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ORIGINAL RESEARCH

Diagnostic Value of Superb Microvascular Imaging of the Rotator Cuff Interval for the Early Diagnosis of Frozen Shoulder

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Purpose: To explore the early diagnostic value of superb microvascular imaging (SMI) features within the rotator cuff gap for frozen shoulder.
Patients and Methods: This prospective study enrolled patients with acute early-stage frozen shoulder seeking treatment at Zhabei Central Hospital in Jing'an District, Shanghai, between July 2021 and December 2022 were enrolled in this study. Healthy controls were collected in a 1:1 ratio from the same hospital's physical examination center. All participants underwent SMI and power Doppler ultrasound (PDUS) of the rotator cuff gap.
Results: The study included 79 patients with frozen shoulder and 77 healthy controls. Compared with the healthy control group, the patient group had a higher proportion of hypoechoic rotator cuff gap (81.0% vs 48.1%, P<0.001), a thicker coracohumeral ligament (2.60±1.01 vs 2.03±0.97, P<0.001), a thicker glenohumeral joint capsule (3.10±0.99 vs 2.46±1.17, P<0.001), and elevated blood grading using SMI (P<0.001) and PDUS (P=0.014). The highest area under the curve (AUC) was observed for SMI blood flow grading (AUC=0.824, 95% CI: 0.755–0.880, P<0.001), resulting in 82% sensitivity and 77% specificity when using a cutoff of 1. SMI blood flow grading was associated with external rotation <30° (P=0.007) and abduction <30° (P=0.013) but not with internal rotation <30° (P=0.630) or flexion <30° (P=0.562).
Conclusion: The grading of SMI blood flow may emerge as a valuable predictive indicator for the early stages of frozen shoulder. This simple ultrasound technique holds the potential to enhance the diagnostic process, enabling early initiation of treatment and potentially improving patient outcomes.
Keywords: adhesive capsulitis of the shoulder, microcirculation, ultrasonography, early diagnosis, predictive value

Introduction

Frozen shoulder, also known as adhesive capsulitis of the shoulder, is a debilitating condition characterized by the development of excessive scar tissue or adhesions within the glenohumeral joint capsule, leading to stiffness, severe pain, and restricted passive and active range of motion in the shoulder.[1–4] The prevalence of frozen shoulder is 2%-5% in the general population,[3,4] 5%-11% after shoulder surgery,[4] about 10 after breast cancer surgery,[4] and 10%-20% of patients with diabetes (type 1 or 2).[2] While a frozen shoulder typically resolves on its own within 1–3 years, it can persist long-term in 20%-50% of patients. Early diagnosis and intervention are crucial, as they can significantly alleviate shoulder pain, enhance joint mobility, expedite recovery, and reduce the overall burden of the disease.[4,5]

A primary pathological mechanism appears to center around chronic inflammatory reactions and fibrosis affecting various tissues, including shoulder muscles, ligaments, tendons, synovial sacs, and joint capsules.[6] These early pathophysiological changes are associated with angiogenesis and vascular endothelial growth factor in these structures, with angiogenesis preceding both organic and functional alterations.[7,8] Furthermore, vascular abnormalities have been linked to increased adjacent nerve abnormalities.[9] As a result, early changes in local blood flow due to inflammatory reactions could be early events in the pathogenesis of frozen shoulder. The rotator cuff gap is located between the supraspinatus and subscapularis and is a crucial

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structure for maintaining shoulder joint stability. Frozen shoulder often involves the rotator cuff gap and surrounding soft tissues early in the disease, leading to corresponding pathological changes captured by imaging techniques.[10]

Among these imaging techniques, ultrasound provides real-time dynamic examination with high soft tissue resolution. Color Doppler ultrasound (CDFI) and power Doppler ultrasound (PDUS) hold diagnostic values for frozen shoulder by detecting increased blood flow in the rotator cuff gap and subacromial fat triangle, early features of the condition.[11–13] However, the shallow location of these anatomical structures and the prevalence of low-velocity microvascular blood supply limit the blood flow display rates of CDFI and PDUS. Superb microvascular imaging (SMI) represents an innovative ultrasound blood flow imaging technique that effectively distinguishes blood flow signals from tissue motion artifacts, enabling the visualization of extremely low flow microvessels without the need for contrast agents.[14,15] While research has extensively explored SMI in conditions associated with angiogenesis, such as breast cancer,[16] rheumatoid arthritis,[17] and thyroid nodules,[18] the application of SMI in the context of the frozen shoulder has been notably limited. Only two studies, conducted in South Korea and Singapore, have investigated the use of SMI in frozen shoulder and exhibited superior diagnostic value for frozen shoulder compared to CDFI and PDUS.[19,20] Despite the promising findings, both studies had limited sample sizes, and research on SMI in the context of frozen shoulder remains scarce.

Therefore, this study aimed to explore the early diagnostic value of SMI features within the rotator cuff gap for frozen shoulder. We hypothesized that SMI could be used to diagnose frozen shoulder, even in its early stages.

Materials and Methods

Study Design and Participants

This prospective study enrolled patients with acute early-stage frozen shoulder who sought treatment at Zhabei Central Hospital in Jing'an District, Shanghai, between July 2021 and December 2022. The healthy controls were enrolled from the same hospital at the physical examination center with a 1:1 ratio.

The diagnosis of frozen shoulder relied primarily on medical history and clinical presentation, characterized by progressive restrictions in both active and passive shoulder movements, accompanied by pain. Early cases were defined as those presenting symptoms for 1–3 months. Patients who were 30–75 years of age, complained of persistent shoulder pain with nocturnal exacerbation for 0–3 months, and displayed multi-directional restrictions in both active and passive shoulder movements were enrolled. Patients with shoulder joint trauma or surgery within the past 6 months, those with bilateral shoulder movement restrictions or pain, or patients with a history of rotator cuff tear, rheumatoid arthritis, or previous frozen shoulder were excluded. Healthy controls of 30–75 years of age and without frozen shoulder diagnosis at physical examination were enrolled. The exclusion criteria were the same with frozen shoulder patients.

This study adhered to the principles outlined in the Declaration of Helsinki, and was approved by the ethics committee of Zhabei Central Hospital in Jing'an District, Shanghai (ZBLL2022020904). All participants provided signed informed consent.

Procedure

The participants' demographic and clinical data were retrieved from the electronic patient chart, including demographic data (age, sex, height, and weight), current medical history (symptoms related to frozen shoulder and treatment history), past medical history (comorbidities such as diabetes, hypertension, and hyperlipidemia), and medication history. The pain intensity was evaluated using the visual analogue scale (VAS).

Two attending physicians, each with over 10 years of experience in ultrasound, conducted shoulder joint range of motion (external rotation, internal rotation, abduction, and flexion) examinations on the enrolled study population using a standard goniometer for measurement and evaluation. The intraclass correlation coefficient (ICC) was determined between the two physicians.

A Toshiba Aplio 400 color Doppler ultrasound diagnostic apparatus with a probe frequency of 14 MHz was used for SMI. The participants assumed a seated position with the shoulder joint in a neutral position. The probe was obliquely oriented to display the rotator cuff gap between the supraspinatus and subscapularis. The echogenicity of the rotator cuff gap was assessed. Subsequently, the shoulder joint was externally rotated, placing the probe on the lateral aspect of the acromion to visualize the coracohumeral ligament and measure its maximum thickness (Figure 1).

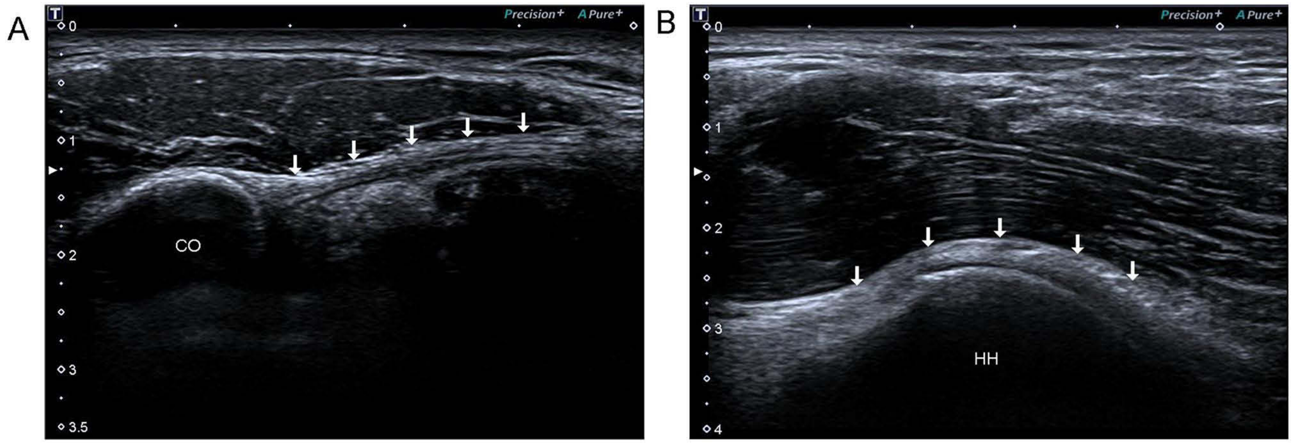

Figure 1 Measurement of coracohumeral ligament and capsule thickness. (**A**) Coracohumeral ligament. The arrow indicated coracohumeral ligament; (**B**) Glenohumeral joint capsule. The arrow indicated glenohumeral joint capsule.
Abbreviations: CO, coracoid; HH, head of humerus.

Blood flow information was collected in the rotator cuff gap using SMI and PDUS. For SMI, the image depth range in B-mode was 3 cm, with a fixed-size (1.5x1 cm) region of interest (ROI) box used for SMI to maintain a high frame rate of over 50 frames per second. The velocity range was less than 2.5 cm/s, the SMI frequency was 7 MHz, low-grade filter levels were applied, and maximum SMI gain was achieved before the occurrence of background color aliasing. The PDUS examination was performed at the same level, with the color velocity range adjusted to less than 2.5 cm/s, color frequency set at 7 MHz, and gain adjusted just below the level of aliasing. The blood flow signals were graded on a scale of 0–3: 0: no blood flow signals in the rotator cuff gap (Figure 2A); Grade I: one or two dot-like blood flow signals visible in the rotator cuff gap (Figure 2B); Grade II: three or four short linear blood flow signals visible in the rotator cuff gap, not exceeding 50% of the gap (Figure 2C); Grade III: branching or mesh-like blood flow signals visible in the rotator cuff gap, exceeding 50% of the gap (Figure 2D).[19]

Sample Size Calculation

The sample size for this study was calculated using the following formula:

Where N represents the sample size per group, α=0.05, δ=0.1, $Z_{1-\alpha/2}$=1.96, and p represents the estimated sensitivity or specificity of the diagnostic test. In this study, the estimated sensitivity was approximately 0.90, and the specificity was approximately 0.80. Therefore, the required sample size was 62 participants per group. Considering potential data invalidity during sample collection, it was anticipated to collect at least 70 participants in each group.

Statistical Analysis

SPSS 26.0 (IBM, Armonk, NY, USA) was used for statistical analysis. The categorical data were presented as n (%) and analyzed using the chi-square test. The continuous data were tested for normality using the Shapiro–Wilk test. The continuous data with a normal distribution were presented as means ± standard deviations (SD) and analyzed using the independent samples *t*-test. The continuous data with a skewed distribution were presented as medians (ranges) and analyzed using the Mann–Whitney *U*-test. Receiver operating characteristics (ROC) curve analysis was conducted using MedCalc (MedCalc Software bvba, Ostend, Belgium). Two-sided P <0.05 were considered statistically significant.

Results

Characteristics of the Participants

The study enrolled 79 patients with frozen shoulder and 77 healthy controls. There were no significant differences in sex, hypertension, diabetes, medication and rehabilitation history, body mass index (BMI), age, height, and weight between the two groups (all P>0.05). Compared with the healthy controls, the patients had a higher frequency of thyroid diseases (19.0% vs 5.2%, P=0.008) and higher pain scores (6.00±2.00 vs 1.00±0.00, P<0.001) (Table 1).

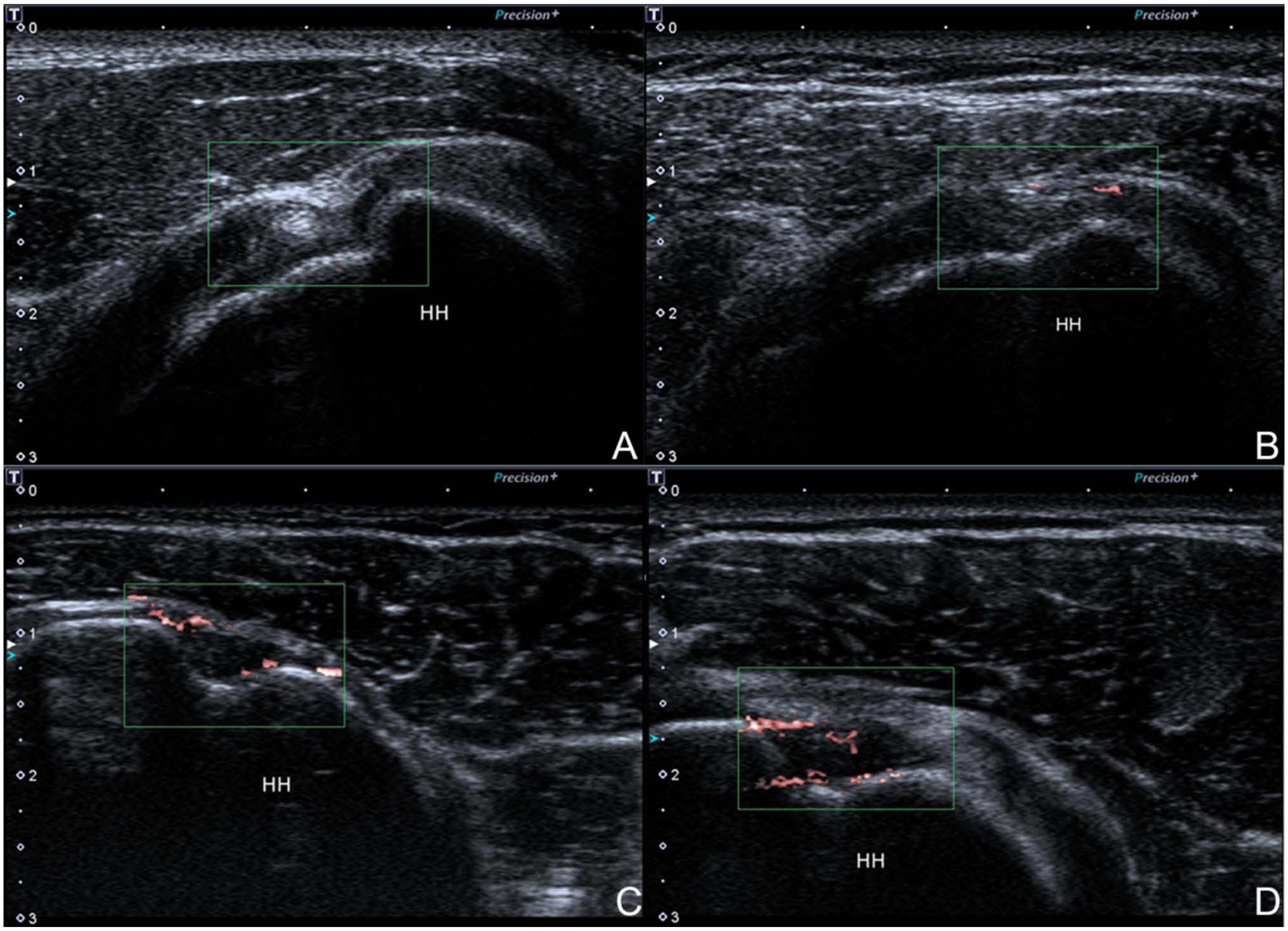

Figure 2 The blood flow signals. (**A**) Grade 0: no blood flow signals; (**B**) Grade 1: one or two dot-like blood flow signals; (**C**) Grade 2: three or four short linear blood flow signals; (**D**) Grade 3: branching or mesh-like blood flow signals.

Ultrasound Characteristics

The ICC between the two physicians was 0.906. Compared with the healthy control group, the patient group had a higher proportion of hypoechoic rotator cuff gap (81.0% vs 48.1%, P<0.001), a thicker coracohumeral ligament (2.60±1.01 vs 2.03±0.97, P<0.001), a thicker glenohumeral joint capsule (3.10±0.99 vs 2.46±1.17, P<0.001), and a higher blood grading using SMI (P<0.001) and PDUS (P=0.014) (Table 2).

Receiver Operating Characteristics Analysis

The highest area under the curve (AUC) was observed for SMI blood flow grading (AUC=0.824, 95% CI: 0.755–0.880), resulting in 82% sensitivity and 77% specificity when using a cutoff of 1. The DeLong test indicated the SMI blood flow grading had superior diagnostic value compared to other characteristics (all P<0.05): hypoechoic rotator cuff gap (AUC=0.665), glenohumeral joint capsule thickness (AUC=0.651), coracohumeral ligament thickness (AUC=0.643), and PDUS blood flow grading (AUC=0.600) (Table 3 and Figure 3).

Association Between SMI and Clinical Features

As shown in Table 4, the SMI blood flow grading was associated with external rotation <30° (P=0.007) and abduction <30° (P=0.013) but not with internal rotation <30° (P=0.630) or flexion <30° (P=0.562).

Table 1 Characteristics of the Patients

Characteristics	Healthy Controls (n=77)	Patients (n=79)	P
Sex			0.432
Male	42 (54.5)	48 (60.8)	
Female	35 (45.5)	31 (39.2)	
Hypertension	6 (7.8)	13 (16.5)	0.098
Diabetes	2 (2.6)	4 (5.1)	0.423
Thyroid Disease	4 (5.2)	15 (19.0)	0.008
Medication and Rehab history	0 (0.0)	3 (3.8)	0.084
BMI			0.789
Underweight	5 (31.3)	11 (68.8)	
Normal	49 (57.6)	36 (42.4)	
Overweight	13 (34.2)	25 (65.8)	
Obese	9 (60)	6 (40)	
Age (years)	55.09±9.18	57.05±10.61	0.219
Height (cm)	167.50±9.86	169.26±8.85	0.242
Weight (Kg)	66.02±8.00	68.18±11.09	0.167
Pain score (points)	1.00±0.00	6.00±2.00	<0.001

Table 2 Ultrasound Feature Indicators Between the Two Groups

Characteristics	Healthy Controls (n=77)	Patients (n=79)	P
Rotator cuff gap hypoechoic	37 (48.1)	64 (81.0)	<0.001
Coracohumeral ligament thickness (mm)	2.03±0.97	2.60±1.01	<0.001
Glenohumeral joint capsule thickness (mm)	2.46±1.17	3.10±0.99	<0.001
SMI blood flow grading			<0.001
0	0 (0.0)	0 (0.0)	
1	59 (76.6)	14 (17.7)	
2	18 (23.4)	45 (57.0)	
3	0 (0)	20 (25.3)	
PDUS blood flow grading			0.014
0	10 (13)	7 (8.9)	
1	50 (64.9)	40 (50.6)	
2	17 (22.1)	29 (36.7)	
3	0 (0)	3 (3.8)	

Abbreviations: SMI: superb microvascular imaging; PDUS: power Doppler ultrasound.

Table 3 ROC Analysis

Test Result Variable	AUC	Standard error	P	95% CI	Youden index	Cutoff	Sensitivity (%)	Specificity (%)	DeLong test (vs SMI)
SMI blood flow grading	0.824	0.0338	<0.0001	0.755–0.880	0.589	1	82.28	76.62	–
PDUS blood flow grading	0.600	0.0453	0.0265	0.519–0.678	0.184	1	40.51	77.92	<0.001
Rotator cuff gap hypoechoic	0.665	0.043	0.001	0.585–0.738	0.330	1	81.01	51.95	0.001
Coracohumeral ligament thickness	0.643	0.046	0.002	0.563–0.718	0.426	2.3	60.76	81.82	0.003
Glenohumeral joint capsule thickness	0.651	0.048	0.002	0.571–0.726	0.488	2.73	70.89	77.92	0.005

Discussion

This prospective study explored the early diagnostic value of SMI features in the rotator cuff gap for frozen shoulder. The Results indicate that the grading of SMI blood flow in the rotator cuff gap may serve as a predictive indicator for the

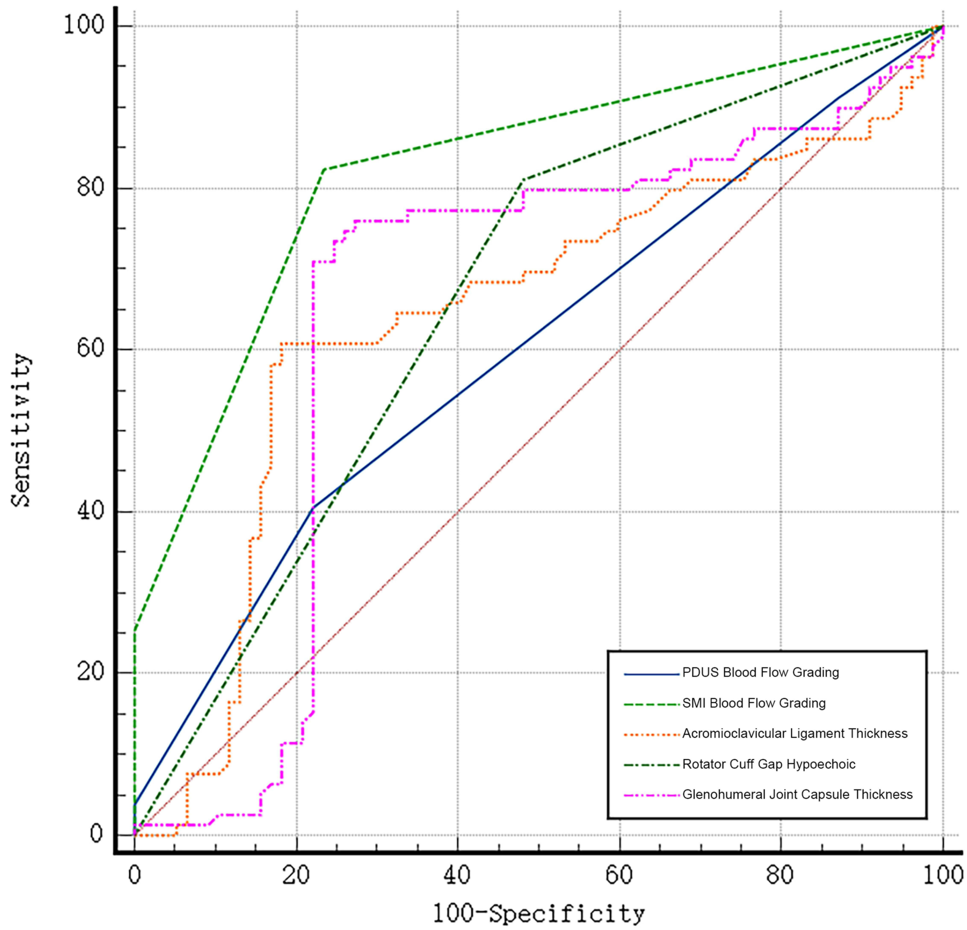

Figure 3 Receiver operating characteristics (ROC) curves for different features.

early stages of frozen shoulder. These findings offer compelling evidence supporting the application of SMI in the diagnosis of frozen shoulder. The integration of SMI into diagnostic protocols has the potential to facilitate the earlier identification of frozen shoulder, enabling prompt initiation of treatment and possibly improving prognosis.

Increased vascular responses are observed in rotator cuff tendinopathy, which has been hypothesized to result from microtrauma.[21,22] That increased microvessel density is considered to participate in the weakening of the mechanical properties of the tendons and other fibrous structures, predisposing them to degeneration.[22,23] Studies on frozen shoulder revealed higher vascularity using MRI,[12,24] arthroscopy,[25] histology,[8] and angiography.[7] Accordingly, in the present study, SMI and PDUS blood flow signals were higher in the patients with frozen shoulder than in healthy controls. Those results are supported by studies that reported higher neovascularization in symptomatic tendons than in asymptomatic ones.[26,27]

The present study is supported by previous ones that showed higher SMI signals than conventional Doppler ultrasound or PDUS in affected tendinous and fibrous structures.[19,28,29] Kim et al[19] showed that SMI was superior to

Table 4 Activity in the Patient Group in Relation to the SMI Blood Flow Grading

Activity	SMI Blood Flow Grading				P
	0 (n=0)	1 (n=14)	2 (n=45)	3 (n=20)	
External rotation <30° (n=65)	0 (0.0)	7 (10.6)	41 (62.1)	18 (27.3)	0.007
Internal rotation <30° (n=32)	0 (0.0)	3 (9.4)	22 (68.8)	7 (21.9)	0.630
Abduction <30° (n=61)	0 (0.0)	5 (8.2)	40 (65.6)	16 (26.2)	0.013
Flexion <30° (n=58)	0 (0.0)	10 (17.2)	35 (60.3)	13 (22.4)	0.562

PDUS in depicting blood flow in patients with frozen shoulder. Kim et al[19] also reported that SMI blood flow signals in patients with frozen shoulder correlated to the range of shoulder motion. In the present study, the SMI blood flow signals correlated to the external rotation <30° and abduction <30°, but not with internal rotation <30° or flexion <30°. Since SMI measures blood flow, it could be that specific movements block or impair blood flow from specific intraarticular sources. The findings need to be explained by further pathology or anatomy studies.

Previous studies reported changes like tendon thickening, hypoechogenicity, and/or heterogeneity between symptomatic and asymptomatic tendons using MRI and conventional ultrasound.[30,31] Cook & Purdam[32] and Abate et al[33] suggested that the progression of fibrous tissue diseases is a continuing process, progressing from asymptomatic to symptomatic conditions. All patients in the present study were with early frozen shoulder. Various indicators were tested, including SMI blood flow grading, hypoechoic rotator cuff gap, glenohumeral joint capsule thickness, coracohumeral ligament thickness, and PDUS blood flow grading. SMI blood flow grading displayed the highest AUC for early frozen shoulder diagnosis. The findings indicated although the initial signs of fibrous structure neovascularization and degeneration are usually asymptomatic,[34] they can be used for early diagnosis. Nevertheless, longitudinal studies of SMI in patients with frozen shoulder would be necessary to examine the changes in time.

This study had limitations. It was performed at a single center, limiting the generalizability of the conclusions. Only ultrasound was performed, and there were no comparisons with X-ray, CT, or MRI. A previous study showed that exercise could produce a vascular response in tendons,[35] and the dose-response between exercise and SMI signal in relation to frozen shoulder diagnosis is unknown. Even though good reliability in SMI assessment has been reported, it was not examined in the present study.[36,37] Prospective, multicenter, large-sample studies are needed to provide higher-level evidence.

Conclusion

In Conclusion, the grading of SMI blood flow in the rotator cuff gap may serve as a predictive indicator for the early stages of frozen shoulder. It is a simple ultrasound technique that could be used to improve the diagnosis of frozen shoulder and start treatments early.

Data Sharing Statement

All data generated or analyzed during this study are included in this published article.

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Disclosure

The authors report no conflicts of interest in this work.

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