomes, such as: the size of re-tear, muscle atrophy and fatty infiltration [30, 83, 99, 101], which may explain the reasons for the observed discrepancy between clinical and anatomical results.

Several classifications have been reported in the literature for MRI assessment of the rotator cuff after repair, but no clear information is available on the reliability of these outcome measurements. The purpose of the present systematic review was threefold: to identify all the MR criteria available in the literature for the assessment of rotator cuff after repair; to summarize available data on reliability of identified criteria, and to assess methodological quality of reliability studies.

METHODS

This systematic review was conducted following the PRISMA guideline (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [107].

Literature search

Two authors independently searched the major electronic databases to identify studies which reported postoperative MR assessment following rotator cuff repair. There were no restrictions on the date of publication or language. This search was applied to MEDLINE through OVID (1948 to February 2014), and adapted for EMBASE (1988 to February 2014). To minimize the number of missed studies, no filters were applied to the search strategy (see **Appendix A**). Studies with levels of evidence I, II, III, and IV were included. Articles designated as E-published only as well as E-published ahead of print were included. All studies enrolling people of any age who underwent rotator cuff repair and reporting postoperative MR assessment of the rotator cuff were included.. No restrictions on surgical technique were applied; therefore, studies reporting MR imaging outcomes following open, mini-open or arthroscopic rotator cuff repair were considered. Studies that included different postoperative imaging modalities were allowed, with only the data from MR evaluation included in this analysis. Exclusion criteria were evaluation of repair of isolated subscapularis tears and revision surgeries. Literature reviews, editorial pieces and expert opinions were also excluded.

References within included studies and review articles were manually cross-referenced for potential inclusion if omitted from the initial search.

In cases of disagreement of paper inclusion/exclusion at any stage of the selection process, a consensus was reached through discussion or, if not possible, by arbitration from the senior author. Titles of journals, names of authors or supporting institutions were not masked at any stage.

Data extraction and analysis

The same reviewers independently extracted available data from all eligible studies using a piloted form. Information gathered included the following study characteristics: authors and year of publication, MR setting (magnetic field strength and sequences obtained), semi-quantitative or qualitative MR criteria; precise definitions of the criteria; normal and abnormal values (if applicable), data reflecting the reproducibility of results such as the intra- and inter-observer reliability of each semi-quantitative or qualitative MR criterion. A third author checked the extracted data.

In view of the studies' objectives, heterogeneous populations and outcomes investigated, descriptive statistics were used to summarize findings across all reliability studies. Although different measures of reliability are reported in the literature, according to the most accredited recommendations on measurement properties of reliability [96, 108], the following statistical methods were considered valid for the assessment of intra-observer and inter-observer reliability: Kappa (k) statistics for dichotomous/nominal/ordinal scores and intraclass correlation coefficients (ICCs) for continuous scores.

Magnitude of agreement between repeated observations was interpreted according to the values of k coefficients and ICCs as follows: < 0 as absent (complete discordance between observations), 0–0.20 as poor, 0.21–0.40 as fair, 0.41–0.60 as moderate, 0.61–0.80 as good, and 0.81–1 as very good [85].

Methodological quality

Only studies reporting intra- and/or inter-observer reliability were included in the evaluation of the study methodological quality. Methodological quality was assessed using the Quality Appraisal of Reliability Studies (QAREL) checklist [96]. It has been developed as a specific quality appraisal tool for studies of diagnostic reliability. The QAREL checklist includes 11 items that explore seven principles. Items cover the spectrum of subjects, spectrum of examiners, examiner blinding, order effects of examination, suitability of the time interval among repeated measurements, appropriate test application and interpretation, and appropriate statistical analysis. Each item is equally weighted and graded as Yes, No or Unclear based on guidelines provided [96]. The risk of bias was based on the number of positive items (scored Yes). A high risk of bias was considered if < 7 items were positive and a low risk was considered if > 8 items were positive. Seven positive items identified a moderate risk of bias [12, 140]. Methodological evaluation was initially conducted independently by two reviewers and results were subsequently discussed until a completely unanimous grade was allocated to each item. If a consensus was not possible, the grade was assigned by arbitration of the senior author.

RESULTS

Literature search

The electronic search resulted in 3410 hits, 2283 for Medline and 1127 for Embase. After removing the duplicates and studies not eligible for inclusion based on their title and abstract, 156 studies remained.

Of these, 36 were excluded based on the full text. One hundred twenty studies were included in the review (**Fig. 1**).

Included studies

All the included studies reported an MRI evaluation after rotator cuff repair [2–11, 13, 15–18, 20–23, 26–28, 31, 32, 34, 37–42, 44, 46–53, 55–79, 81, 82, 84, 86, 87, 90–93, 97, 98, 100, 102–106, 109, 111, 113, 114, 117–124, 126, 127, 129–132, 135, 137–139, 144, 145, 147, 148, 150–152, 156–158, 161–163, 166, 167, 169]. Twenty six different criteria for the evaluation of the rotator cuff after repair have been described. Each criterion has been evaluated through a semi-quantitative method (present/absent) or a dedicated classification. Moreover, different MR settings have been used for the evaluation of the same criteria. Detailed data on study characteristics and MR criteria are reported in the **Table 1.**

Reliability studies

Only 2 studies [48, 63] reported intra-observer agreement, whereas 10 studies [7, 23, 52, 63, 73, 82, 103, 104, 106, 166] reported inter-observer agreement for some of the above-mentioned criteria.

Structural integrity

Structural integrity was assessed in almost all the included studies using 7 different staging systems [22, 50, 62, 98, 117, 147, 152]. Intra-observer reliability was evaluated only by 2 studies [48, 63]. Both studies dichotomized the outcome (yes or no). Hantes et al [48] showed an ICC equal to 0.96 (95% CI, 0.90-0.98), indicating an excellent reliability, whereas Khazzam et al [63] showed a k coefficient equal to 0.71, indicating a good reliability. Inter-observer reliability was evaluated by 6 studies [7, 23, 52, 73, 106, 166]. Four studies [7, 23, 52, 166] analyzed a dichotomous outcome (yes or no). The reliability analysis showed k coefficients between 0.68 and 0.81 and Cronbach's alfa coefficient equal to 0.92 indicating good to very good reliability. Sugaya's classification [147] was evaluated by one study and it showed a good reliability (k= 0.72; 95%CI, 0.63-0.80) [73]. Two studies [73, 106] dichotomized the Sugaya's classification, as follows: type I-II were considered intact, type III-V were considered re-torn/non-healed. Kappa coefficients were between 0.80 and 0.91, indicating a very good reliability.

Footprint coverage

Footprint coverage was assessed in the healed rotator cuff repair in 4 studies[9, 13, 21, 63] using 2 different classifications [9, 13] . One study [63] reported intra and inter-observer reliability for Burks' classification [9]. Intra-observer reliability was poor (k=0.10). Inter-observer reliability analysis showed a complete disagreement (k=-0.01).

Tendon thickness

Tendon thickness was evaluated in the healed cuff repair and compared to normal thickness in 5 studies [9, 13, 63, 82, 158] using 4 different classifications [9, 13, 82, 158]. Poor intra- (k=0.13) and inter-observer reliability (k =0.01) was found in one study [63] for Burks' classification [9].

Tendon signal intensity

Tendon signal intensity was evaluated in the healed cuff repair in 7 studies [9, 13, 21, 63, 74, 82, 145] using 5 different classifications [9, 13, 74, 82, 168]. Poor intra-observer reliability (k=0.09) and a complete inter-observer disagreement were reported by one study [63] for Burks' classification [9].

Partial re-tear

Khazzam et al [63] defined partial-thickness re-tear location as bursal- or articular-sided. Poor intra and inter-observer reliability was found (k=0.06 and k=0.01, respectively).

Full thickness re-tear location

One study [63] evaluated full-thickness re-tear location on the coronal view, as follows: greater tuberosity or musculotendinous junction Intra- and inter-observer reliability was poor (k=0.21 and k=0.04, respectively).

Tear size

The size of re-tear was reported in 12 studies [60, 61, 63, 103, 104, 109, 119, 120, 131, 151, 163, 169]. Intra-observer reliability was evaluated only by one study [63], which reported a poor to fair reliability in both sagittal and coronal planes: k=0.20 and k=0.23, respectively. Inter-observer agreement was evaluated by 3 studies [63, 103, 104]. The overall reliability was very different between studies. On the coronal view, Mellado et al [103, 104] showed a Pearson's correlation coefficient (PCC) of 0.90 in both studies, whereas Khazzam et al [63] reported a poor reliability (k =0.14). Similarly, on the sagittal plane, Mellado et al [103, 104] showed PCCs between 0.8 and 0.9, whereas Khazzam et al [63] reported a k coefficient equal to 0.31, indicating a fair reliability.

Number of tendons involved

Assessment of number of tendons involved in full-thickness re-tears was reported only by one study [63]. Fair intra- and inter-observer reliability (k=0.29 and k = 0.40, respectively) was found for this outcome.

Tendon retraction

The amount of retraction was reported in 4 studies using 4 different classifications [16, 22, 63, 151] . Moderate inter-observer reliability (k=0.45) was found for the classification reported by Khazzam et al [63].

Muscle atrophy

Muscle atrophy was assessed on 34 studies [2, 4, 5, 15, 21, 32, 37–40, 47, 49, 56–58, 61, 63, 74, 78, 82, 93, 104, 114, 119, 130, 152, 157, 161, 164, 166, 167, 169] and 8 classifications were reported [39, 49, 63, 153, 159, 162, 164, 165]. Only one study reported the intra-oberserver reliability [63] and two studies [63, 104] reported the inter-observer reliability for the Zanetti's classification [165]. Intra-observer reliability was moderate for supraspinatus (k=0.52) and infraspinatus (k=0.43), and poor for subscapularis (k=0.32). The overall inter-observer reliability was very different between studies. Mellado et al [104] showed a PCC of 0.90 for each muscle belly, whereas Khazzam et al [63] reported k values ranging from 0.11 for the subscapularis, 0.28 for the infraspinatus to 0.31 for the supraspinatus, showing a poor to fair reliability.

Fatty infiltration

Although fatty infiltration was described on postoperative MRIs in several studies using 3 different classifications [43, 44, 112], fair intra- and inter-observer reliability (k= 0.34 and k=0.24, respectively) was reported only by one study [63] for the Goutallier's classification [43].

Long head of the biceps

The evaluation of associated pathologies involving the long head of the biceps (LHB) has been reported only by one study [63]. The authors evaluated the presence of the LHB into the intertubercular groove (yes or no) as well as the presence of a longitudinal split of the intra-articular portion of the tendon (yes or no) on T2 axial cuts. Intra-observer reliability was moderate for the two outcomes (k=0.43 and k=0.49, respectively). Inter-observer reliability was poor for the presence of LHB signal (k=0.10) and fair for the presence of a longitudinal split (k=0.35).

Bone marrow edema in the humeral head

Presence and location of the bone marrow edema in the humeral head were considered by one study [63]. Moderate intra-observer reliability has been shown for the presence of bone marrow edema (k= 0.48), whereas a complete disagreement was found for the location of the edema (k= -0.03). Poor inter-observer reliability was found for both criteria (k=0.22).

Cysts in the greater tuberosity

A moderate intra and inter-observer reliability (k=0.47 and k=0.43, respectively) was found for the presence of cysts of the greater tuberosity by one study [63].

Glenohumeral joint effusion

Glenohumeral joint effusion was assessed by the amount of fluid in subcoracoid and axillary recesses as well as biceps tendon sheath and classified into 4 categories from absent to large amount of fluid [63]. Only one study reported the intra and inter-observer reliability [63] Kappa coefficients were equal to 0.47 (moderate reliability) and 0.24 (very low reliability), respectively.

Acromio-humeral distance

Acromio-humeral distance was assessed in one study [63] on fat-suppressed sagittal sequences as the distance between the superior aspect of the humeral head and the undersurface of the acromion. Measurements were taken in millimeters at the midhumeral level. Results were classified into 4 categories: $\geq$ 10 mm, between 10 and 5 mm, < 5 mm, contact between the surfaces. Intra and inter-observer reliability was fair (k=0.38 and k=0.31, respectively).

Methodological quality

The risks of bias of the included studies, according to the QAREL checklist are presented in **Table 2** . Most of the studies showed a high risk of bias. The grading of the studies varied from 3 to 9 positive items out of 11 possible. Seven studies were considered to be of high risk of bias [7, 23, 48, 52, 82, 103, 104]. Among these studies, four did not use appropriate statistical measures [23, 82, 103, 104] . Three studies were considered to be of moderate risk [73, 106, 166] and only one was found to be at low risk of bias [63]. None of the included studies specified if the order of MR examination varied between observers or between different observation series. Among intra-observer reliability studies, only one study [63] clearly stated the time interval between repeated measurements.

DISCUSSION

Summary of evidence

To our knowledge, the present study is the first systematic review assessing MR criteria for the evaluation of rotator cuff after repair and summarizing risk of bias and results of intra- and inter-observer reliability studies.

The principal finding is that only the evaluation of the structural integrity showed a good intra- and inter-observer reliability [7, 23, 48, 52, 63, 73, 106, 166]. Specifically, the dichotomization of the Sugaya's classification[147] into type I-II (intact) versus type III-V (re-tear) showed the highest reliability. Several authors [8, 55, 57–59, 71, 81, 113] also proposed a different dichotomization into Type I-III versus Type IV-V, but no data on intra- and inter-observer reliability are available.

Despite the high number of criteria and the multiple classifications reported by the studies included in the present review, only eleven studies reported reliability of a few criteria [7, 23, 48, 52, 63, 73, 82, 103, 104, 106, 166]. Moreover, methodological quality of available reliability studies was low to moderate. According to the QAREL checklist only one study was judged to be at low risk of bias [63]. QAREL checklist was chosen because is the most frequently reported quality appraisal tool for reliability studies[1, 12, 80]; moreover, it has been recently shown to be a [95] reliable assessment tool for reliability studies .

Structural integrity was the most investigated topic after rotator cuff repair across the studies included in the review. Apart from Sugaya's classification, or its dichotomization, and the definition of presence or absence of tendon integrity, we found other 5 different classifications reported in the literature [22, 50, 62, 98, 152]. Moreover, some studies applied existing classification to different MR sequences [4, 5, 39, 167]. Currently, neither proof of reliability of those classifications, nor estimation of the best sequence for the evaluation of tendon integrity has been reported. Similarly, different classifications or imaging planes and sequences have been proposed for the evaluation of fatty infiltration and muscle atrophy, but reliability on postoperative MRI has been taken into account only by one study [63] for Goutallier's classification [43] and by two studies [63, 104] for the quantification of muscle atrophy according to Zanetti et al [165]. Although reported in several follow-up studies the following criteria were never tested for reliability: re-rupture pattern, tendon length, musculotendineous junction position, tendon thickness, acromial morphology, thickness of the subacromial bursa, acromio-clavicular osteoarthritis, gleno-hum eral osteoarthritis, artifacts and anchor characteristics. More interestingly, although most of these criteria could be considered to be of secondary importance in clinical practice, several authors proposed different grading system for their evaluation. Moreover, it must be highlighted that the lack of a detailed description of planes and sequences increases the uncertainty of their application.

Only one study analyzed reliability of multiple criteria [63]. Seven fellowship-trained orthopaedic shoulder surgeons reviewed 31 MR scans from 31 patients who had previous rotator cuff repair. The authors reported moderate inter-observer agreement for tendon retraction and presence of cysts of the greater tuberosity. Moderate intra-observer reliability was found for muscle quality of supraspinatus and infraspinatus tendons, presence of a split in the long head of the biceps tendon, cysts in the greater tuberosity and bone marrow edema involving the humeral head. All other criteria showed poor to fair intra- and inter-observer reliability. Finally, tendon signal intensity and footprint coverage showed a complete discordance between observers.

In contrast, Mellado et al [103, 104], in two consecutive studies, found high inter-observer reliability for tear size and muscle atrophy. Data pooling was not possible due to the use of different statistical measures of reliability. From a methodological standpoint, the study by Khazzam et al [63] was the only one with a low risk of bias, whereas the studies by Mellado et al [103, 104] were found to be at high risk, due to inappropriate statistical analysis. In fact, as stated by the general guidelines provided by the QAREL checklist [96], correlation statistics, such as Pearson's r or Spearman's rank correlation coefficient used by Mellado et al [103, 104] are not appropriate for assessing reliability. Those correlation coefficients provide information regarding the consistency of the scores between repeated measures but does not account for systematic differences, which may occur between repeated measures. Therefore, these correlations are overly liberal, and inappropriate estimates of reliability [146].

Reliability is an important indicator of the potential of a test to be accurate and reproducible, therefore it is important to know that most of the commonly used criteria to assess the status of the rotator cuff after surgery have never been tested or show only moderate to low intra- and inter-observer reliability.

Agreements and disagreements with other studies or review

Although MRI has become the standard imaging modality for the assessment of the rotator cuff pathology and it allows the evaluation of a large number of features, surprisingly, no previous systematic review investigated the reliability of the criteria used for the MR evaluation after rotator cuff repair.

After carefully analyzing the results of the present review, apart from data on structural integrity, it has been noticed that the evaluation of fatty infiltration showed poor inter-obsever agreement and moderate intra-observer reliability. According to the current literature, fatty infiltration constitutes one of the most important predictive factor for successful outcomes after rotator cuff repair [30, 99, 101]. Therefore, the presence of a reliable and valid classification system to assess the postoperative changes of rotator cuff muscles is crucial. However, qualitative assessment of fatty infiltration of rotator cuff after surgery should be interpreted with caution due to the limited reliability of the current grading systems and several concerns still remain. A consensus on imaging modalities, planes and sequences need to be achieved [33, 94, 110, 115, 149, 160]. Despite MRI is the reference standard for the evaluation of the rotator cuff features, the grades of fatty infiltration are measured at one cross-sectional image, thus the section for evaluation may be placed at a relatively medial portion and may not represent the true degree of fatty infiltration of the whole muscle belly [115]. Moreover, the cross-sectional areas of the muscle may be highly influenced by retraction of the musculotendinous junction of the rotator cuff [153, 154]. It has been showed in an animal model that fatty infiltration is an infiltrative process that progresses over time from the musculotendinous junction toward the muscle origin [128]. In clinical studies performed after rotator cuff repair, if the repair is successful and the retracted tendon end is brought back to the footprint, lateralization of the muscle belly may falsely improve the degree of fatty infiltration [88, 115] . Finally the qualitative nature of the Goutallier’s system implies a subjective assessment of the fatty infiltration and the role of observer’s experience on inter-observer reliability has been also questioned [115, 142].

Therefore, quantitative measurements of muscle atrophy (rather than fatty infiltration) have been proposed, but none of them has been widely accepted yet [149, 152, 165].

Limitations

The present study has several limitations. Although an attempt was made to minimize the number of missed studies during the search process, only few reliability studies were found, despite the wide number of identified criteria for the assessment of the rotator cuff after repair. Secondly, results of the present review have been widely influenced by the results of one study [63] because it was the only well-conducted study available, which took into account different criteria. Furthermore, in case of multiple studies assessing the same criteria, with meta-analysis deemed inappropriate, the choice of providing an average level of reliability is definitely arbitrary, although largely used in systematic reviews of reliability studies [45, 133]. Some other limitations are strictly dependent on the design of the included studies. Due to the lack of detailed descriptions on how to use some classifications or how to interpret some MR findings, several criteria often are used or applied in a different way among similar studies by using custom–made modifications or dichotomizations of original classifications. Moreover, MR settings varied across the studies. Although most of the studies used 1.5 Tesla (T) magnetic fields, some studies used lower and some others used higher fields. Undoubtedly, the strength of the magnetic field can influence the accuracy of the MR evaluation. In absence of reliability studies that take into account comparisons between different planes and sequences described in literature, it is very difficult to state any clear conclusion on the best modality to evaluate any criterion. Overall, this variability reduces comparability of radiologic reports and may lead to misinterpretation of findings and severely limits the value of some studies. In clinical practice, this uncertainty may have negative effects on the evaluation of the outcome of rotator cuff repair.

CONCLUSION

In the present study, we have systematically reviewed the MR criteria to assess rotator cuff repair described in the literature and what has been reported about their intra- and inter-observer reliability. We found 26 different criteria described by multiple classification systems, albeit reliability of most of them has not been analyzed yet. With the data available, only the presence of structural integrity after rotator cuff repair showed substantial intra- and inter-observer reliability.

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FIGURE LEGENDS

Fig. 1 Studies selection based on PRISMA flowchart.

Appendix B

Outcome	MR setting	CLASSIFICATION	REFERENCES
Structural integrity	T2 weighted images Coronal view	Y/N Full thickness tear: fluid-like signal intensity that extends through an area of the rotator cuff or the nonvisualization of a portion of the rotator cuff	[3, 6, 7, 13, 15–18, 20, 21, 26, 28, 32, 37, 38, 40–42, 44, 48, 51–53, 60, 61, 64, 64, 72, 84, 86, 87, 90–93, 97, 100, 102–104, 109, 114, 117, 119–121, 123, 124, 126, 127, 131, 132, 132, 135, 137, 138, 145, 150, 158, 166, 169]
	T2-weighted and STIR images. Coronal view	Full thickness tear: high signal intensity traversing the entire tendon thickness Partial-thickness tendon tear: fluid traversing a portion of the tendon (whether on the articular or the bursal surface or both) but not traversing the full thickness of the tendon. Cuff integrity	[10, 11, 34, 74, 98, 118]
	T2 weighted[152] T2 fat-suppressed sequences, including axial transverse, coronal oblique (parallel to the	Type I: Continuous and thick Type II: Continuous, but thin Type III: Retorn	[4, 5, 152, 167]

	supraspinatus muscle), and sagittal oblique (perpendicular to the supraspinatus muscle)[167] T2-weighted, proton density weighted, as well as STIR, axial and paracoronal[4, 5]		
	T2 weighted Oblique coronal, oblique sagittal, and transverse views Proton density weighted spin echo sequences, paracoronal view[39]	Sugaya's classification: type I, repaired cuff appeared to have sufficient thickness compared with normal cuff with homogenously low intensity on each image; type II, sufficient thickness compared with normal cuff associated with partial high intensity area; type III, insufficient thickness with less than half the thickness when compared with normal cuff, but without discontinuity, suggesting a partial-thickness delaminated tear; type IV, presence of a minor discontinuity in only 1 or 2 slices on both oblique coronal	[39, 42, 46, 47, 55, 73, 75, 77–79, 105, 122, 129, 139, 142, 147, 148, 161, 162]*

		and sagittal images, suggesting a small full-thickness tear; type V: presence of a major discontinuity observed in more than 2 slices on both oblique coronal and sagittal images, suggesting a medium or large full-thickness tear	
	T2 weighted Oblique coronal, oblique sagittal, and transverse views	Sugaya’s dichotomization intact (Sugaya types I and II); insufficient/not healed/retorn (Sugaya types III-V)	[65–68, 70, 73, 76, 79, 106, 157]
	T2 weighted Oblique coronal, oblique sagittal, and transverse views	Sugaya’s dychotmization: intact:Sugaya types I-III retorn: Sugaya types IV-V	[8, 55, 57–59, 71, 81, 113]
	Fast proton-density with fat saturation and fast STIR Oblique coronal T2 with fat saturation	type 1: sufficient thickness with homogeneously low intensity, type 2: sufficient thickness with partial high intensity, type 3: insufficient thickness without discontinuity,	[22]

	Sagittal view	type 4-A: presence of a partial-thickness focal discontinuity, type 4-B: presence of a full-thickness focal discontinuity, type 5: presence of a major discontinuity with retraction.	
	Not clearly specified	Type 1: tendon intact with regular thickness Type 2: tendon intact, but thinning Type 3: small hole<225 mm^2(e.g. 1.5cm x 1.5 cm) Type 4: big hole>225 mm^2	[62]
	Not clearly specified	Type 1: well-repaired tendon with thick continuity; Type 2: deep partial retearing (continuity of the thin superficial tendon and interruption of the deep tendon); Type 3: superficial partial retearing (continuity of the thin deep tendon and interruption of the superficial tendon around the medial anchors with a well-	[50]

		preserved tendon on the footprint); Type 4: complete retearing at the middle of the tendon around the medial anchors with a healed rotator cuff footprint; Type 5: complete retearing of the tendon from the footprint	
Muscle atrophy	T1 weighted Oblique sagittal view Y shaped view: the most lateral image on which the scapular spine is in contact with the rest of the scapula	Only supraspintus Grade 1: Normal/ slight atrophy Occupation ratio(1.00-0.60) Grade 2: Moderate atrophy Occupation ratio(0.60-0.40) Grade 3: Severe atrophy Occupation ratio(<0.40) Occupation ratio=cross section area of the muscle/cross section area of the fossa	[4, 5, 21, 28, 56, 57, 78, 82, 93, 114, 130, 152, 153, 157, 167]
	T2-weighted Oblique sagittal views obtained about 20mm proximal to the deepest point on the concave curve of the glenoid surface	The occupation ratio[153] is evaluated not only for suspraspiantus, but also for the subscapularis, and the combined infraspinatus and teres minor muscles	[162]

	T1-weighted Parasagittal turbo spin-echo Y shaped view	*Cross sectional area* Regions of interest are determined by the contours of the supraspinatus, infraspinatus, teres minor, and subscapularis muscles. The cross-sectional areas (in Cm^2) of these structures are alculated. The area of the supraspinatus fossa is also measured. Standardized areas are calculated by dividing muscle areas by the area of the fossa supraspinatus. Measurements (mean and SD) obtained in patients are expressed as multiples of SD below or above the mean of the corresponding decade Muscle atrophy is considered to be present when the value of the standardized area were more than 2 SD below the mean *Tangent sign*: A line (tangent) is drawn through the superior borders of the scapular spine and the	[2, 28, 32, 37, 57, 78, 91, 104, 114, 119, 130, 157, 165, 166, 169]

		superior margin of the coracoid. The tangent sign is abnormal (positive) when the supraspinatus muscle do not cross the tangent.	
	NA	Normal Atrophic Hypertrophic	[74]
	Oblique sagittal plane image medial to the level of the coracoid process	No atrophy = muscle completely fills its fossa, and the outer contour is convex; Minimal atrophy = muscle's outer contour is flat compared with its fossa; Moderate atrophy = muscle's outer contour is concave into the fossa; Severe atrophy = muscle is barely apparent in its fossa. The overall degree of atrophy of the rotator cuff muscles is recorded on the basis of the most severely affected muscle.	[15, 40, 159, 163]
	T1 weighted	*Supraspinatus*	[49]

	Oblique coronal plane: supraspinatus muscle. Axial plane: infraspinatus muscle. The slice that pass through the center of the glenoid is selected for evaluation.	The first line (L1) is drawn from the superior rim of the glenoid to the inferior rim, and the second line (L2) iss drawn parallel to L1 at the neck of the glenoid. Width of the supraspinatus muscle: the distance between the superior and inferior end of the supraspinatus muscle on L2. (mm) *Infraspinatus* The first line (M1) is drawn from the anterior rim to the posterior rim, and the second line (M2), parallel to M1, is drawn at the neck of the glenoid. Width of the infraspinatus muscle: The distance between the anterior end and posterior end of the infraspinatus muscle on M2. (mm)	
	Oblique sagittal T1 Y shaped view	Modified tangent sign grade 3, positive sign; grade 2, borderline; grade 1, negative sign	[56, 164]

	Non fat satured sagittal view Y shaped view	Subjective grading applied to all muscles Normal 25% atrophy 50% atrophy 75% atrophy complete atrophy	[63]
	Parasagittal T1-weighted Y shaped view	After definition of elliptical regions of interest of identical size (25 mm2), the signal intensity was measured. Five elliptical regions of interest in the supraspinatus muscle and, for comparison, 5 elliptical regions of interest in the teres minor muscle were located to calculate the signal to- signal ratio : teres minor/supraspinatus.	[39, 47]
Fatty infiltration	Tl-weighted turbo spin-echo Parasagittal view Y shaped view T1 weighted	Grade 0 No fatty deposits Grade 1 Some fatty streaks Grade 2 More muscle than fat Grade 3 As much muscle as fat Grade 4 Less muscle than fat	[2, 32, 33, 37–40, 43, 51, 56, 57, 60, 61, 63, 78, 84, 91, 93, 104, 105, 111, 114, 119, 123, 132, 135, 144, 156, 157, 162, 163, 167, 169]*

	Coronal view[40] T2 weighted, Y shaped view [78, 123, 163] Non fat saturated Y shaped view[63, 167]		
		Global fatty degeneration index (GFDI): mean value of the grades for the supraspinatus, infraspinatus, and subscapularis	[15–18, 44, 57, 156, 163]
	T1-weighted images Oblique coronal plane	Linear bands of bright signal in the SS muscle belly: Grade 1: no linear band. Grade 2: 1 or 2 narrow linear bands. Grade 3: 3 or more narrow linear bands or 1 or 2 thick linear bands	[49, 112]
Footprint coverage	Not clearly specified	Footprint is compared with footprint of a normal supraspinatus tendon, which covers the entire greater	[9, 21, 63]

		tuberosity from medial to lateral. In cases where the tendon attachment is medialized, width of the medialized footprint is compared with width of the greater tuberosity Grade 4: >75%; Grade 3: 51-75%; Grade 2: 26-50%; Grade 1: <25%	
	Not clearly specified	Footprint is compared with footprint of a normal supraspinatus tendon, which covers the entire greater tuberosity from medial to lateral. In cases where the tendon attachment is medialized, width of the medialized footprint is compared with width of the greater tuberosity Grade 3: 3/3; Grade 2: 2/3; Grade 1: 1/3	[13]
Tear size	T2 weighted	maximal mediolateral diameter	[60, 61, 103, 104, 109, 131, 163, 169]

	T2 STIR[103, 104] Oblique coronal and sagittal view	maximal anteroposterior diameter	
	T2 weighted Sagittal view	Anteroposterior length of the exposed rotator cuff footprintof the lateral-most section of the greater is measured. small: <1 cm; medium: 1-3 cm; large: 3 to 5 cm; massive: > 5 cm	[119, 151]
	T2 weighted Coronal and sagittal view	The tear is measured at the greater and lesser tuberosities (insertion of the rotator cuff). less than 1cm 1cm< x < 2cm 2cm< x < 3cm 3cm< x < 4cm	[63]

		4cm< x < 5cm greater than 5cm	
Retear pattern (full thickness)	Oblique sagittal plane	Anterior: the center of the tear is within the anterior half of the supraspinatus tendon. Posterior: the center of the tear is within the posterior half of the tendon	[103]
	At least one T2 weighted or proton density weighted image	Type 1: if the cuff tissue repaired at the insertion site of the rotator cuff is not at all observed to be remaining on the greater tuberosity; Type 2: remnant cuff tissue remained at the insertion site in spite of retear	[15, 17, 64, 113]
	Not clearly specified	Greater tuberosity Muscolotendinous junction	[63]
Partial retear	T2 weighted Coronal and sagittal view	Articular surface tear Bursal surface tear Can not be determined	[63]
Tendon retraction	Coronal plane	Stage 1: the tear edge is lying over the greater tuberosity	[22]

		(usually < 1 cm in greatest diameter); Stage 2: the tear exposes the humeral head but does not retract to the glenoid articular surface (between 1 and 3 cm in greatest diameter); Stage 3: tears that extends to the glenoid (between 3 and 5 cm in greatest diameter); Stage 4: tears that is severely retracted medial to the glenoid (> 5 cm in greatest diameter)	
	Not clearly specified	Minimal (within 5mm of the greater or lesser tuberosity) Midhumeral Glenohumeral Medial to the glenoid	[63]
	T2- weighted Coronal sections through the center of the supraspinatus muscle	Millimeters from the lateral edge of the greater tuberosity to the tendon end	[151]

Tendon length	T2 weighted Coronal view	Millimeters from the lateral tendon edge to the musculotendinous junction	[151]
Musculotendinous junction position	same coronal T2-weighted image on which tendon retraction is measured	The most lateral point of the supraspinatus at which inserting muscle fibers on the central tendon Two measurements: Distance from the glenoid face line (mm): a positive value if the musculotendinous junction is lateral to the glenoid face line and a negative value if the musculotendinous junction is medial to the glenoid face line Binary variable of medial/lateral position	

		(glenoid face line: a line connecting the supraglenoid and infraglenoid tubercles; same coronal cut on which the musculotendinous junction position is identified)	
Tendon signal intensity	Not clearly specified	Low High Intermediate	[74]
	Intermediate weighted and T2 weighted	Type 1: diffuse mildly increased signal (not equal to that of fluid) and an intact tendon) Type 2:focally increased signal intensity (equal to that of fluid) bursal or articular Type 3: focal increased signal entire thickness with or without retraction	[82, 145, 168]
	Spin echo T1 and fast spin echo T2 sequences	Fullthickness tear: a signal intensity equal to water filling the entire thickness of the tendon	[82]

		Partial tear: signal equal to water extended through part of the thickness of the tendon. Degenerative tendinosis: signal appeares moderately bright in the spin echo T1 and fast spin echo T2 sequences, but not as bright as water in fast spin echo T2, or a tendon that is heterogeneous or longitudinally striated in both sequences Normal tendon: normal in thickness and low in signal intensity in all sequences	
	Not clearly specified	Grade 4: normal signal intensity (low signal on all sequences) Grade 3: increased signal intensity in the tendon involving <1 cm distance or <25% of tendon width	[9, 21, 63]

		Grade 2: increased signal intensity in the tendon involving 1-2cm distance or 25%-50% of tendon width Grade 1: increased signal intensity in the tendon involving >2cm distance or >75% of tendon width	
	Not clearly specified	Grade 3: light and diffused increase of the signal (different from that of the synovial fluid); Grade 2: tendon appears undamaged but there is a focal increase of the signal (the same as that of the synovial fluid) on the bursal or articular side; Grade 1: the increase of the signal's intensity (the same as that of the signal of the synovial fluid) involves the entire thickness of the tendon, with or without tendinous retraction	[13]

Tendon thickness	Coronal oblique plane	Supraspinatus tendon thickness (mm) is measured from the clear tendinous area below the anterolateral tip of the acromion Scale 0.5 mm	[82]
	Oblique coronal view	Mimimum thickness: measured immediately medial to the insertion of the supraspinatus tendon into the greater tuberosity, 1 cm posterior to the biceps tendon. 0 mm if there is a reatear	[158]
	Not clearly specified	Comparison with normal tendon thickness: Grade 4: >75%; Grade 3: 51-75%; Grade 2: 26-50%; Grade 1: <25%	[9, 21, 63]
	Not clearly specified	Comparison with normal tendon thickness: Grade III, normal thickness;	[13]

		Grade II, more than 50% normal thickness; Grade I, less than 50% normal thickness.	
Number of tendons involved	T2 coronal and sagital views	Supraspinatus only Supraspinatus and infraspinatus (posterosuperior tear) Supraspinatus, infraspinatus and teres minor (posterosuperior tear) Subscapularis Supraspinatus and subscapularis (anterosuperior tear)	[63]
Acromiohumeral distance	Non fat-saturated sequence Sagittal view	The slice that best represents the midhumeral level with regard to its anteroposterior dimension is chosen to measure the distance from the superior aspect of the humeral head and the undersurface of the acromion. 10mm or greater 10mm > x > 5mm	[63]

		less than 5mm contact between the 2 surfaces	
	Not clearly specified	Subacromial space narrowing: acromiohumeral distance $\leq$ 3 mm	[82]
Acromial morphology	Sagittal view (anterior third of the acromion) Coronal view (lateral third of the acromion: the image just anterior to the posterior aspect of the acromioclavicular joint)	Flat: the apex of the acromion undersurface is in the medial third of the acromion or there is no apex under the acromion. Curved: one with the apex of the acromion undersurface in the middle third Hooked: one with the apex in the lateral third	[29, 77]
Subacromial bursa (thickness)	Not clearly specified	Pathologic if measured more than 2 mm in thickness	[145]
	STIR or T2-weighted fat-suppressed	images parallel to the supraspinatus tendon Y/N: signal intensity abnormalities	[166]
Acromioclavicular osteoarthritis	Not clearly specified	Y/N	[74, 145]
Glenohumeral joint effusion	T1 weighted and T2 weighted fast spin echo and fat suppression	Based on the amount of fluid in the subcoracoid and axillary	[63, 134, 145]

	Coronal oblique	recesses and the biceps tendon sheat: Absent Small Moderate Large	
Evidence of subacromial impingement	Not clearly specified	Y/N: presence of a spur from the undersurface of the acromion or distal clavicle that indentes on the supraspinatus muscle or tendon	[98]
Bone marrow edema	T2 weighted	Y/N **Localization:** greater tuberosity lesser tuberosity subchondral bone of articular surface	[63]
Cysts of the greater tuberosity	T2 weighted Coronal view	Y/N	[63]
Artifacts	T2 weighted fast spin echo without fat saturation	Absent	[74, 145]

	Oblique coronal	Mild: involvement of the subutaneous tissue alone Moderate: involvement of the capsular structures Severe: preclude tha assessment of the rotator cuff	
Anchor features	Transaxial PD-weighted and paracoronal PD-sequences	**Peri implant fluid** Increased signal intensity around the anchor: No fluid slightly present fluid seam (1 mm) pronounced fluid (>1mm). For all measurements, care must be taken to distinguish between proximal, medial and lateral parts of the anchor. **Structure** Assuming that degradation is represented by a decreased visibility of the anchor structure:	[47]

		Grade 1 indicates a clearly visible structure, Grade 2 a visible structure, Grade 3 a partially visible structure Grade 4 describes a structure which is not delimitable from the surrounding tissue **Tunnel** Applying an axis through the central pin of the screw: This enabled three perpendicular measurements with a distance of at least 0.5 mm	
	T1 and T2 weighted	**Humeral head osteolysis** Y/N: when the normal marrow fat around the suture anchors is replaced by tissue with a signal isointense to muscle on T1-weighted images and hypointense to water on intermediate and T2-weighted images	[123]

Integrity of the long head of the biceps	Multiplanar gradient recall images or T2-weighted and proton-density Axial cut	Y/N Absence of the biceps tendon from the intertubercular groove and the inability to identify a medial dislocation of the tendon	[34]
	T2 weighted Axial cut	Y/N (increased or normal signal)	[63]
Presence of the long head of the biceps abnormality	T2 weighted Axial cut	Y/N Presence of a longitudinal split in the biceps	[63]