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Correlation Between Ultrasonography and Magnetic Resonance Imaging in the Diagnosis of Adhesive Capsulitis: A Prospective Study

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Abstract

Introduction

Adhesive capsulitis is a painful and disabling shoulder disorder characterized by progressive restriction of active and passive movements. Although magnetic resonance imaging (MRI) provides comprehensive assessment of capsular and periarticular abnormalities, its cost and limited availability may restrict its use. This study evaluated the correlation and agreement between ultrasonography (USG) and MRI findings and assessed the diagnostic performance of selected ultrasonographic parameters against MRI-based classification in adhesive capsulitis.

Materials and methods

A prospective comparative diagnostic study was conducted among 35 patients with clinically suspected or diagnosed adhesive capsulitis at the Department of Radio-Diagnosis, Vydehi Institute of Medical Sciences and Research Centre, Bengaluru. All participants underwent high-resolution USG followed by MRI. Coracohumeral ligament (CHL) thickness, axillary recess (AR) thickness, rotator interval (RI) soft-tissue abnormality, and joint capsule thickening were assessed. MRI-based classification was used as the reference classification. Pearson correlation, diagnostic performance measures, receiver operating characteristic (ROC) analysis, and Cohen's kappa agreement analysis were used for statistical evaluation.

Results

MRI classified adhesive capsulitis as positive in 26 (74.3%) participants. Mean CHL and AR thicknesses were higher among MRI-positive participants. Strong correlation was observed between USG and MRI measurements for CHL thickness (r=0.861) and AR thickness (r=0.931). Both CHL and AR demonstrated excellent discriminatory performance on ROC analysis (area under the curve (AUC)=0.987 for each parameter). RI abnormality and joint capsule thickening showed substantial agreement between USG and MRI.

Conclusion

USG demonstrated strong correlation and substantial agreement with MRI-based findings for selected quantitative and qualitative parameters associated with adhesive capsulitis. A structured multi-parameter ultrasound assessment may have potential as a practical initial imaging approach, particularly in settings with limited access to MRI. Given the small single-centre cohort, use of MRI-based classification, and lack of independent validation, these findings should be considered preliminary and require confirmation in larger multicentre studies.

Categories: Radiology
Keywords: adhesive capsulitis, axillary recess, coracohumeral ligament, magnetic resonance imaging, ultrasonography

Introduction

Adhesive capsulitis, commonly referred to as frozen shoulder, is a painful and disabling disorder of the glenohumeral joint characterized by progressive pain and restriction of both active and passive shoulder movements [1,2]. The underlying pathological process involves synovial inflammation followed by fibrosis, capsular thickening, and contracture, resulting in reduced joint volume and impaired shoulder mobility [3]. The condition typically progresses through freezing, frozen, and thawing phases, with pain predominating initially, followed by marked stiffness and gradual recovery of movement [4]. Diabetes mellitus is an important associated condition and has been linked to increased prevalence, severity, and prolonged duration of adhesive capsulitis [5].

The rotator interval (RI) and coracohumeral ligament (CHL) are important sites of pathological involvement

in adhesive capsulitis [6]. Inflammation and fibrosis in the RI, together with thickening of the CHL and the capsule of the axillary recess (AR), contribute substantially to restriction of external rotation, abduction, and forward flexion [7]. Although the diagnosis is primarily clinical, imaging is valuable for supporting the diagnosis and excluding other causes of shoulder pain and stiffness, including rotator cuff tears, calcific tendinitis, labral lesions, impingement, and glenohumeral osteoarthritis [8]. Characteristic imaging findings include CHL thickening, AR capsular thickening, obliteration of RI fat, synovial hypertrophy, and pericapsular edema [9].

Ultrasonography (USG) is increasingly used in the evaluation of adhesive capsulitis because it is widely available, relatively inexpensive, non-invasive, and permits real-time and dynamic assessment of the shoulder [10]. It can demonstrate CHL thickening, abnormalities within the RI, changes in the long head of the biceps tendon, and capsular alterations [11]. Magnetic resonance imaging (MRI), in contrast, provides comprehensive visualization of the glenohumeral capsule and periarticular structures and can demonstrate AR capsular thickening, CHL thickening, RI abnormalities, synovial changes, and pericapsular edema [9]. Thus, MRI is an important reference imaging modality for characterization of adhesive capsulitis, although the diagnosis remains primarily clinical and MRI is not considered an absolute diagnostic gold standard.

Despite the established role of MRI, there is a need to determine whether readily available ultrasonographic parameters can identify imaging features of adhesive capsulitis and demonstrate concordance with MRI-based classification. Establishing such a correlation could support the use of USG as a practical initial imaging modality, particularly where access to MRI is limited. Therefore, the present study aimed to evaluate the correlation and agreement between ultrasonographic and MRI findings in patients with suspected adhesive capsulitis and to assess the diagnostic performance of selected ultrasonographic parameters against MRI-based classification.

Materials And Methods

Study design and setting

A prospective comparative diagnostic study was conducted in the Department of Radiodiagnosis, Vydehi Institute of Medical Sciences and Research Centre, Bengaluru, India, a tertiary care teaching hospital. The study was conducted over 18 months, from July 2024 to December 2025, after obtaining approval from the Vydehi Institutional Ethics Committee (VIEC; IEC No. VIEC/2023/APP/PG/116; dated: 19 February 2024). Written informed consent was obtained from all participants before enrollment. Patients referred to the Department of Radiodiagnosis for shoulder MRI with clinical suspicion or diagnosis of adhesive capsulitis were screened for eligibility. Consecutive sampling was used, and every eligible patient presenting during the study period was invited to participate.

Sample size

The required sample size was calculated using the formula: $n = \frac{Z_{\alpha/2}^2 \times \sigma^2}{d^2}$, where Zα/2 = 1.96 for a 95% confidence interval, σ = 1.4 representing the standard deviation of AR capsule thickness obtained from the reference study, and d = 0.5 representing the desired precision [12]. Substitution of these values yielded a calculated sample size of 30.12, which was rounded up to 31 participants. Allowing for a 10% attrition rate, the final required sample size was calculated as 34.1 and rounded to 35 participants, who constituted the final study population. The sample-size calculation was primarily based on achieving the prespecified precision for the quantitative measurement of AR capsule thickness and was not specifically powered to detect differences in diagnostic sensitivity, specificity, or other diagnostic-accuracy estimates. Accordingly, the diagnostic-performance analyses were considered exploratory and were interpreted in the context of the relatively small sample size.

Inclusion and exclusion criteria

Patients referred to the Department of Radiodiagnosis for shoulder MRI with clinical suspicion of adhesive capsulitis and those clinically diagnosed with adhesive capsulitis by the referring physician based on shoulder pain with progressive restriction of both active and passive range of motion were included. Patients with a previous history of surgical intervention involving the affected shoulder, documented major shoulder trauma such as fractures or full-thickness rotator cuff tears that could confound imaging findings, contraindications to MRI, including non-MRI-compatible pacemakers, claustrophobia, or incompatible metallic implants, and those unwilling or unable to provide written informed consent were excluded.

Two screened/enrolled patients were subsequently excluded because complete imaging data required for comparison between USG and MRI were unavailable. These exclusions were made before the final comparative analysis. The final analytical cohort therefore comprised 35 participants.

Imaging protocol and study parameters

After obtaining written informed consent, each participant underwent high-resolution USG of the affected

shoulder followed by MRI, preferably on the same day to minimize temporal variation between the two imaging examinations. USG was performed using a Philips ultrasound system (Philips Healthcare, Bothell, WA, USA) equipped with a 5-12 MHz linear-array transducer. The patient was examined in a seated position on a rotating stool. A systematic examination was performed in multiple positions to assess the long head of the biceps tendon, subscapularis, supraspinatus, infraspinatus, glenoid labrum, and AR capsule. The shoulder was abducted and externally rotated for assessment of the AR capsule, and dynamic assessment was also performed during abduction and adduction [13]. The AR capsule was assessed at the level of the inferior glenohumeral joint, with the measurement obtained at the point of maximum capsular thickness. The CHL was assessed in the RI region, and its maximum visible thickness was measured. The same anatomical landmarks and measurement approach were used consistently for all participants.

MRI was performed using a Siemens Magnetom 1.5-Tesla MRI system (Siemens Healthineers, Erlangen, Germany) with a dedicated shoulder surface coil. No intravenous contrast was administered. Images were acquired with a 3-mm section thickness. The MRI protocol included oblique coronal proton-density fat-suppressed (PD-FS), oblique coronal T1-weighted, oblique sagittal PD-FS, and axial PD-FS sequences. CHL thickness was measured on the oblique sagittal PD-FS images at the point of maximum visible ligament thickness. AR capsule thickness was measured on the oblique coronal PD-FS images at the thickest portion of the AR capsule, with the measurement performed perpendicular to the adjacent humeral cortex. The principal imaging parameters evaluated on both modalities were CHL thickness, AR capsule thickness, RI soft-tissue abnormality, and joint capsule thickening [14]. CHL and AR thicknesses were measured in millimetres, whereas RI soft-tissue abnormality and joint capsule thickening were recorded as present or absent. For categorical analysis, a CHL thickness ⩾2.2 mm and an AR capsule thickness ⩾3.0 mm were considered positive findings, whereas values below these respective thresholds were considered negative. The cut-off values were selected on the basis of previously published imaging criteria [12,14].

Demographic and clinical characteristics, including age, sex, diabetes mellitus, and other relevant comorbidities, were recorded. Quantitative and qualitative imaging findings were also documented. The sonographic examination and initial measurements were performed by the principal investigator, who recorded the USG findings before review of the MRI images. MRI images were subsequently interpreted independently by the radiologist, with the MRI interpreter blinded to the specific USG measurements and qualitative findings wherever feasible. The USG and MRI findings were subsequently correlated for the final analysis. Participants with incomplete imaging data were excluded from the final analysis. Imaging-detected full-thickness rotator cuff tears were considered potential confounding findings and were excluded according to the predefined eligibility criteria. The participant selection and imaging workflow are shown in Figure *1*.

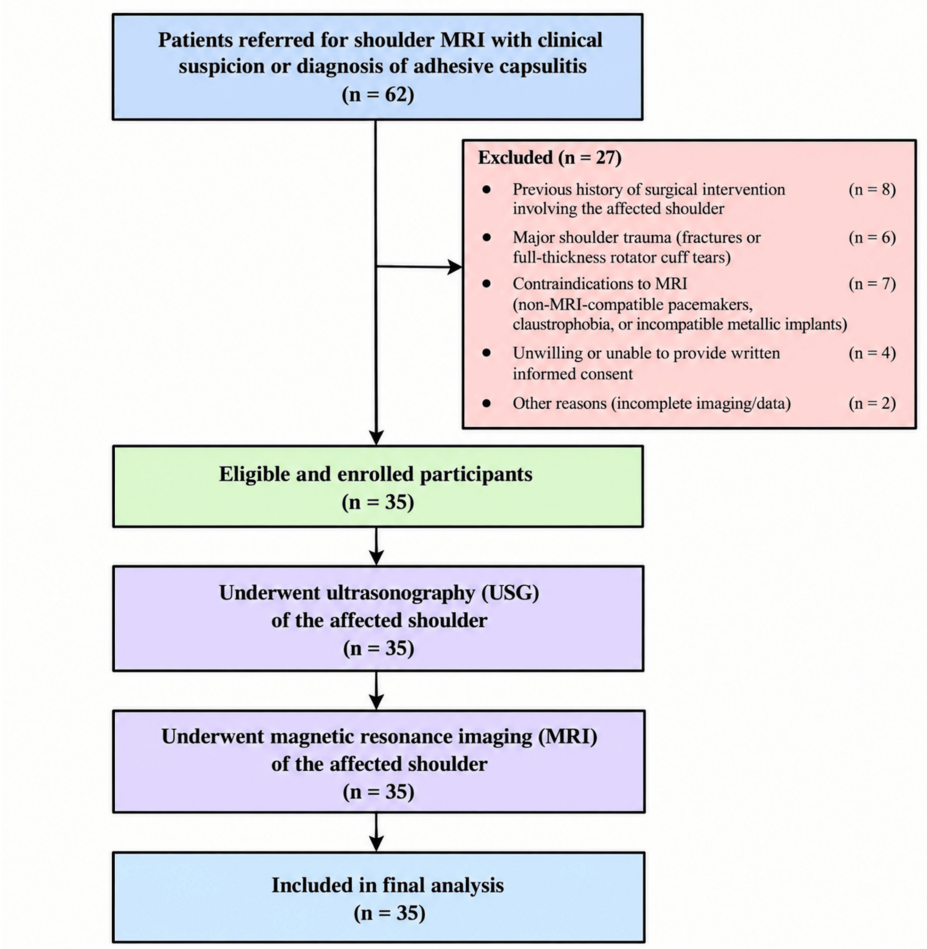


FIGURE 1: Participant Flow Chart

Statistical analysis

Data were entered into a Microsoft Excel spreadsheet (Microsoft Corporation, Redmond, WA, USA) and analysed using IBM SPSS Statistics for Windows, Version 26.0 (Released 2018; IBM Corp., Armonk, NY, USA). Categorical variables were summarized as frequencies and percentages, while continuous variables were expressed as mean ± standard deviation (SD). The quantitative measurements of CHL and AR capsule thickness obtained by USG and MRI were compared using Pearson's correlation coefficient. Correlation coefficients were interpreted as weak (0.00-0.39), moderate (0.40-0.69), and strong (0.70-1.00), with positive values indicating a positive correlation and negative values indicating an inverse correlation. Because correlation assesses the strength of association rather than interchangeability between two measurement methods, the results were interpreted as correlation between USG and MRI measurements rather than as evidence of agreement. Diagnostic performance of USG was assessed using MRI as the reference standard, with calculation of sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and diagnostic accuracy. Receiver operating characteristic (ROC) curve analysis was performed to assess the discriminatory performance of quantitative USG measurements and to identify optimal cutoff values. Agreement between qualitative USG and MRI findings was assessed using observed agreement and Cohen's kappa coefficient. The strength of agreement was interpreted as slight (κ = 0.00-0.20), fair (κ = 0.21-0.40), moderate (κ = 0.41-0.60), substantial (κ = 0.61-0.80), and almost perfect (κ = 0.81-1.00). A p-value <0.05 was considered statistically significant.

Results

The study included 35 participants, with the largest proportion aged 51-60 years (13 (37.1%)), followed by 41-50 years (11 (31.4%)) and 61-70 years (7 (20.0%)). Females constituted the majority of the study population (24 (68.6%)), while males accounted for 11 (31.4%). Diabetes mellitus was present in 8 (22.9%) participants. The right shoulder was more frequently affected (25 (71.4%)) than the left shoulder (10 (28.6%)). Regarding symptom duration, 11 (31.4%) participants had symptoms for 4-8 weeks, followed by 9 (25.7%) with symptoms for 12 weeks, and 7 (20.0%) for 8-12 weeks (Table *1*).

Variable	Category	n (%)
Age group (years)	31-40	4 (11.4%)
	41-50	11 (31.4%)
	51-60	13 (37.1%)
	61-70	7 (20.0%)
Gender	Female	24 (68.6%)
	Male	11 (31.4%)
Diabetes mellitus	Yes	8 (22.9%)
Affected shoulder	Right	25 (71.4%)
	Left	10 (28.6%)
Duration of symptoms	<4 weeks	9 (25.7%)
	4-8 weeks	11 (31.4%)
	8-12 weeks	7 (20.0%)
	>12 weeks	8 (22.9%)

TABLE 1: Demographic and Clinical Characteristics of the Study Population (N=35)

Data are presented as frequencies and percentages (n (%)).

USG, ultrasonography; MRI, magnetic resonance imaging

MRI classified adhesive capsulitis in 26 (74.3%) participants, while 9 (25.7%) were MRI-negative. RI soft-tissue abnormality was identified in 27 (77.1%), while joint capsule thickening was observed in 24 (68.6%) participants. The nine MRI-negative participants were retained as the reference-negative group for assessment of the diagnostic performance of USG (Table *2*).

Variable	Category	n (%)
MRI diagnosis of adhesive capsulitis	Positive	26 (74.3%)
Rotator interval soft-tissue abnormality	Present	27 (77.1%)
Joint capsule thickening	Present	24 (68.6%)

TABLE 2: MRI Diagnosis of Adhesive Capsulitis and MRI Qualitative Findings (N=35)

Data are presented as frequencies and percentages (n (%)).

MRI, magnetic resonance imaging

On USG, CHL thickness was ⩾2.2 mm in 24 (68.6%) participants and <2.2 mm in 11 (31.4%), with a mean thickness of 2.33 ± 0.79 mm and a range of 0.8-3.5 mm. AR thickness was ⩾3.0 mm in 24 (68.6%) and <3.0 mm in 11 (31.4%), with a mean thickness of 3.33 ± 1.13 mm and a range of 1.4-5.2 mm. RI soft-tissue abnormality and joint capsule thickening were observed in 26 (74.3%) and 25 (71.4%) participants, respectively (Table *3*).

Ultrasonographic parameter	Category	n (%) / Mean ± SD
CHL thickness	Mean ± SD	2.33 ± 0.79 mm
AR thickness	Mean ± SD	3.33 ± 1.13 mm
Rotator interval soft-tissue abnormality	Present	26 (74.3%)
Joint capsule thickening	Present	25 (71.4%)

TABLE 3: Ultrasonographic Measurements and Qualitative Findings (N=35)

Data are presented as frequencies and percentages (n (%)) for categorical variables and mean ± SD for continuous variables.

USG, ultrasonography; CHL, coracohumeral ligament; AR, axillary recess; SD, standard deviation

Participants with MRI-classified positive adhesive capsulitis demonstrated greater mean CHL and AR thicknesses than those with MRI-negative classification. Mean CHL thickness was 2.73 ± 0.41 mm in the MRI-positive group compared with 1.20 ± 0.42 mm in the MRI-negative group, while mean AR thickness was 3.87 ± 0.69 mm and 1.77 ± 0.50 mm, respectively (Table *4* and Figure *2*).

Parameter	MRI-positive (n=26)	MRI-negative (n=9)
CHL thickness (mm)	2.73 ± 0.41	1.20 ± 0.42
AR thickness (mm)	3.87 ± 0.69	1.77 ± 0.50

TABLE 4: Ultrasonographic Measurements According to MRI Diagnosis

Data are presented as mean ± SD.

MRI, magnetic resonance imaging; CHL, coracohumeral ligament; AR, axillary recess; SD, standard deviation

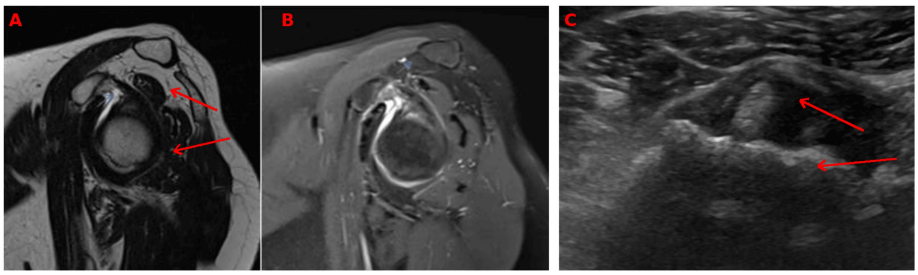


FIGURE 2: Representative MRI and Ultrasonography Findings in Adhesive Capsulitis

(A) MRI image demonstrating thickening of the CHL with associated soft-tissue abnormality in the rotator interval. (B) MRI image showing corresponding abnormality involving the CHL and rotator interval. (C) Ultrasonography image demonstrating thickened CHL with ill-defined hypoechoic soft tissue within the rotator interval. Arrows indicate the areas of CHL thickening and rotator interval soft-tissue abnormality.

MRI, magnetic resonance imaging; CHL, coracohumeral ligament

A strong positive correlation was observed between ultrasonographic and MRI measurements of CHL thickness (Pearson's r=0.861, 95% CI: 0.740-0.928; R^2=0.741). AR thickness demonstrated a strong positive correlation between USG and MRI (Pearson's r=0.931, 95% CI: 0.866-0.965; R^2=0.866). These findings indicate a strong association between the measurements obtained by the two modalities and should not be interpreted as evidence of direct measurement interchangeability (Table *5*).

Parameter	Pearson's r	95% CI	R^2	Interpretation
CHL thickness	0.861	0.740-0.928	0.741	Strong positive correlation
AR thickness	0.931	0.866-0.965	0.866	Very strong positive correlation

TABLE 5: Correlation Between Ultrasonographic and MRI Measurements

Data are presented as Pearson's correlation coefficient (r), 95% CI, coefficient of determination (R^2), and qualitative interpretation of correlation strength. Pearson's correlation was used to assess association between ultrasonographic and MRI measurements; it was not used as a measure of agreement or interchangeability.

MRI, magnetic resonance imaging; CHL, coracohumeral ligament; AR, axillary recess; CI, confidence interval

ROC curve analysis demonstrated high discriminatory performance for both ultrasonographic measurements. CHL thickness had an area under the curve (AUC) of 0.987 (95% CI: 0.958-1.000), with an exploratory ROC-derived optimal cutoff of 1.6 mm yielding 100.0% sensitivity and 88.9% specificity. Similarly, AR thickness demonstrated an AUC of 0.987 (95% CI: 0.958-1.000), with an exploratory ROC-derived optimal cutoff of 2.2 mm, yielding 100.0% sensitivity and 88.9% specificity. These ROC-derived thresholds were obtained from the present study dataset and should therefore be considered exploratory rather than independently validated diagnostic thresholds (Table *6*).

Parameter	AUC	95% CI	Optimal cutoff	Sensitivity (%)	Specificity (%)
CHL thickness	0.987	0.958-1.000	1.6 mm	100.0	88.9
AR thickness	0.987	0.958-1.000	2.2 mm	100.0	88.9

TABLE 6: ROC Curve Analysis of Ultrasonographic Measurements

Data are presented as AUC, 95% CI, ROC-derived optimal cutoff value, sensitivity, and specificity. ROC curve analysis was performed to assess the discriminatory ability of ultrasonographic CHL and AR thickness measurements using MRI classification as the reference classification. The ROC-derived cutoffs were exploratory and were not independently validated.

ROC, receiver operating characteristic; AUC, area under the curve; CI, confidence interval; CHL, coracohumeral ligament; AR, axillary recess; MRI, magnetic resonance imaging

Using MRI classification as the reference classification, CHL thickness ≥2.2 mm and AR ≥3.0 mm each demonstrated 88.5% sensitivity, 88.9% specificity, 95.8% PPV, 72.7% NPV, and 88.6% diagnostic accuracy. RI soft-tissue abnormality showed 96.2% sensitivity, 88.9% specificity, 96.2% PPV, 88.9% NPV, and 94.3% accuracy. Joint capsule thickening demonstrated 92.3% sensitivity, 88.9% specificity, 96.0% PPV, 80.0% NPV, and 91.4% accuracy. The presence of ≥2 positive ultrasonographic parameters, evaluated as an exploratory combined rule, provided the highest observed diagnostic performance, with 96.2% sensitivity, 100.0% specificity, 100.0% PPV, 90.0% NPV, and 97.1% accuracy. Because this combined rule was derived and evaluated within the same study cohort, these estimates should be considered exploratory and require validation in an independent population (Table *7*).

Ultrasonographic parameter	Sensitivity	Specificity	PPV	NPV	Accuracy
CHL ≥2.2 mm	88.5%	88.9%	95.8%	72.7%	88.6%
AR ≥3.0 mm	88.5%	88.9%	95.8%	72.7%	88.6%
Rotator interval soft-tissue abnormality	96.2%	88.9%	96.2%	88.9%	94.3%
Joint capsule thickening	92.3%	88.9%	96.0%	80.0%	91.4%
≥2 positive USG parameters	96.2%	100.0%	100.0%	90.0%	97.1%

TABLE 7: Diagnostic Accuracy of Ultrasonographic Findings for Adhesive Capsulitis

Data are presented as percentages. Diagnostic performance was assessed using MRI classification as the reference classification, with calculation of sensitivity, specificity, PPV, NPV, and overall diagnostic accuracy. Categorical findings were evaluated using 2 × 2 contingency tables. The reported diagnostic performance therefore represents agreement of USG findings with the MRI-based classification rather than definitive diagnostic accuracy against an independent gold standard.

USG, ultrasonography; MRI, magnetic resonance imaging; PPV, positive predictive value; NPV, negative predictive value; CHL, coracohumeral ligament; AR, axillary recess

Agreement between USG and MRI was substantial for both qualitative findings. RI soft-tissue abnormality demonstrated 91.4% observed agreement with a Cohen's κ of 0.767, while joint capsule thickening demonstrated 85.7% observed agreement with a Cohen's κ of 0.660. These findings indicate substantial categorical agreement between the two imaging modalities for the qualitative parameters assessed (Table *8*).

Finding	Observed agreement	Cohen's κ	Interpretation
Rotator interval soft-tissue abnormality	91.4%	0.767	Substantial agreement
Joint capsule thickening	85.7%	0.660	Substantial agreement

TABLE 8: Agreement Between USG and MRI

Data are presented as observed percentage agreement and Cohen's kappa (κ) coefficient. Agreement between USG and MRI qualitative findings was assessed using Cohen's kappa statistic.

USG, ultrasonography; MRI, magnetic resonance imaging; κ, Cohen's kappa coefficient

Discussion

The present study demonstrated that USG showed good observed diagnostic performance for identifying MRI-classified adhesive capsulitis when MRI was used as the reference classification. For CHL thickness, a cutoff of ⩾2.2 mm yielded a sensitivity of 88.5%, specificity of 88.9%, PPV of 95.8%, NPV of 72.7%, and overall diagnostic accuracy of 88.6%. These findings support CHL thickening as an important sonographic marker of adhesive capsulitis. In comparison, Do et al. reported that a CHL cutoff of 2.2 mm provided 77% sensitivity and 91.8% specificity, showing comparable specificity but somewhat lower sensitivity than the present study [12]. Rilshad et al. reported an optimal CHL cutoff of 1.8 mm with 92.72% sensitivity and 98.4% specificity, indicating that differences in threshold selection and study population may influence diagnostic performance [15]. Tandon et al. also demonstrated that CHL thickness was significantly increased in adhesive capsulitis and that sonographic assessment using multiple parameters could achieve high diagnostic accuracy [16]. Thus, the present findings are consistent with previous evidence supporting CHL thickening as a useful sonographic parameter for the assessment of adhesive capsulitis, although differences in diagnostic thresholds and study populations should be considered when interpreting these results.

The AR demonstrated a particularly strong association between USG and MRI in the present study, with a Pearson correlation coefficient of $r = 0.931$ ($p < 0.001$). This strong correlation indicates that the two modalities showed a similar linear pattern of AR measurements; however, correlation alone does not establish agreement or interchangeability between the methods. Do et al. reported that AR thickness was significantly increased in adhesive capsulitis and proposed a 4-mm cutoff, with 68.9% sensitivity and 90.2% specificity [12]. Similarly, a dedicated ultrasound-MRI correlation study by Kim et al. demonstrated a significant correlation between ultrasound-measured AR capsule thickness and MRI measurements ($r = 0.83$, $p < 0.001$), supporting the ability of ultrasound to reflect MRI-detected capsular pathology [17]. Suh et

al., in a systematic review and meta-analysis of MRI findings, identified axillary joint capsule enhancement among the most diagnostically informative MRI features of adhesive capsulitis, further emphasizing the importance of axillary capsular abnormalities [14]. The strong correlation observed in the present study therefore supports the potential utility of AR thickness as a quantitative sonographic marker, while further agreement studies are required to establish whether ultrasound measurements can be used interchangeably with MRI measurements.

The qualitative parameters also showed substantial agreement between ultrasound and MRI. RI soft-tissue abnormality demonstrated a Cohen's kappa of 0.767, while joint capsule thickening demonstrated a kappa of 0.660, indicating substantial agreement beyond chance. These findings are consistent with the established importance of the RI and capsuloligamentous structures in adhesive capsulitis. Tandon et al. reported increased soft tissue within the RI as a sensitive and specific sonographic finding, with sensitivity of 86.2% and specificity of 92.8% [16]. In another study, Rilshad et al. reported RI soft-tissue abnormality with 69.09% sensitivity and 91.2% specificity [15]. The MRI meta-analysis by Suh et al. similarly identified RI fat obliteration and enhancement, along with inferior glenohumeral ligament abnormalities, as important MRI features for diagnosis [14]. The substantial agreement demonstrated in the present study therefore supports the ability of USG to identify qualitative structural abnormalities in the RI and joint capsule that correspond to MRI-classified findings.

Importantly, the present study demonstrated that a combined ultrasound approach provided higher observed diagnostic performance compared with individual parameters. When two or more sonographic criteria were present, the overall diagnostic accuracy was 97.1%, with 96.2% sensitivity, 100% specificity, 100% PPV, and 90.0% NPV. However, this composite rule was derived and evaluated within the same small study cohort and was not independently validated; consequently, its performance should be regarded as exploratory and should not be interpreted as evidence of a validated diagnostic algorithm. Tandon et al. similarly reported that combining multiple static and dynamic sonographic parameters substantially improved diagnostic performance, achieving 100% sensitivity and 87% specificity [16]. Rilshad et al. reported a combined ultrasound sensitivity of 98.18% and specificity of 91.2%, further supporting the potential value of a multi-parameter approach [15]. The present findings, together with the high ROC performance observed for CHL and AR thickness (AUC = 0.987 for both), suggest that a structured multi-parameter ultrasound assessment may have potential clinical utility. However, given the small sample size, single-centre design, use of MRI as the reference classification, and lack of independent validation, these findings should be considered preliminary and require confirmation in larger, prospective multicentre studies.

Strengths and limitations

The strengths of the present study include its prospective comparative diagnostic design, consecutive sampling, assessment of all participants using both USG and MRI, and within-subject comparison of quantitative and qualitative imaging parameters. The study evaluated multiple imaging markers, including CHL thickness, AR thickness, RI abnormalities, and joint capsule thickening, and incorporated correlation, ROC analysis, diagnostic performance, and inter-modality agreement measures. However, the study has several limitations. The sample size was relatively small (n = 35), and the sample-size calculation was based on the precision of mean AR capsule thickness rather than a prespecified diagnostic-accuracy endpoint; therefore, the diagnostic performance estimates, particularly those based on the nine MRI-negative participants, should be considered exploratory. The single-centre design may limit generalizability. USG assessment was performed by a single principal investigator, and inter-operator reproducibility was not assessed. Disease-stage-specific analysis and longitudinal follow-up were not performed. MRI without intravenous contrast was used as the reference classification; however, adhesive capsulitis is primarily a clinical diagnosis, and MRI is not an absolute gold standard. Enhancement-based MRI features described in previous literature could not be assessed with the non-contrast protocol used in this study. Accordingly, the findings should be interpreted as the concordance of ultrasound with MRI-based classification rather than definitive diagnostic accuracy against an independent gold standard. Finally, the combined ultrasound rule based on ≥2 positive parameters was derived and evaluated in the same cohort and was not independently validated; its performance should therefore be considered exploratory.

Conclusions

The present study demonstrates that USG provides useful diagnostic information in the evaluation of adhesive capsulitis, with good observed correlation and agreement with MRI-based findings for quantitative and qualitative imaging parameters. Assessment of the CHL, AR, RI, and joint capsule provided complementary diagnostic information, while a combined assessment of multiple sonographic features showed higher observed diagnostic performance than individual parameters. Therefore, structured USG may have potential as a practical first-line imaging modality for suspected adhesive capsulitis. However, given the small sample size, single-centre design, use of MRI as the reference classification, and lack of independent validation of the combined ultrasound criteria, these findings should be considered preliminary and require confirmation in larger, multicentre prospective studies.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Acquisition, analysis, or interpretation of data: Swara BS, Suresh A, Aditi Nadamani, Mounika Malreddygari

Drafting of the manuscript: Swara BS, Suresh A, Aditi Nadamani, Mounika Malreddygari

Critical review of the manuscript for important intellectual content: Swara BS, Suresh A, Aditi Nadamani, Mounika Malreddygari

Disclosures

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