

The value of percutaneous ultrasound-guided subacromial bursography in the diagnosis of rotator cuff tears

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Article

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Abstract

Purpose

To determine the feasibility and diagnostic value of percutaneous ultrasound-guided subacromial bursography (PUSB) in the diagnosis of rotator cuff tears.

Methods

Between July 2019 to October 2021, 78 patients who had suspected rotator cuff injury and who were admitted to the Second Affiliated Hospital of Xi'an Jiaotong University were selected, including 32 males and 46 females, aged 31–70 years (mean age 53.9 ± 9.1 years), with a course of 1D-2 years. The MRI, US and PUSB images of patients were retrospectively analyzed to obtain the diagnostic and predictive indexes (sensitivity, specificity, positive predictive value, negative predictive value and accuracy) of these three methods for different rotator cuff tears types (full-thickness tears, partial-thickness tears and no tears of rotator cuff). With the results of shoulder arthroscopy serving as the standard, PUSB results were compared with MRI and US results using the χ^2 -test ($\alpha = 0.05$, two-sided).

Results

In all 78 patients, the overall accuracy of MRI, US, and PUSB in diagnosing rotator cuff tears was 82.1% (64/78), 75.6% (59/78) and 96.2% (75/78), respectively ($P < 0.001$). Among 21 patients with full-thickness tears, the numbers of cases correctly diagnosed by MRI, US and PUSB were 19, 19 and 21, respectively. The sensitivity and specificity of MRI, US and PUSB in diagnosing full-thickness tears were 90.5%, 90.5%, 100% and 98.2%, 93.0%, 100%, respectively. The diagnostic accuracies of full-thickness rotator cuff tears were 90.5%, 90.5% and 100%, respectively, with no statistical difference ($P = 0.344$). Among 42 patients with partial-thickness tears, the numbers of patients whose cases were correctly diagnosed on MRI, US and PUSB were 32, 27 and 40, respectively. The sensitivity and specificity of MRI, US and PUSB in diagnosing partial-thickness tears were 76.2%, 64.3%, and 95.2% and 88.9%, 88.9%, and 97.2%, respectively. The diagnostic accuracies of partial-thickness rotator cuff tears were 76.2% (32/42), 64.3% (27/42) and 95.2% (40/42), respectively ($P < 0.05$). Among the 15 patients without tears, the numbers of misdiagnosed cases by MRI, US and PUSB were 2, 2, and 1, respectively, and they were all misdiagnosed as partial-thickness tears. The sensitivity and specificity of MRI, US and PUSB in the diagnosis of complete rotator cuff were 86.7%, 86.7%, and 93.3% and 85.7%, 82.5% and 96.8%, respectively, and the accuracies in diagnosing no tears were 86.7% (13/15), 86.7% (13/15) and 87.5% (14/15), respectively ($P = 0.997$).

Conclusions

It is feasible to diagnose rotator cuff tears by PUSB, and its overall effect is superior to MRI and US, especially for patients with partial-thickness tears, which can be used as an important imaging method to evaluate rotator cuff tears.

Introduction

Shoulder pain or limited movement is very common in the general population, with an incidence of 0.9–2.5% in different age groups and a 1-year prevalence of 4.7–46.7%¹, making it the third most common musculoskeletal disorder in orthopaedics². The common causes of shoulder pain include rotator cuff disease, adhesive arthritis, shoulder instability and shoulder arthritis, which are generally caused by rotator cuff tears and/or shoulder impingement syndrome (SIS)³. Rotator cuff disorders include tendinopathy, partial-thickness tears and full-thickness tears. Clinical signs and symptoms that contribute to the diagnosis of rotator cuff tears include pain from overhead movement, weakness during the Jobe test or the External Rotation Resistance Strength test, and positive impingement sign^{4,5}.

Rotator cuff tears must be distinguished from impingement syndrome and shoulder instability^{6,7}. Shoulder X-rays and physical examinations have been shown to be inadequate in the effective detection of rotator cuff tears^{8–10}. With advances in imaging techniques, a variety of imaging methods, such as US (ultrasound) and MRI, have been routinely used to assess rotator cuff tears, which have significantly improved the accuracy in diagnosing rotator cuff tears and are often helpful in demonstrating positive results supporting rotator cuff tears and in identifying different causes of shoulder pain and disease staging¹¹. Both US and MRI showed high soft tissue resolution, sensitivity and specificity in the evaluation of rotator cuff pathology. The clinical application of MRI is limited due to its high cost, time-consuming examination and contraindications. US is increasingly widely used in the diagnosis and treatment of rotator cuff injury because of its good penetration of soft tissue, real-time, dynamic imaging ability and repeated examination of the site of interest.

Contrast-enhanced ultrasound (CEUS) is a novel US technology based on the principle of US. Compared with conventional US, CEUS has more advantages, including improved spatial resolution and real-time dynamic evaluation of normal and abnormal tissue perfusion imaging of large vessels and microvessels, etc¹². Kudo M et al demonstrated that CEUS has a very significant effect on the early detection and diagnosis of hepatocellular carcinoma in the Kupfer stage¹³. CEUS has also been used for intravascular injection for urinary US examination, detection of complications after paediatric transplantation, evaluation of inflammatory bowel disease activities, and evaluation of tumour response to angiogenesis therapy¹⁴. Under the guidance of US, Xueqing Cheng et al injected a contrast agent mixture into the subacromial sac of SIS patients, and its distribution could reportedly be used to diagnose subacromial impingement syndrome¹¹.

Based on previous studies, we attempted to explore the feasibility and diagnostic value of PUSB in evaluating the location and degree of rotator cuff tears.

Methods

Patients A retrospective study was performed on 78 patients who had suspected rotator cuff injury and who were admitted to the Second Affiliated Hospital of Xi'an Jiaotong University from July 2019 to

October 2021. All patients underwent US, MRI and PUSB examinations. There were 32 males and 46 females, aged 31-70 years (mean age 53.9 ± 9.1 years), with a course of 1D-2 years. The inclusion criteria for shoulder arthroscopy or surgical treatment were as follows: (1) full rotator cuff tears or large partial tears confirmed by US, MRI and PUSB and (2) no significant improvement in symptoms after more than 3 months of conservative treatment or sleep pain at night that seriously affected daily life. The exclusion criteria included periarthritis of the shoulder, previous shoulder surgery, infectious periarthritis of the shoulder or rheumatoid arthritis.

The Ethics Committee of the Second Affiliated Hospital of Xi'an Jiaotong University approved this study, and all participants signed informed consent forms. Effectively, all the methods in this study were performed in accordance with the relevant guidelines and regulations.

Equipment and Methods

MRI MRI was performed with 1.5 T superconducting MRI equipment from the German Siemens Magnetom Avanto equipped with a special coil for the shoulder joint. For coronal section scanning, the scanning plane was perpendicular to the glenoid cavity and ranged from the acromion to subscapular humerus with a fast-spin echo T2-weighted sequence (TR/TE=2200 ms/84 ms) and a spin echo T1 weighted sequence (TR/TE=450 ms/16 ms). For oblique coronal scanning, the scanning plane was parallel to the long axis of the supraspinatus muscle and ranged from the outer end of the clavicle to the acromion with rapid spin echo T2-weighted imaging (TR/TE= 2370 ms/39 ms). The scanning parameters were as follows: a FOV = 20 cm×20 cm; a matrix =257×192; a layer thickness =4 mm; and a layer spacing =4.8 mm.

US US and PUSB examinations were performed using a crystal precision E9 (Loqiq E9 XD Clear 2.0) whole-body US machine with a linear array probe and a frequency of 5-10 MHz. The patient is seated and is facing the operator, who performs the procedure according to the shoulder US technical guidelines recommended by the European Society of Musculoskeletal Radiology to obtain US images¹⁵. The biceps long-head tendon, subscapularis muscle, coracoid shoulder ligament, supraspinatus tendon and subscapularis tendon were examined successively. Transverse and longitudinal images were observed, and the dynamic and static images were retained.

PUSB All 78 patients underwent PUSB examination after initial 2-D US. PUSB is similar to the previous US procedure but has its own characteristics. First, US examination was performed to routinely scan the rotator cuff and identify the acromial glide capsule clearly (the in-plane needle path was preferred) so that the skin puncture site could be marked. Sonovue was diluted with sterile saline to 10 mL and thoroughly shaken. Then, a medical ultrasonic couplant was applied to the surface of the probe, and the probe was wrapped with a disposable sterile probe sleeve. Under the guidance of conventional US, the tip was entered into the subacromial bursa, and the CEUS mode was initiated. In the case of the double-amplitude control, a small amount of contrast agent was injected to ensure that it entered the bursa, and all the remaining contrast agent was injected. At the same time, the probe was rotated to observe the

distribution of contrast agent in the bursa and tendon. Typical images were captured and stored during the inspection for recording and analysis. After the examination, the puncture was disinfected and covered with a sterile dressing.

Patients were observed and asked if they experienced any pain or discomfort during the examination. After treatment, the patients were instructed to keep the puncture site dry and clean for at least 24 h.

Diagnostic criteria

MRI (1) Full-thickness tear: the supraspinatus tendon was thickened and twisted, with a high signal involving the whole layer. (2) Partial-thickness tear: the supraspinatus tendon was irregular in shape, with a focal high signal, and the whole layer is not involved.

US (1) Full-thickness tear: (i) a hypoechoic defect extends from the bursal to the articular sides; (ii) local defects are on the internal tendon and articular sides in the short-axis and long-axis views; and (iii) the rotator cuff is not visible due to extensive full-thickness tears and retraction below the acromion. (2) Partial-thickness tear: (i) an obvious hypoechoic defect area or a discontinuous area on the bursal or articular sides of the tendon is present; (ii) there is a high/low echo mixed area; and (iii) focal hypoechoic defects within the tendon are seen in the longitudinal and transverse planes.

PUSB (1) Full-thickness tear: In the PUSB process, contrast agent leaks from the subacromial bursa through the rotator cuff into the joint cavity, as shown by the glenohumeral joint, including the long head sheath of the biceps tendon, which is filled with contrast agent that spills into the joint through the cuff defect. (2) Partial-thickness tear: for the part of bursa-side tears, PUSB shows that the contrast agent filled the bursa-side tear parts and the contrast agent flows from the subacromial bursa to the bursa-side tears area in the PUSB dynamic imaging. The tears of the internal tendon and articular side are difficult to observe but can be observed through combinations of 2-D US images. (3) No tear: the contrast agent is scattered only in the subacromial bursa, outlines the regular surface of the rotator cuff, and does not leak into the rotator cuff or joint cavity.

Image analysis The imaging results of MRI, US and PUSB were independently diagnosed by 2 physicians who had worked for more than 5 years. When the results were inconsistent, multidisciplinary consultation was conducted, and a consensus was reached. Finally, the results of MRI, US and PUSB were compared with those of arthroscopy.

Shoulder arthroscopy All the patients underwent shoulder arthroscopy or surgery performed by an associate chief physician with more than 10 years of shoulder arthroscopy experience. Under arthroscopy, the types of rotator cuff tears were classified as full-thickness tears, partial-thickness tears and no tears according to whether there were any rotator cuff defects and the location and size of defects. The diagnostic results of shoulder arthroscopy were considered standard.

Statistical analysis SPSS 18.0 (SPSS, Inc., Chicago, IL, USA) software was used for statistical data processing. The MRI, US and PUSB results were correlated with the shoulder arthroscopy results. The

sensitivity, specificity, positive predictive value, negative predictive value and accuracy of MRI, US and PUSB in the diagnosis of rotator cuff tears of different types were calculated, with the results of shoulder arthroscopy serving as the standard. Enumeration data are presented as examples, and the χ^2 -test ($\alpha=0.05$, two-sided) was used to compare the difference in diagnostic accuracy between different methods.

Results

Arthroscopic diagnosis of the shoulder The results of shoulder arthroscopy showed that among 78 patients with suspected rotator cuff tears, there were 21 cases of full-thickness tears, 42 cases of partial-thickness tears and 15 cases of no tears (Table 1). Among the 42 patients with partial tears, 2 cases were articular tears, and the rest were bursal tears. Of the 15 patients without tears, 1 had biceps head-long tendinitis with a small amount of fluid, 1 had low elastic tendons (accompanied by hypertension and diabetes), 5 had calcified supraspinatus tendons, and 8 had acromial bursitis.

Table 1

Comparison of MRI, US and PUSB in detecting rotator cuff tears with arthroscopy as a standard

Arthroscopy	MRI			US			PUSB			Total
	FTT	PTT	NT	FTT	PTT	NT	FTT	PTT	NT	
FTT	19	2	0	19	2	0	21	0	0	21
PTT	1	32	9	4	27	11	0	40	2	42
NT	0	2	13	0	2	13	0	1	14	15
Total	20	36	22	23	31	24	21	41	16	78

US = ultrasound; MRI = magnetic resonance imaging; PUSB = percutaneous ultrasound-guided subacromial bursography;

FTT = full-thickness tear; PTT = partial-thickness tear; NT = no tear.

Results of MRI, US and PUSB in the diagnosis of rotator cuff tears For the 78 patients with suspected rotator cuff tears, the diagnostic results of MRI, US, and PUSB for full-thickness tears, partial-thickness tears, and no tears are shown in Table 1. The diagnostic and predictive indexes (sensitivity, specificity, positive predictive value and negative predictive value) of these three methods for different rotator cuff tear types are shown in Table 2, Table 3 and Table 4.

Table 2
Performance of MRI,US and PUSB in the diagnosis of full-thickness rotator cuff tears

	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
MRI	90.5	98.2	95.0	96.6
(CI)	(76.68,104.17)	(94.73,101.76)	(84.53,105.47)	(91.71,101.39)
US	90.5	93.0	82.6	96.4
(CI)	(76.68,104.17)	(86.14,99.82)	(65.85,99.37)	(91.26,101.47)
PUSB	100	100	100	100
(CI)	-	-	-	-

Table 3
Performance of MRI,US and PUSB in the diagnosis of partial-thickness rotator cuff tears

	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
MRI	76.2	88.9	88.9	76.2
(CI)	(62.76,89.62)	(78.10,99.67)	(78.10,99.67)	(62.76,89.62)
US	64.3	88.9	87.1	68.1
(CI)	(49.17,79.40)	(78.10,99.67)	(74.60,99.60)	(54.25,81.92)
PUSB	95.2	97.2	97.6	94.6
(CI)	(88.52,101.95)	(91.58,102.86)	(92.63,102.49)	(86,95,102.24)

Table 4
Performance of MRI, US and PUSB in the diagnosis of no tears of rotator cuff

	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
MRI	86.7	85.7	59.1	96.4
(CI)	(67.18,106.15)	(76.83,94.60)	(36.78,81.40)	(91.41,101.44)
US	86.7	82.5	54.2	96.3
(CI)	(67.18,106.15)	(72.90,92.18)	(32.67,75.66)	(91.09,101.50)
PUSB	93.3	96.8	87.5	98.4
(CI)	(79.03,107.63)	(92.37,101.28)	(69.30,105.70)	(95.16,101.61)

Among the 21 patients with full-thickness tears, the numbers of cases correctly diagnosed by MRI, US and PUSB were 19, 19 and 21, respectively (Table 1). Both MRI and US misdiagnosed 2 patients with cases of full-thickness tears as partial-thickness tears, while PUSB could correctly diagnose all patients with full-thickness tears. The sensitivity of MRI, US and PUSB was 90.5%, 90.5%, 100%, respectively, and the specificity was 98.2%, 93.0%, 100%, respectively; moreover, the positive predictive value and negative predictive value were 95.0%, 82.6%, 100% and 96.6%, 96.4%, 100%, respectively (the 95% CI is shown in Table 2).

Among 42 patients with partial-thickness tears, the numbers of patients whose cases were correctly diagnosed on MRI, US and PUSB were 32, 27 and 40, respectively (Table 1). For the diagnosis of partial-thickness tears, the sensitivity was 76.2%, 64.3%, and 95.2%, respectively, and the specificity was 88.9%, 88.9%, and 97.2%, respectively, and the positive predictive value and negative predictive value were 88.9%, 87.1%, and 97.6% and 76.2%, 68.1%, and 94.6%, respectively. (95% CI is shown in Table 3). Among them, MRI diagnosed 1 partial-thickness tear as a full-thickness tear and 9 as no tear, US diagnosed 4 partial-thickness tears as full-thickness tears and 11 as no tears, and PUSB diagnosed only 2 partial-thickness tears as no tears.

Among the 15 patients without tears, the numbers of misdiagnosed cases by MRI, US and PUSB were 2, 2, and 1, respectively, and they were all misdiagnosed as partial-thickness tears (Table 1). For the diagnosis of no tear, the sensitivity of MRI, US and PUSB was 86.7%, 86.7%, and 93.3%, respectively, and the specificity was 85.7%, 82.5% and 96.8%, respectively; moreover the positive predictive value and negative predictive value were 59.1%, 54.2%, 87.5% and 96.4%, 96.3% and 98.4%, respectively.

Among all 78 patients, the accuracy and differences in MRI, US and PUSB for different types of rotator cuff tears are shown in Table 5. The overall accuracy of MRI, US and PUSB in the diagnosis of rotator cuff tears was 82.1% (64/78), 75.6% (59/78) and 96.2% (75/78), respectively. The overall accuracy of PUSB in the diagnosis of rotator cuff tears was higher than that of MRI and US ($P < 0.001$).

Table 5
Comparison of MRI, US and PUSB in detecting various types of rotator cuff tear with arthroscopy as a standard

Method	Rotator Cuff, n(%)	FTTs, n(%)	PTTs, n(%)	NTs, n(%)
MRI	64/78(82.1%)	19/21(90.5%)	32/42(76.2%)	13/15(86.7%)
US	59/78(75.6%)	19/21(90.5%)	27/42(64.3%)	13/15(86.7%)
PUSB	75/78(96.2%)	21/21(100%)	40/42(95.2%)	14/15(87.5%)
P	$P < 0.001$	$P = 0.344$	$P < 0.05$	$P = 0.997$

For full-thickness rotator cuff tears, the diagnostic accuracy of the three methods was 90.5% (19/21), 90.5% (19/21) and 100% (21/21), respectively, and there was no significant difference ($P = 0.344$). The

diagnostic accuracies of MRI, US and PUSB were 76.2% (32/42), 64.3% (27/42) and 95.2% (40/42), respectively. The diagnostic accuracy of PUSB for partial-thickness tears was higher than that of MRI and US ($P < 0.05$). Among 15 patients with no tears, the diagnostic accuracies of MRI, US and PUSB were 86.7% (13/15), 86.7% (13/15) and 87.5% (14/15), respectively, and the difference was not statistically significant ($P = 0.997$). In general, PUSB was more accurate than MRI and US in the overall diagnostic rate of rotator cuff tears, and PUSB had higher diagnostic efficiency for patients with partial-thickness rotator cuff tears.

Discussion

The rotator cuff is a sleeve-like structure formed by the tendons of the supraspinatus, infraspinatus, subscapularis and teres minor in front, above and behind the humeral head, which is located between the coraco-shoulder arch and the humeral head. The front of the rotator cuff is the acromion sliding capsule, and the deep surface is the joint capsule, which plays an important role in maintaining the structure of the shoulder joint¹⁶. A common cause of shoulder pain or limited movement is rotator cuff injury, including rotator cuff tendonitis and rotator cuff tears, of which rotator cuff tears are the most common. Patients with calcified tendonitis are also more likely to have rotator cuff tears¹⁷. Some studies¹⁸ have shown that rotator cuff injury is related to age, and the incidence of rotator cuff injury in people over 80 years old can be as high as 80%. Rotator cuff tears can be divided into partial-thickness tears or full-thickness tears according to the degree of tear, which is highly important for surgical treatment. At present, US and MRI have been frequently applied in the diagnosis of rotator cuff tears. Different studies have reported the accuracy of US and MRI in different levels of full-thickness and partial-thickness rotator cuff tears^{19–21}. However, with the progress of US technology and the widespread application of contrast agents, CEUS has become an important diagnostic method²². SonoVue, the contrast agent used in shoulder arthrography, has been proven to be safe in relevant studies^{23,24}.

In this group of 78 cases, PUSB correctly diagnosed 75 cases with an accuracy of 96.2%, which was higher than that of both MRI and US (82.1% and 75.6%, respectively) ($P < 0.001$). Roy JS et al²⁵ showed that the overall sensitivity and specificity of US, MR and MRA in the diagnosis of full-thickness rotator cuff tears were all greater than 90%, indicating the positive role of US, MR and shoulder arthrography in the diagnosis of full-thickness rotator cuff tears. For the 21 full-thickness tears, the accuracies of the three methods were 90.5%, 90.5% and 100%, respectively. MRI and US misdiagnosed 2 full-thickness tears as partial-thickness tears, while PUSB diagnosed all 21 full-layer tears correctly (Fig. 1). The reason why MRI and US misdiagnosed 2 full-thickness tears as partial-thickness tears may be that the defect of the supraspinatus muscle laceration on the bursa side was large and easy to observe, but the defect on the articular side was difficult to observe because of the small tear range, the influence of local new granulation tissue and the limitation of MRI stratification scanning. These findings also indicate that PUSB is advantageous in terms of timeliness and dynamic observations in the diagnosis of rotator cuff tears. Interestingly, in some patients with rotator cuff tears, PUSB showed the extent of the tear more accurately than US did (Fig. 2).

For the diagnosis of partial-thickness tears, the accuracy of PUSB was 95.2%, which was significantly higher than that of US and MRI (64.3% and 76.2%, $P < 0.05$); these findings are consistent with the results of Tang Y-Q et al²⁴. However, the accuracy of PUSB in this study was higher than that in the study by Cheng X et al¹¹ (85.4%), which may be related to the regional and random distribution of patients, the experience of physicians and imaging equipment. For 42 patients with partial-thickness tears, MRI correctly diagnosed 32 cases and misdiagnosed 10 cases, in which 1 case was a full-thickness tear and 9 cases were no tears; US correctly diagnosed 27 cases and misdiagnosed 15 cases, in which 4 cases were full-thickness tears and 11 cases were no tears; PUSB was correctly diagnosed in 40 cases and misdiagnosed as no tears in 2 cases.

PUSB can not only show the range and morphology of rotator cuff tears but also clearly show the size and shape of the tears. In particular, PUSB can make a clearer and faster diagnosis of typical supraspinatus partial-thickness tears (Fig. 3). However, there are also limitations of PUSB; that is, only when there is a tear on the bursa surface can the contrast agent flow from the defect to the deep surface of the tear. When the tear is small or the disease course is long, there will be a scar or granulation tissue hyperplasia area in the defect, leading to the failure of the contrast agent to enter and resulting in false negatives²⁶. In addition, PUSB has a certain rate of missed diagnosis in patients without tears on the bursal side but with tears on the articular side (Fig. 4). However, US examination is required before PUSB operation, so this mode of operation can also significantly reduce the rate of missed diagnosis. In this study, the number of patients with simple articular side tears was low, which was also an important factor that led to the results being inconsistent with those of Cheng X et al¹¹.

For patients with shoulder pain or limited motion but not with rotator cuff tears, US, MRI, and PUSB can be used to diagnose such patients accurately. Among 15 patients with no tears, the diagnostic accuracies of US, MRI and PUSB were 86.7%, 86.7% and 87.5%, respectively ($P = 0.997$), and the difference was not statistically significant. Most of the 15 patients were elderly patients with complications such as diabetes, hypertension and hyperlipidaemia. Tony Tung-Liang Lin et al²⁷ reported that the present longitudinal, population-based follow-up study suggested that having diabetes or hyperlipidaemia alone was an independent risk factor for the development of rotator cuff injury. In a high cholesterol environment, such as familial hyperlipidaemia, lipids will accumulate in the extrinsic tendinocyte stroma and form deposits such as lipomatous fibroma. The related mechanisms of cholesterol change are multifaceted, including changes in the gene and protein expression of tendon cells, matrix transformation, tissue vascularization and cytokine production²⁸. Therefore, in the diagnosis of rotator cuff injuries, other systemic diseases, such as age, hyperlipidaemia, hypertension and diabetes, should be taken into consideration, which may have an impact on the diagnosis of US, MRI and PUSB.

There are still some limitations in the current research. First, PUSB is an invasive examination, which may be associated with negative experiences in some patients, such as pain, fear and infection. However, no infections occurred among the 78 patients. Second, in this study, elderly patients accounted for a large proportion of all patients. Due to the low activity and high pain threshold of elderly individuals, tears are

often serious during examination, while young patients usually experience acute trauma. At the same time, the US diagnosis of rotator cuff injury is highly dependent on doctors' experience. Taken together, these factors may affect the reference importance of this study.

Conclusions

In conclusion, PUSB is highly accurate, sensitive and specific for the diagnosis of rotator cuff tears, which is consistent with the results of shoulder arthroscopy, especially for patients with partial-thickness tears. At the same time, PUSB can be used to dynamically observe and effectively determine the specific location and scope of rotator cuff tears in a timely manner. Compared with US and MRI, PUSB can show small rotator cuff tears more clearly, with decreased cost and increased efficiency, making this method a good choice for patients in urgent need of surgery.

Declarations

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Authors' contributions

All of the authors contributed to the conception and design of this study. RL and ML were responsible for experiment performing and the drafting of the manuscript. YC was responsible for data analysis. PY aided in design of the study and participated in its coordination, critical revision of the manuscript. CZ was participated in experiment design and final approval of the version to be published. All authors have read and approved the final manuscript.

Conflict of interest

The authors declare that they have no competing interests.

Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval

The Ethics Committee of the Second Affiliated Hospital of Xi'an Jiaotong University approved the study protocol.

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Figures

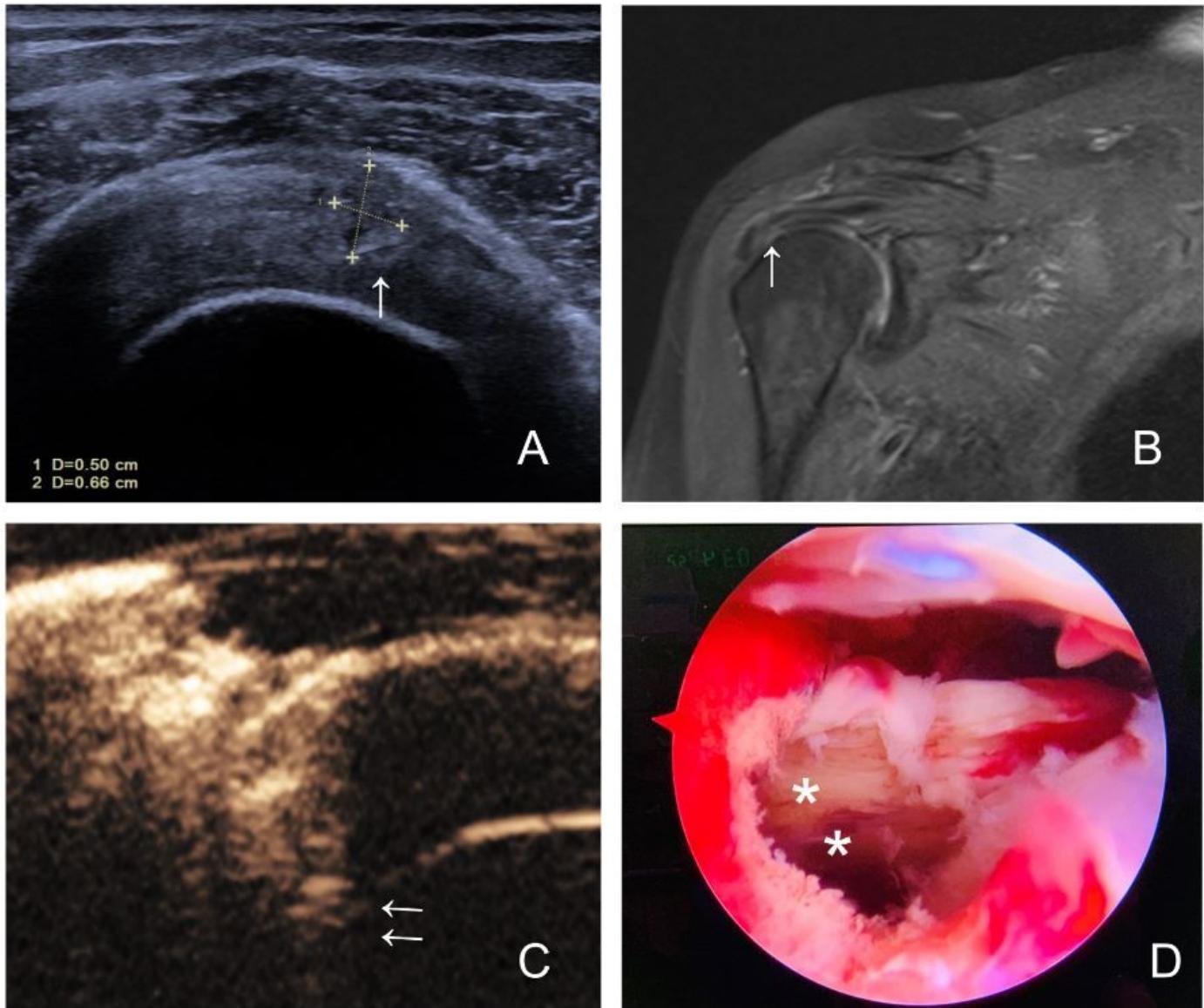


Figure 1

US, MRI, PUSB, and shoulder arthroscopic images of a 65-year-old woman with full-thickness tear. (A) US revealed a partial-thickness tear of the supraspinatus muscle on bursal side that did not reach the articular surface (↑). (B) The T2 image of MRI indicated the presence of high signal in the supraspinatus tendon (↑), which did not penetrate the whole layer. (C) PUSB showed that contrast agent flowed from the defect of the supraspinatus muscle bursal to the articular side (↑) and reached the articular cavity, suggesting a full-thickness supraspinatus tear. (D) Arthroscopy showed a full-thickness tear of the supraspinatus muscle.

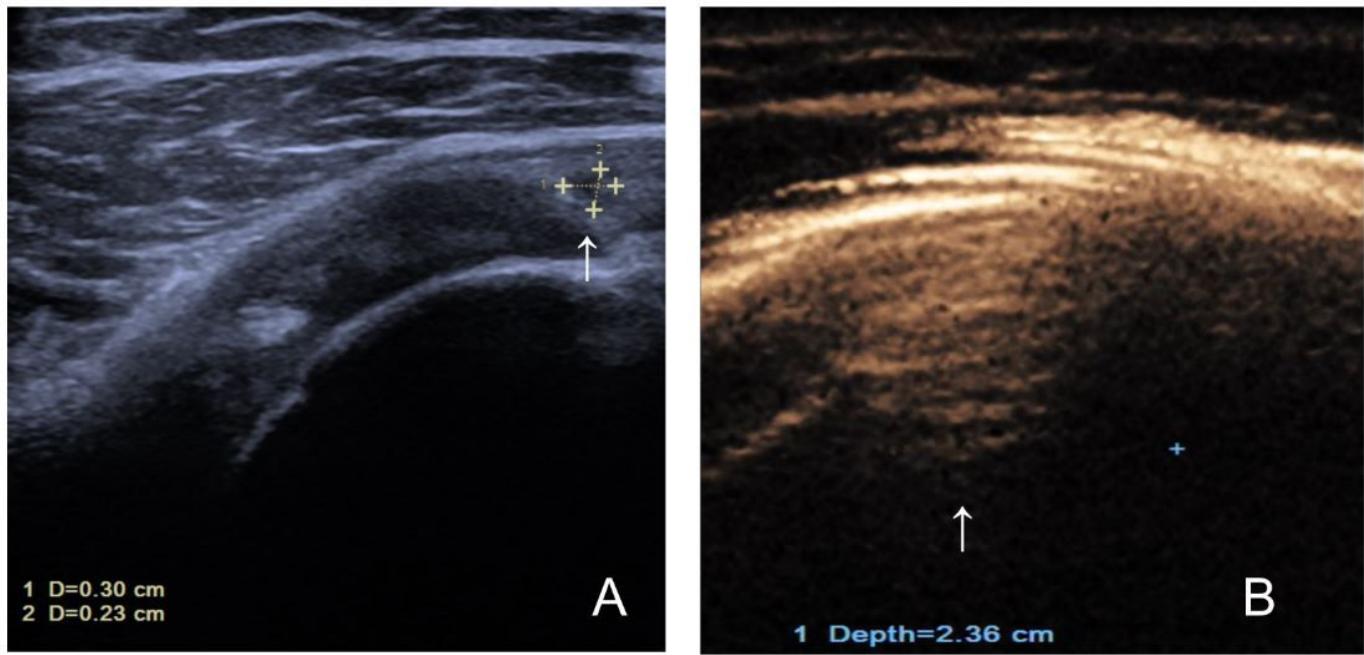


Figure 2

Comparison of US and PUSB results in a 31-year-old man with avulsion fracture of the left greater tubercle of the humerus with full-thickness tears of supraspinatus muscle. □A□Ultrasound suggested a high signal area of $0.30*0.23\text{cm}$ in supraspinatus muscle (↑).□B□PUSB results showed that the contrast agent entered into the supraspinatus tendon in a patchy distribution, and the range was significantly wider than that of the US image.

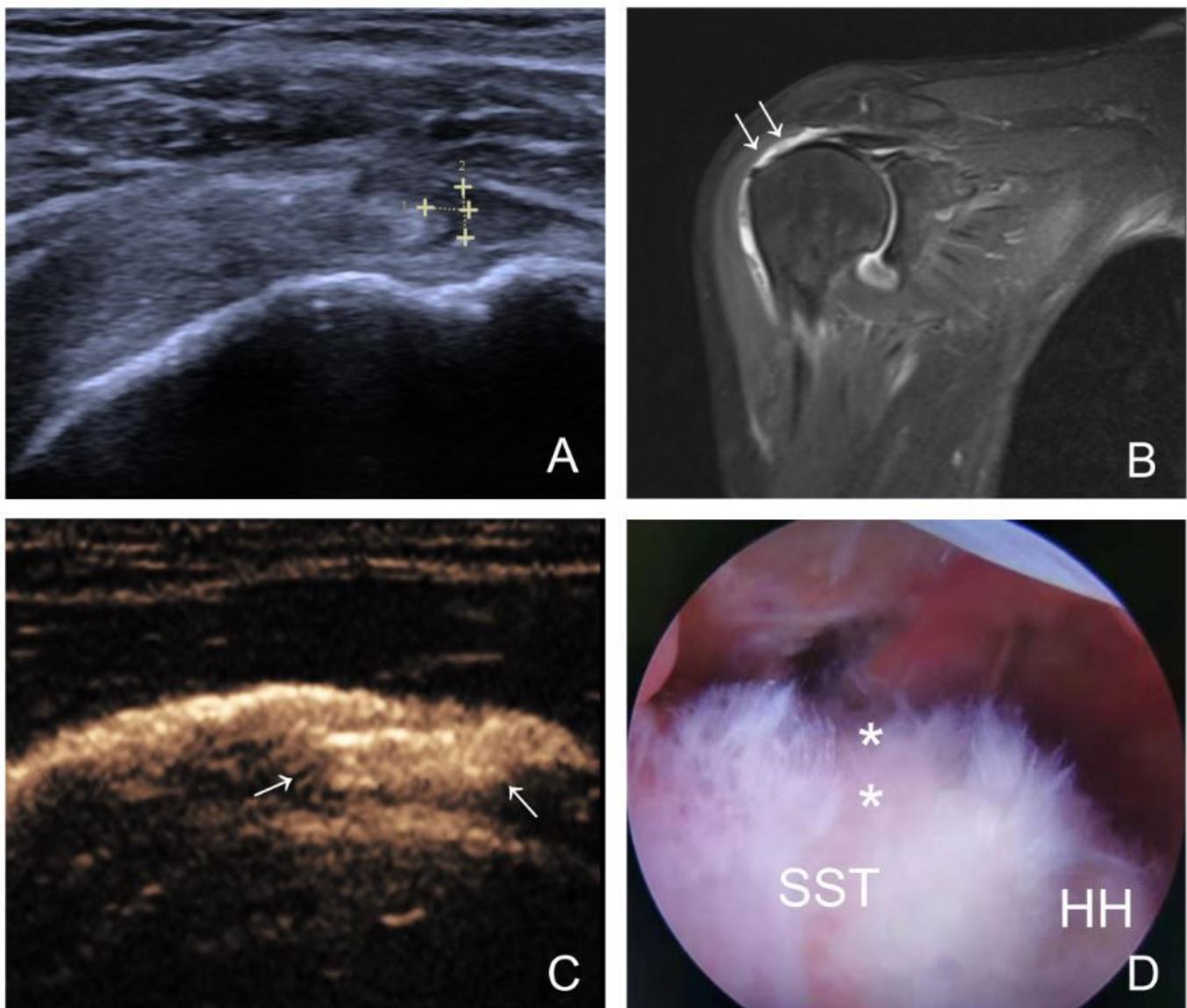


Figure 3

A 63-year-old female with partial-thickness tear of supraspinatus on bursal side. A US showed that the echo of supraspinatus tendon was not uniform, and the anechoic zone of 2.5×2.1 mm could be detected near synovial surface (+). B MRI showed high signal shadow on the supraspinatus tendon bursa (↑↑). C PUSB results showed that contrast agent could enter the anechoic area near the synovial surface of supraspinatus tendon (↑). D Arthroscopic results of the shoulder revealed a partial-thickness tear of the supraspinatus muscle on bursal side with abundant surrounding synovial tissue hyperplasia (**). SST=supraspinatus tendon; HH=humeral head.

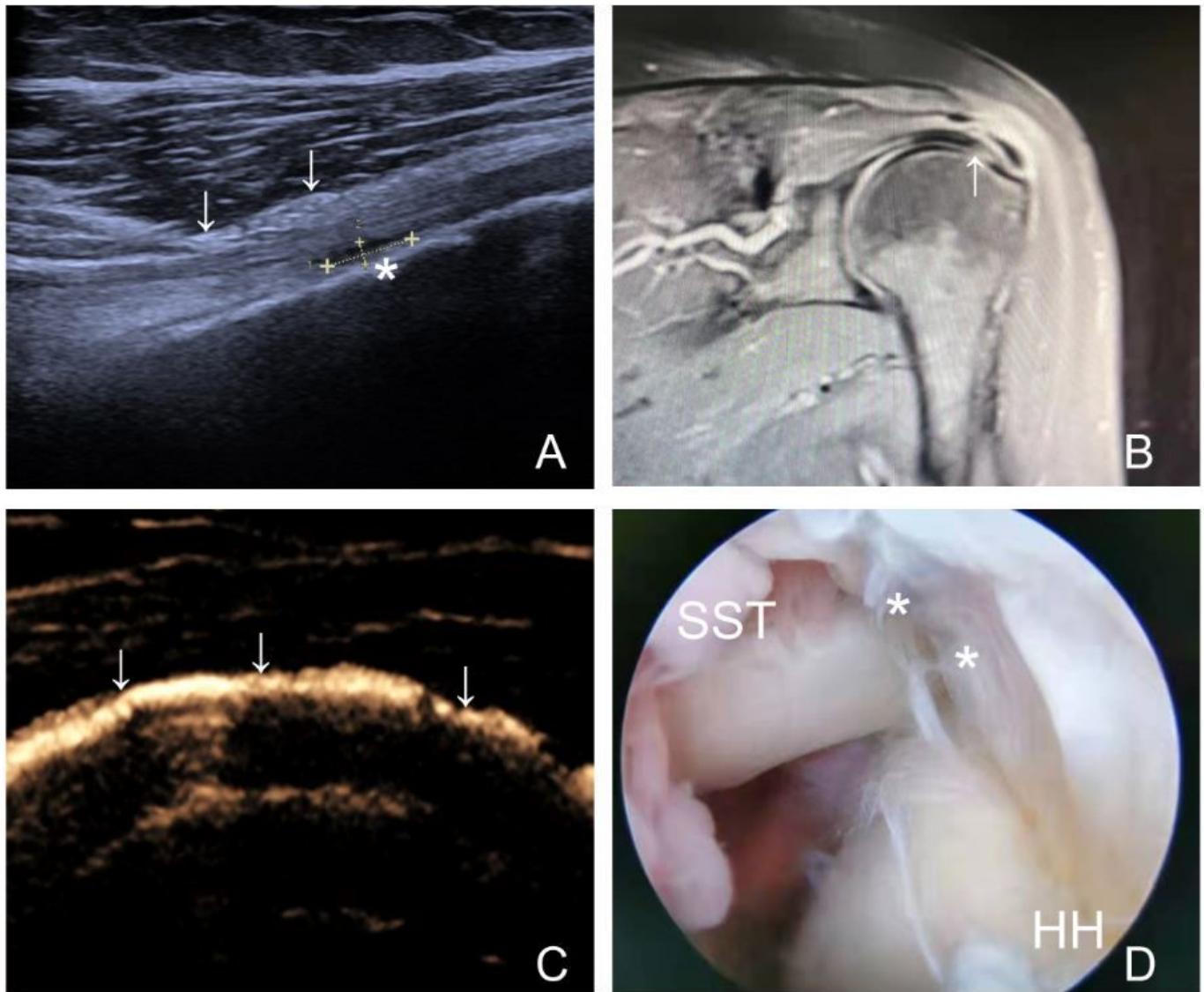


Figure 4

A 50-year-old female with partial-thickness tear of supraspinatus on articular side. A US showed that the supraspinatus tendon bursal plane was intact (\uparrow), and the hypoechoic zone could be detected near the articular side of the supraspinatus tendon (*). B MRI showed high signal shadow at the articular surface of the supraspinatus tendon (\uparrow), indicating a partial-thickness tear of the supraspinatus tendon on articular side. C POCUSB results suggested that the contrast agent was evenly distributed along the supraspinatus tendon on bursal side after entering the subacromial bursa, and no contrast agent was found in the supraspinatus tendon. D Shoulder arthroscopy revealed a partial-thickness tear of the supraspinatus muscle on articular side (**). SST = supraspinatus tendon; HH = humeral head.