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Evaluation of hypervascularity in synovitis of the shoulder using ultrasound: comparison of preoperative ultrasound findings and intraoperative arthroscopic findings

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Background: Synovitis of the shoulder causes pain; however, it is difficult to accurately determine the area and degree of synovitis from preoperative images. This study investigated the correlation between intraoperative arthroscopic findings and preoperative power Doppler ultrasonography (PDUS) findings for synovitis evaluation.

Methods: Forty patients (mean age = 62.0 years; 24 men and 16 women) underwent arthroscopic surgery for partial rotator cuff tears. Three observation areas were evaluated: rotator interval (RI), subacromial bursa, and bicipital groove. The Doppler flow areas and PDUS grade were measured one day before surgery. Arthroscopic findings were visualized intraoperatively and classified into 3 groups: pale, pink, and red. The correlation between the arthroscopic classification and PDUS findings was analyzed.

Results: The correlation between intraoperative arthroscopic classification and preoperative PDUS findings, Doppler flow area and PDUS grade, was high for the RI ($r = 0.82, 0.70$). There was no correlation for the subacromial bursa ($r = 0.01, -0.02$) and the bicipital groove ($r = -0.03, 0.3$).

Conclusion: Hypervascularity findings in the PDUS were highly correlated with arthroscopic color classification in the RI. Therefore, visualization of hypervascularity in the RI area could be a reliable measure for the assessment of glenohumeral synovitis in patients with partial-thickness rotator cuff tear.

Shoulder pain and stiffness are common complications after arthroscopic rotator cuff repair (ARCR). Although the pathology of shoulder pain is still controversial, several studies have reported subacromial and glenohumeral synovitis as being a source of pain in rotator cuff disease.[1,3,12,16,20] Being female, age less than 50 years old, workers' compensation, diabetes, patients with partial tears, preoperative pain, and adhesive capsulitis have been reported as predictive factors for shoulder stiffness after ARCR.[13,14,25,30] Glenohumeral synovitis would be associated with early postoperative shoulder stiffness after ARCR.[29] Jo et al showed that there is excellent reliability between macroscopic and microscopic assessments of the glenohumeral and subacromial synovitis in rotator cuff disease.[15] A recent article has also proposed a macroscopic scoring system for glenohumeral synovitis.[4] Davis et al proposed a validated intraoperative scoring system to classify the degree of glenohumeral synovitis based on the capsule characteristic during arthroscopy.[4] However, preoperative evaluation of the glenohumeral and subacromial synovitis has not been established.

Recent imaging studies have revealed that abnormal vascularization is associated with synovitis. Several researchers have shown the relationship between hypervascularity and synovitis of the glenohumeral joint using digital subtraction angiography and dynamic magnetic resonance imaging.[23,26] Ultrasound (US) has been widely used as another diagnostic modality to accurately detect soft tissue disorders, and vascularity in rotator cuff disease has been diagnosed using US techniques.[6,8-10] Several imaging studies have shown that evaluation of hypervascularity using power Doppler ultrasonography (PDUS) is feasible for determining the degree of synovitis.[31,32] However, the reliability of PDUS evaluation of synovitis has not yet been determined. Consequently, this study investigated the correlation between preoperative PDUS findings and intraoperative arthroscopic findings.

This study was approved by the Institutional Review Board of Keiyu Orthopaedic Hospital (#3012).

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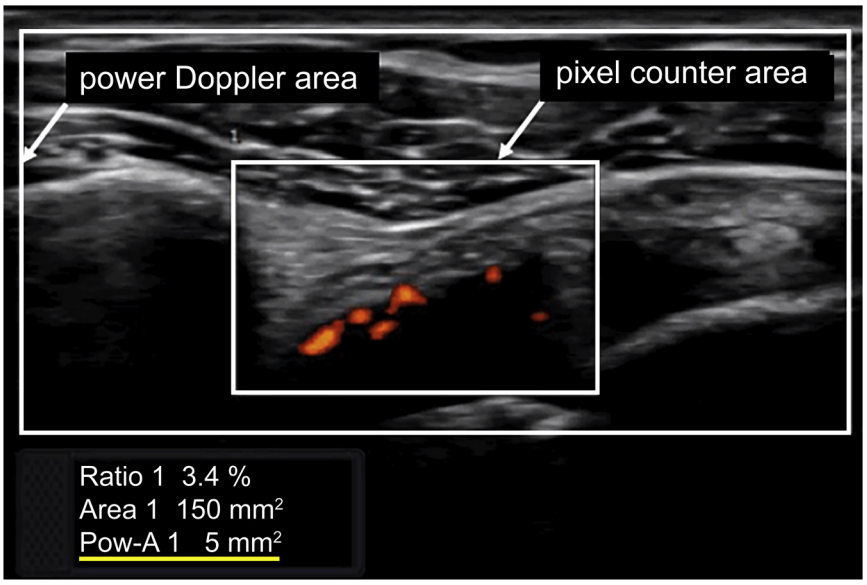

Figure 1 The pixel counter was used to quantify the flow signal area of the power Doppler ultrasound.

Materials and methods

Patient selection

We performed a retrospective review of data from 40 patients (24 men and 16 women) diagnosed with partial rotator cuff tear who underwent ARCR. To separately evaluate the inside and outside of the glenohumeral joint, partial rotator cuff tear was selected in this study. The mean age of the patients was 62.0 ± 10.9 years at the time of the operation. The exclusion criteria were complete rotator cuff tear, long head biceps rupture, collagen disease including rheumatoid arthritis, and history of fracture, dislocation, or previous shoulder surgery.

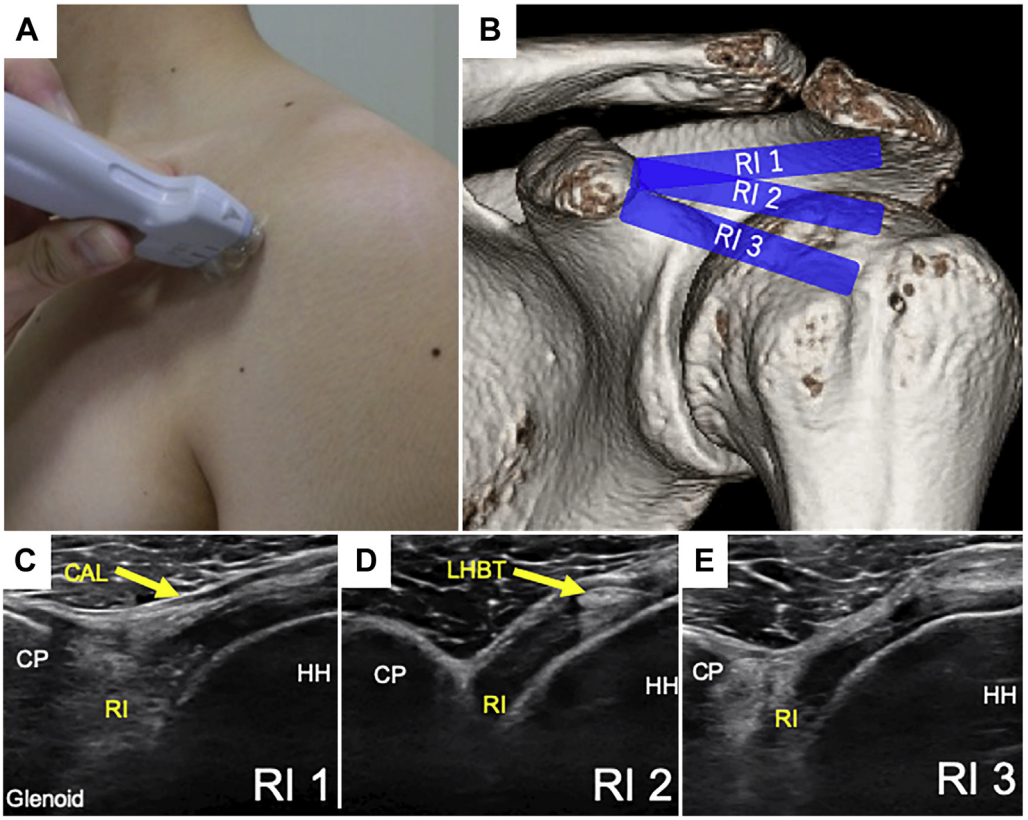

Figure 2 Rotator interval (RI) ultrasound measurement. (**A**) Performed in neutral limb position. (**B**) The bony landmarks are the coracoid process (CP), humeral head (HH), and acromion. (**C**) The soft tissue landmarks are the coracoacromial ligament (CAL) for RI 1, (**D**) long head of the biceps tendon (LHBT) for RI 2, (**E**) until the subscapularis tendon appeared for RI 3.

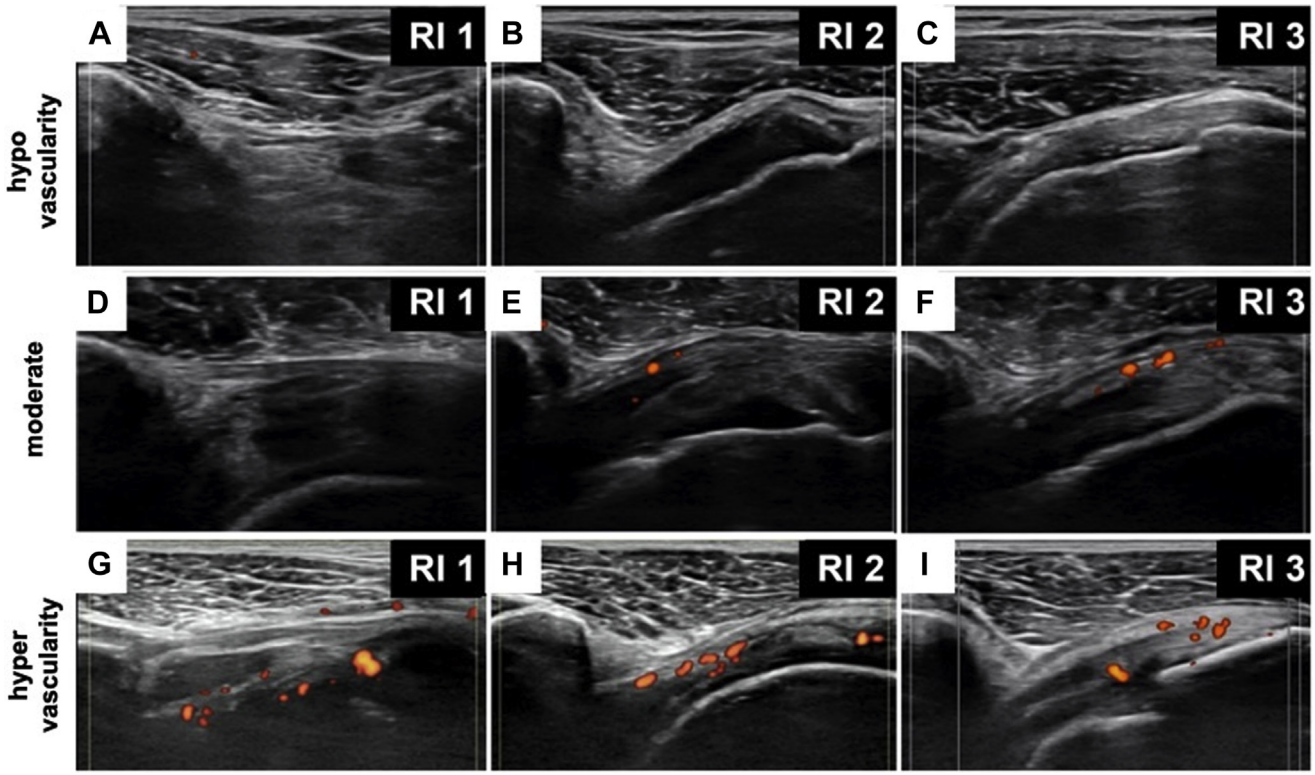

Figure 3 The PDUS grade system in the RI. The original PDUS grade images, "hypovascularity" groups (**A**), (**B**), and (**C**) with no Doppler response in three sites. The "moderate" groups (**D**), (**E**), and (**F**) with single- or two-site Doppler response. In "hypervascularity" groups (**G**), (**H**), and (**I**), all three sites have Doppler response. *PDUS*, power Doppler ultrasonography.

All patients underwent PDUS one day before surgery. Subsequently, we investigated the correlation between the preoperative PDUS findings and the intraoperative arthroscopic findings. This study was approved by the relevant institutional review board.

Power Doppler ultrasonography

Each patient underwent PDUS one day before surgery. All 40 examinations were performed by a single experienced sonographer using a SONIMAGE HS1 (Konica Minolta Corp., Tokyo, Japan) with an 18 MHz high-frequency transducer. For optimization of PDUS, each patient was comfortably seated and completely relaxed. A generous amount of scanning gel was applied between the transducer and skin for light pressure uniformity and good acoustic contact. The areas of the Doppler flow signals were quantified using a pixel counter (Fig. 1). We observed synovitis and hypervascularity in the US in the rotator interval (RI), subacromial bursa (SAB), and bicipital groove (BG). Each area of investigation (RI, SAB, and BG) was evaluated with 3 measurements to avoid incorrect evaluation of the PDUS findings. The landmarks in the RI were the guides between the supraspinatus and subscapularis tendons of the coracoid process, humeral head, and acromion based on previous studies.[17,19,28] For the observation of RI 1, the coracoacromial ligament was used as a landmark. In RI 2, the US probe was moved downward from RI 1 to the area where the long head of the biceps tendon was drawn on the short axis. For RI 3, the US probe was moved downward from RI 2 until the subscapularis tendon appeared (Fig. 2). The landmarks in the SAB were the superior facet of the greater tuberosity (denoted SAB 1), the middle facet (denoted SAB 2), and the inferior facet (denoted SAB 3). The landmarks in the

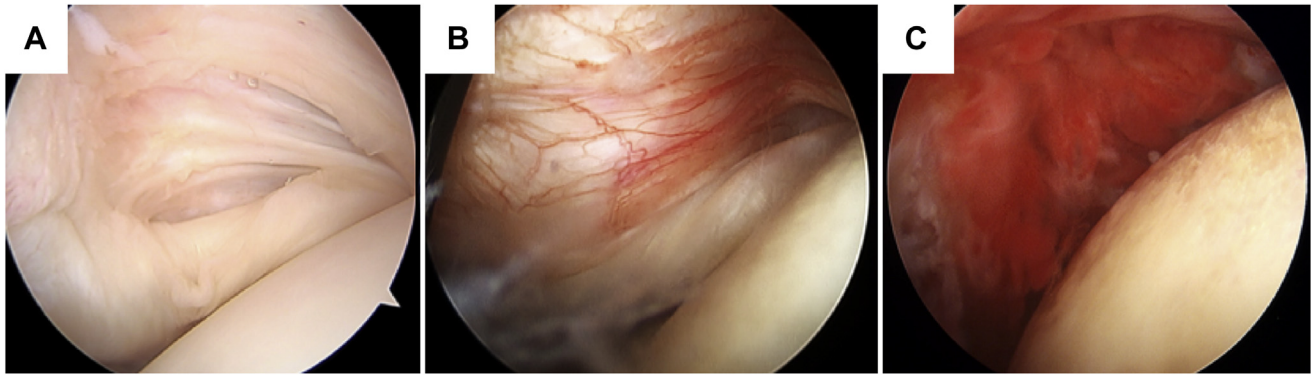

Figure 4 Arthroscopic images of the rotator interval. Arthroscopic images, (**A**) *pale*, (**B**) *pink*, and (**C**) *red*.

Table I
Power Doppler ultrasonography grading system n (%).

Area	Hypovascularity	Moderate	Hypervascularity
RI	11 (27.5)	16 (40.0)	13 (32.5)
SAB	23 (57.5)	16 (40.0)	1 (2.5)
BG	0 (0)	11 (27.5)	29 (72.5)

RI, rotator interval; *SAB*, subacromial bursa; *BG*, bicipital groove.

BG were the greater tuberosity, lesser tuberosity, long head of the biceps tendon, and anterior deltoid muscle. For observation of BG 1, the trapezoidal shape of the lessor tuberosity was used as a landmark, and BG 2 and BG 3 were located in the downward direction of the probe width from BG 1.

Our original PDUS grading system was also used for evaluation of glenohumeral joint inflammation as follows: "hypovascularity" for no Doppler response, "moderate" for single or 2 areas out of 3, and "hypervascularity" for all 3 areas (Fig. 3). The Doppler flow area and the original PDUS grade were compared with arthroscopic classification in the RI, SAB, and BG.

Arthroscopic classification

Standard anterior, lateral, and posterior portals in a lateral decubitus or beach chair position were used for the arthroscopic evaluation. Arthroscopic findings were classified by color classification (pale, pink, and red) based on a previous study by Davis et al (Fig. 4).[4] The areas of investigation were the RI from the glenohumeral side, the SAB from the subacromial side, and the BG from both the glenohumeral side and the subacromial side.

Statistical analysis

The correlation between the Doppler flow area and intraoperative arthroscopic classification and that of the PDUS grade and arthroscopic classification were examined using Spearman's rank correlation coefficient. For the comparison of PDUS with the color classification, multiple comparison tests were performed using the Tukey–Kramer test. The correlations were denoted as high (>0.7), moderate (0.4-0.7), and weak (0-0.4).[18] All analyses were performed using R (version 2.8.1), and the statistical significance was set at $P < .05$.

Intraclass correlation coefficient for intraobserver reproducibility

Intraobserver reproducibility was calculated on the basis of 2 consecutive measurements. An intraclass correlation coefficient (ICC) of 1.0 represents perfect agreement, and ICC = 0 suggests that the measurements are entirely random. Appropriate reproducibility of intraobserver values depends on how one defines the clinical agreement for the analysis.

Results

The Doppler flow area of the RI, SAB, and BG was classified using the PDUS grade (Table I). The color classification of intraoperative arthroscopic findings was evaluated in the RI, SAB, and BG (Table II). The correlation between the Doppler flow area and intraoperative arthroscopic classification was $r = 0.82$ ($P < .001$) in the RI, $r = 0.01$ ($P = .91$) in the SAB, and $r = -0.03$ ($P = .85$) in the BG (Table III, Fig. 5). The correlation between the PDUS grade and intraoperative arthroscopic classification was $r = 0.70$ ($P < .001$) in the RI, $r = -0.02$ ($P = .89$) in the SAB, and $r = 0.3$ ($P = .06$) in the BG (Table III). The correlation between the Doppler flow area and arthroscopic classification and that between the original PDUS grade and arthroscopic classification in the RI were considered as high (Table III).

The ICC for intraobserver reproducibility of the PDUS was 0.90 (95% confidence interval, 0.72-0.96). The agreement in intraobserver variations during the analysis of PDUS was acceptable.

Discussion

The present study showed a high correlation between preoperative PDUS grade and intraoperative arthroscopic color classification in the RI. Therefore, we believe that the assessment of hypervascularity of the RI by PDUS can be used as a tool to predict intra-articular shoulder synovitis. The PDUS grade in the RI was highly correlated with the arthroscopic findings and can therefore be used as a semiquantitative assessment for glenohumeral synovitis.

In patients with rotator cuff tears, synovitis is commonly observed during surgery. Previous studies have identified subacromial and glenohumeral synovitis as being a source of pain in rotator cuff disease.[1,3,12,16,20] Moreover, glenohumeral synovitis would be associated with early postoperative shoulder stiffness after ARCR.[29] Management of synovitis in the shoulder joint is one of the most important factors in the treatment of the shoulder joint. Preoperative evaluation of synovitis in the shoulder joint would therefore be invaluable for determining appropriate surgical indication. However, its evaluation remains challenging. Davis et al reported the classification of arthroscopic findings based on color classification, with pale, pink, and red intensity of synovitis in that order.[4] Jo et al reported a correlation between arthroscopic findings and microscopic observations of synovitis tissue in patients with rotator cuff tears.[15] Arthroscopic color classification would indicate the degree of microscopic synovitis. The results of the present study indicate that vascularity evaluation using noninvasive PDUS provides important information on synovitis in the shoulder joint.

In clinical practice, less-invasive and more convenient tools would be an ideal diagnostic modality. Simultaneously, the reliability and reproducibility should be considered. Noninvasive evaluation of the Doppler flow area in the RI showed a high correlation with intraoperative arthroscopic findings ($r = 0.82$, $P < .001$), whereas there was no correlation in the SAB ($r = 0.001$, $P = .91$) and BG ($r = -0.03$, $P = .85$). The agreement in intraobserver variations during the analysis of PDUS was acceptable (0.90). Our PDUS grade system—"hypovascularity" with no Doppler response, "moderate" with 1 or 2 sites, and "hypervascularity" with 3 sites—would be more convenient for clinical practice than calculation of the Doppler flow area.

Although there was a high correlation between the PDUS and intraoperative findings in the RI, we consider that anatomical factors should be considered for correct diagnosis. Several vascular supplies for inflammation of the RI in cadaveric studies are the thoracoacromial artery, anterior brachial circumflex artery, and suprascapular artery.[2,24] Okuno et al reported that hypervascularity to the RI originated from the coracoid branch of the thoracoacromial and axillary arteries in a digital subtraction angiography study of a frozen shoulder.[23] The thoracoacromial and

Table II
Classification of intraoperative arthroscopic findings n (%).

Area	Pale	Pink	Red
RI	14 (35.0)	13 (32.5)	13 (32.5)
SAB	7 (17.5)	18 (45.0)	15 (37.5)
BG	21 (52.5)	11 (27.5)	8 (20.0)

RI, rotator interval; *SAB*, subacromial bursa; *BG*, bicipital groove.

Table III
Correlation between Doppler findings and arthroscopic classification.

Area	Hypervascularity area			PDUS grading system		
	Correlation	*P* value	95% CI	Correlation	*P* value	95% CI
RI	0.82	.001*	0.63 to 0.88	0.70	.001*	0.51 to 0.83
SAB	0.01	.91	−0.19 to 0.41	−0.02	.887	−0.28 to 0.33
BG	−0.03	.85	−0.27 to 034	0.30	.058	0.003 to 0.57

RI, rotator interval; *SAB*, subacromial bursa; *BG*, bicipital groove; *CI*, confidence interval.
*Statistically significant ($P < .001$).

axillary arteries have a cranial, caudal, and medial blood supply to the RI.[2,24] Therefore, measurement at a single site may lead to incorrect evaluation in the RI. We consider that measurement at 3 sites, as in the present study, improves the reliability of hypervascularity evaluation of the RI. The reason for the lack of correlation in the SAB may be the evaluating position. In the present study, it was performed in the shoulder extension position for visualization of the SAB. In the extension position, the SAB is subjected to a strong compression force and the microvessels disappear; however, when evaluating the rotator cuff and SAB, it is recommended that the rotator cuff be examined in the shoulder extension position.[7] Therefore, we should consider the observation position and area for the evaluation of hypervascularity of the SAB by US. The reason for the lack of correlation in the BG may be the fact that US evaluates the arcuate artery that branches from the anterior circumflex humeral artery. The arcuate artery supplies blood to the humeral head[5,11] and is located about 10 mm inferiorly from the most cranial part of the greater tuberosity and 3 to 4 mm medially from the medial wall of the greater tuberosity.[27] Therefore, the measurement of the BG in PDUS may be anatomically observing the arcuate artery and not synovitis. In addition, although arthroscopic findings in the BG were evaluated from the articular side and bursal side, the observation area in arthroscopic findings in the BG may be different from the area in PDUS.

The current results would support the determination of the timing of surgical intervention and the content of rehabilitation. Synovectomy is the treatment of choice in patients with severe pain, but imaging evaluation to confirm synovitis before surgery has not yet been established. It would be beneficial for clinicians to establish imaging evaluations that provide a preoperative view of the intra-articular condition. Rehabilitation after ARCR is commonly performed with range of motion exercises, rotator cuff muscle strengthening, and mobilization. However, the assessment of inflammation after ARCR is not objective because it is based on the patient's chief complaint and swelling, making it difficult to unify the content of rehabilitation. A recent study reported that US is a more sensitive tool for assessing joint inflammatory activity in rheumatoid arthritis than clinical evaluation.[22] The present study results indicate that hypervascularity in the RI can be used as an objective evaluation of the glenohumeral synovitis at preoperative evaluation or during rehabilitation after ARCR.

Our study has several limitations. First, the PDUS grade and intraoperative arthroscopic findings were semiquantitative evaluations. Recent US imaging technologies have been shown to be more accurate and sensitive for micro blood flows in connective tissues. In previous reports, contrast-enhanced US[8,9,21] and superb microvascular imaging[17,19] have been used to evaluate hypervascularity via US. Conventional PDUS imaging suffers from technical limitations associated with the visualization and quantitative evaluation of fine vessels or low-velocity blood flow. Moreover, the position and pressure of the probe may affect the current results. For optimization of the PDUS, we conducted the evaluation in the same position, with a generous amount of scanning gel, and in several scanning areas. Although the present study showed high agreement in intraobserver variations during the analysis of PDUS, inter-rater reliability has not been studied. Because US and arthroscopic findings are inherently technically demanding, a new system for quantitative evaluation of synovitis in the shoulder joint may provide high inter-rater reliability.

Second, we selected partial-thickness rotator cuff tear in the present study because we separately evaluated the inside and outside of the glenohumeral joint. In clinical practice, subacromial and glenohumeral synovitis should be considered in small or middle rotator cuff tears compared with large or massive rotator cuff tears. However, differences between partial- and full-thickness rotator cuff tear were not evaluated in this study.

Third, the discrepancy of the evaluated areas between PDUS and arthroscopic findings may affect the results. The RI was evaluated by PDUS from the subacromial side and by arthroscopy from the glenohumeral side. Because an RI lesion is a thin tissue, we consider

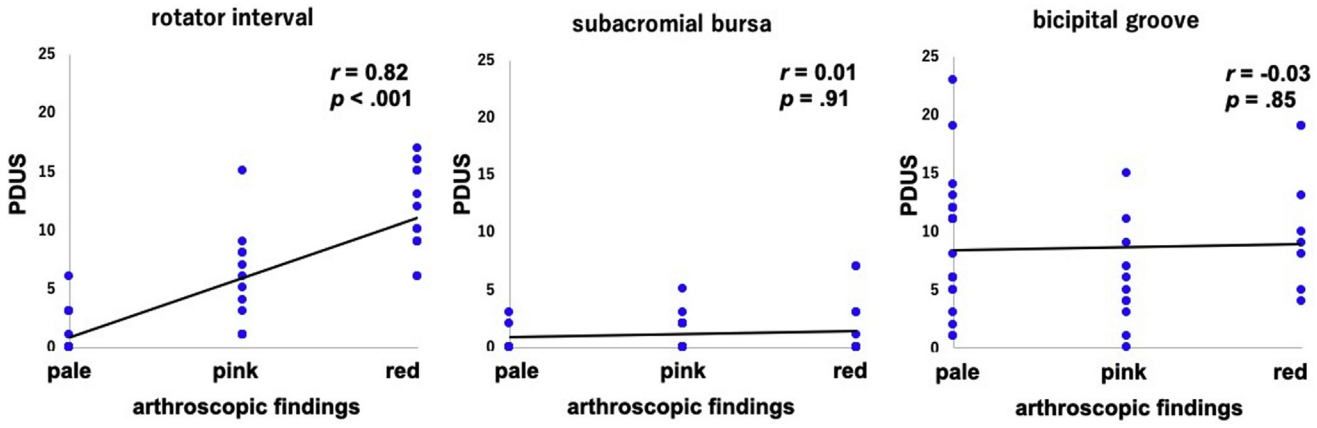

Figure 5 Correlation between the hypervascularity area and arthroscopic classification. *PDUS*, power Doppler ultrasonography.

that this different observation side would not be significant. However, this indirect evaluation may actually be considerable.

Conclusion

We investigated the correlation between preoperative Doppler flow area, our original PDUS grade, and intraoperative arthroscopic classification in the RI, SAB, and BG. The Doppler flow area and the PDUS grade showed a high correlation of arthroscopic synovitis for the RI. Therefore, visualization of hypervascularity in the RI area could be a reliable measure for the assessment of glenohumeral synovitis in patients with partial-thickness rotator cuff tear.

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