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Changes in blood flow in the dorsal scapular artery and relationship to shoulder joint function in rotator cuff tears

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A R T I C L E I N F O

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Level of evidence: Anatomy Study; Imaging

Background: One of the pain-related factors in rotator cuff tears (RCTs) is abnormal scapular motion, which is thought to be related to the levator scapulae muscle activation. Additionally, attention has recently focused on the peak systolic velocity (PSV) as one of the causes of pain, but blood flow outside of the vessels supplying the rotator cuff has not been clarified. This study aimed to determine the difference in PSV in the dorsal scapular artery (DSA), which is the vessel that supplies the levator scapulae muscles, and the association between PSV and pain and shoulder function in patients with RCTs between the tear and nontear sides.

Methods: This study included 31 patients with RCTs with tear and nontear sides. Magnetic resonance imaging and radiographic examinations included Cofield classification, Goutallier classification, thickening of the coracohumeral ligament, and measurement of the acromiohumeral interval. Clinical evaluation included an automatic range of motion (ROM) for flexion, abduction, and external rotation (ER), a visual analog scale, and the Shoulder36. PSV was evaluated using ultrasound pulsed Doppler mode to assess PSV of DSA. The PSV of DSA on the first rib was drawn in the medial aspect of the suprascapular angle in the long axis, and the maximum PSV waveform was measured three times. The average value was used for further analysis.

Results: The PSV in the DSA was significantly higher ($P = .04$, 95% confidence interval: 0.2-7.6) on the tear (22.6 ± 7.4 cm/s) than the nontear sides (18.9 ± 6.9 cm/s). In addition, a significant negative correlation ($r = -0.46$, $P = .0087$) was found between PSV in DSA and ER on the tear side.

Conclusion: This study revealed a significantly increased PSV in the DSA on the tear side in RCTs and negatively correlated with ER ROM. The results suggest that increased PSV in the DSA may contribute to ER ROM limitation in the glenohumeral joint.

Rotator cuff tears (RCTs) are a common cause of shoulder pain, and various factors have been reported to contribute to pain in RCTs, including age, dominant hand, body mass index, and fear-avoidance beliefs for physical activity.[13,17] Conversely, the severity of the tear (eg, tear size, retraction, superior humeral head migration, rotator cuff muscle atrophy) is not associated with pain.[7] A systematic review by Barcia et al reported altered scapular position and kinematics in RCTs.[2] Scibek et al investigated the relationship between scapulohumeral rhythm, pain, and tear size in patients with RCTs and revealed a relationship between pain and tear size and scapulohumeral rhythm, with greater pain and tear size leading to greater reliance on scapular kinematics.[26] Ishikawa et al measured the angle of upward scapular rotation and elasticity of the upper trapezius, levator scapulae, and rhomboid major muscles in patients with symptomatic RCTs, asymptomatic RCTs, and normal subjects via ultrasound elastographic technique to investigate muscle activity related to abnormal scapula motion. They revealed a significantly decreased upward scapular rotation in patients with symptomatic RCTs, which was attributed to the levator scapulae muscle activation.[15] This suggests the involvement of excessive levator scapulae muscle contraction in abnormal scapular motion in patients with RCTs.

Recent studies have focused on blood flow as a cause of pain. Abnormal vascularization in the rotator interval (RI), axillary pouch, and intertubercular groove could be associated with pain scores, tear size, and joint range of motion (ROM) in patients with symptomatic RCTs and frozen shoulder.[25] The arterial supply to the rotator cuff muscles is generally provided by the subscapular, circumflex

The Ethics Committee of Tottori Prefectural Central Hospital approved this study (approval number: 2021-6).

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scapular, posterior circumflex humeral, and suprascapular arteries.[19] Additionally, Asano et al revealed the association between the peak systolic velocity (PSV) of the anterior humeral circumflex artery (AHCA), which is measured by the ultrasound imaging system, and the severity of synovitis of the RCT.[1] PSV of the AHCA is associated with the severity of synovitis in RCTs and is useful in assessing the inflammation of synovitis.[31] This could be due to an increase in blood flow velocity to supply blood to the abnormally increased neovascularization of the synovium.[8] Sachinis et al investigated blood biomarkers for the pathogenesis of pain in RCTs and revealed that inflammation and substance P, interleukin (IL)1a, IL1b, IL2, IL6, IL8, IL10, tumor necrosis factor -α, and vascular endothelial growth factor were related.[24] This suggests that increased inflammatory cytokines cause peritendinous pain and increased blood flow velocity around the rotator cuff. Therefore, pain in RCTs is thought to be related to the blood flow velocity of AHCA.

In conjunction with the aforementioned report that levator scapulae muscle activation affects decreased scapular upward rotation in patients with symptomatic RCTs, we hypothesized that blood flow changes may occur not only in the arteries supplying the rotator cuff but also in the arteries supplying the periscapular region. Specifically, we focused on the dorsal scapular artery (DSA), which supplies the levator scapula muscle. The DSA is from two major vessels, the subclavian artery or transverse cervical artery,[23] which supplies the levator scapulae and rhomboid muscles, and the DSA runs deep to the levator scapulae and rhomboid muscles.[30] Additionally, the deep branch of the DSA runs deep to the greater rhomboid muscle and gives several perforating branches to the rhomboid and trapezius muscles and the overlying skin.[21] Furthermore, Verenna et al reported that DSA might be a factor in thoracic outlet syndrome by passing through the brachial plexus and compressing the nerves.[30] Hence, DSA may affect pain and joint function in the upper extremity, but to our knowledge, the relationship between DSA and pain and shoulder joint function in patients with RCT is unclear. Therefore, we hypothesize that blood flow is increased in DSA in patients with RCTs, which we expect as a factor reflecting shoulder joint pain and function. This study aimed to compare PSV in the DSA between the tear and nontear sides of patients with RCT using ultrasound imaging devices and to determine the association between PSV in the DSA and pain and shoulder joint function.

Material and methods

Participants

Inclusion criteria are patients with preserved RCTs and RCTs for suture surgery at Tottori Prefectural Central Hospital from June 2021 to February 2023. Exclusion criteria were cases with massive tears with pseudoparalysis to the point of difficulty with automatic movement, comorbidities, such as cardiac disease, diabetes, or hypertension that could affect blood flow, or difficulty identifying DSA blood flow. The analysis included 31 patients and excluded 2 patients with pseudoparalysis due to massive tears caused by trauma. This study was conducted after obtaining approval from the Ethics Committee of Tottori Prefectural Central Hospital (approval number: 2021-6) and after fully explaining the purpose and methods of the study to the participants and obtaining their consent.

Magnetic resonance imaging and radiographic examination

The Cofield classification was used to grade tears: small (<1 cm), medium (1-3 cm), large (3-5 cm), and massive (>5 cm).[6] The Goutallier classification was used to evaluate fatty infiltration of the rotator cuff: stages 0 (no fatty degeneration), 1 (mild fatty degeneration and muscle atrophy), 2 (less fatty degeneration than muscle), 3 (equal extent of muscle and fatty degeneration), and 4 (the greater extent of fatty degeneration than muscle).[11] Thickening of the coracohumeral ligament (CHL) was based on the report of Andrew et al, and the average of three measurements of the CHL thickness was used as the representative value in the nonfat suppressed sagittal oblique sequence in the magnetic resonance imaging.[4] Acromiohumeral interval was measured on X-ray as the shortest distance between the cortical bone on the inferior aspect of the acromion and the most proximal cortical bone of the humeral head.[12]

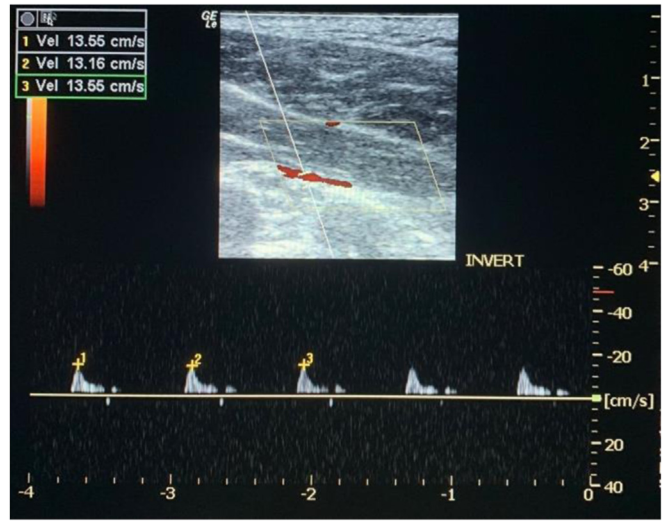

Figure 1 Method of measuring the peak velocity in the dorsal scapular artery in the long-axis pulse Doppler ultrasound image.

Clinical evaluation

Physical function was assessed by an automatic ROM in flexion, abduction, and external rotation (ER), and the visual analog scale was used as a pain scale. The patient automatically measured the ROM in flexion, abduction, and ER to the maximum extent possible, and the angles were measured with a goniometer on both the tear and nontear sides. The visual analog scale measures pain intensity, with a 10-cm horizontal line with no pain at the left end and maximal pain at the right end, and this line was marked by the patient to indicate the level of intensity of pain at rest. The Shoulder36 (Sh36) was assessed as a patient-based outcome. Sh36 was developed by the Japanese Orthopaedic Association and the Japanese Shoulder Society in 2010 as a patient-based scale to assess the relationship between activities of daily living and shoulder joint function. Sh36 consists of six domains: 1) activity-related pain severity, 2) ROM restrictions, 3) effects of muscle strength on activities, 4) effects of the problems on the patient's sense of well-being, 5) effect on activities of daily living, and 6) the degree of determent on athletic ability. Each scale relates to the function of the patient's upper extremity, and each item is scored on a scale of 0 to 4, with five possible responses ranging from "not possible" to "no difficulty." The scores in each domain are averaged and range from 0 (most severe impairment) to 4 (no impairment). A correlation was reported between Sh36 and Quick Disability of the Arm, Shoulder, and Hand.[27]

Assessment of blood flow

The PSV was measured using an ultrasound imaging system (GE LOGIQe). A 7-12 MHz linear probe was used. The pulse Doppler

Table I
Clinical characteristics of all patients.

Characteristic	N = 31
Age	64.8 ± 10.7
Sex	
Male	17 (54%)
Female	14 (45%)
Height	162.4 ± 7.9
Weight	62.9 ± 11.5
Trauma	18
Nontrauma	13
Cofield	
Small	12 (38%)
Medium	12 (38%)
Large	7 (22%)
Massive	0 (0%)
Goutallier	
0	13 (41%)
1	14 (45%)
2	3 (9%)
3	1 (1%)
4	0 (0%)

The Cofield classification was measured to grade the tears: small (<1 cm), medium (1-3 cm), major (3-5 cm), and massive tears (>5 cm). The Goutallier classification was measured to evaluate fatty infiltration of the rotator cuff: stages 0 (no fatty degeneration), 1 (mild fatty degeneration and muscle atrophy), 2 (less fatty degeneration than muscle), 3 (the equal extent of muscle and fatty degeneration), and 4 (the greater extent of fatty degeneration than muscle).

Table II
Comparison of active range of motion and peak systolic velocity in the dorsal scapular artery between the tear and nontear sides.

	Tear side	Nontear side	*P* value	95% CI (upper, lower)
ROM				
FE	108.7 ± 40.0	155.6 ± 18.9	<.01*	63.1, 30.8
AB	96.5 ± 44.0	161.5 ± 22.1	<.01*	83.0, 47.0
ER	45.5 ± 23.5	66.9 ± 14.6	<.01*	32.4, 11.8
PSV in the DSA	22.6 ± 7.4	18.9 ± 6.9	.04*	7.6, 0.2

FE, flexion; *AB*, abduction; *ER*, external rotation; *CI*, confidence interval; *ROM*, range of motion; *PSV*, peak systolic velocity; *DSA*, dorsal scapular artery.
*$P < .01$.

method was used to evaluate blood flow velocity to assess PSV in the DSA. The patient was seated on the table with the hip and knee joints each flexed 90° and the upper limbs hanging down toward the trunk. The eyes gazed forward. The patient was instructed to relax completely. The Doppler was manually adjusted for gain until the color box was almost uniformly filled with the first color and only the smallest amount of the following signal began to appear.[28] The DSA, which is located medial to the superior angle of the scapula and on the first rib, was delineated in the short axis with the ultrasound probe; the beating was confirmed on the Doppler image; and then the probe was rotated to delineate the vessel in the long axis. In a prior study, the DSA was observed in 94% at this specific site,[5] and our study observed the DSA in all cases. The angle of incidence was set at 60°. The maximum PSV waveform was measured thrice using the manual tracing function in the ultrasound device after obtaining a stable blood flow waveform, and the average value was used as the representative value (Fig. 1). A physical therapist with 12 years of experience and 5 years of ultrasound device use performed all blood flow measurements. PSV in the DSA was measured twice in 12 participants, with three consecutive measurements three days apart, to check reproducibility. The percentage of agreement between the two measurements of the measured representative values was calculated as intraexaminer reliability intraclass correlation coefficients (ICC [1.2]). The ICC (1,2) for the DSA measurements was 0.95 (95% confidence interval [CI]: 0.84-0.99).

Table III
Clinical characteristics of Sh36, acromiohumeral interval, and coracohumeral ligament (CHL) in the tear side.

	Tear side
Sh36-P	2.69 ± 1.0
Sh36-ROM	2.66 ± 0.95
Sh36-MS	2.04 ± 1.23
Sh36-GH	3.57 ± 2.36
Sh36-ADL	2.85 ± 0.76
Sh36-S	1.74 ± 1.44
AHI	8.24 ± 2.24
VAS	2.25 ± 2.36
CHL	3.85 ± 1.38

Sh36-P, the severity of activity-related pain; *Sh36-ROM*, the restrictions to range of motion; *Sh36-MS*, the effects of muscle strength on activities; *Sh36-GH*, the effects of the problems on the patient's sense of well-being; *Sh36-ADL*, the effect on activities of daily living; *Sh36-S*, the degree of determent on athletic ability; *VAS*, visual analog scale; *AHI*, acromiohumeral interval; *CHL*, coracohumeral ligament.

Table IV
Correlation between the peak velocity in the dorsal scapular artery and each variable on the tear side.

	P value	r
Cofield	.46	−0.13
Goutallier	.74	0.06
AHI	.08	0.31
ROM-FE	.44	−0.14
ROM-AB	.34	−0.18
ROM-ER	<.01	−0.46*
VAS	.18	0.24
Sh36-P	.44	−0.14
Sh36-ROM	.89	0.024
Sh36-MS	.49	−0.12
Sh36-GH	.06	−0.34
Sh36-ADL	.6	−0.09
Sh36-S	.93	−0.01
CHL	.09	−0.3

AHI, acromiohumeral interval; *ROM*, active range of motion; *FE*, flexion; *AB*, abduction; *ER*, external rotation; *VAS*, visual analog scale; *Sh36-P*, the severity of activity-related pain; *Sh36-ROM*, the restrictions to range of motion; *Sh36-MS*, the effects of muscle strength on activities; *Sh36-GH*, the effects of the problems on the patient's sense of well-being; *Sh36-ADL*, the effect on activities of daily living; *Sh36-S*, the degree of determent on athletic ability; *CHL*, coracohumeral ligament.
*$P < .01$.

Data analysis

Statistical processing was performed using Statistical Package for the Social Sciences Statistics Version 20, and differences between the two groups were compared using a two-sample *t*-test or Wilcoxon rank sum test after checking for normality and equal variances. Correlations between the DSA and each item were determined by Pearson's product rate or Spearman's rank correlation coefficient.

Results

Clinical characteristics of patients were shown in Tables I-III. The PSV in the DSA on the tear and nontear sides was 22.6 ± 7.4 cm/s and 18.9 ± 6.9 cm/s on the nontear side, respectively, and was significantly higher on the tear side ($P = .04$, 95% CI: 0.2-7.6, Table II). The results of the correlations for each item are shown in Table IV. Statistical processing revealed a significant negative correlation between the PSV and ER on the tear side ($r = -0.46$, $P = .0087$, Fig. 2).

Discussion

This study aimed to compare the PSV in the DSA between the tear and nontear sides of RCT cases and to further determine the

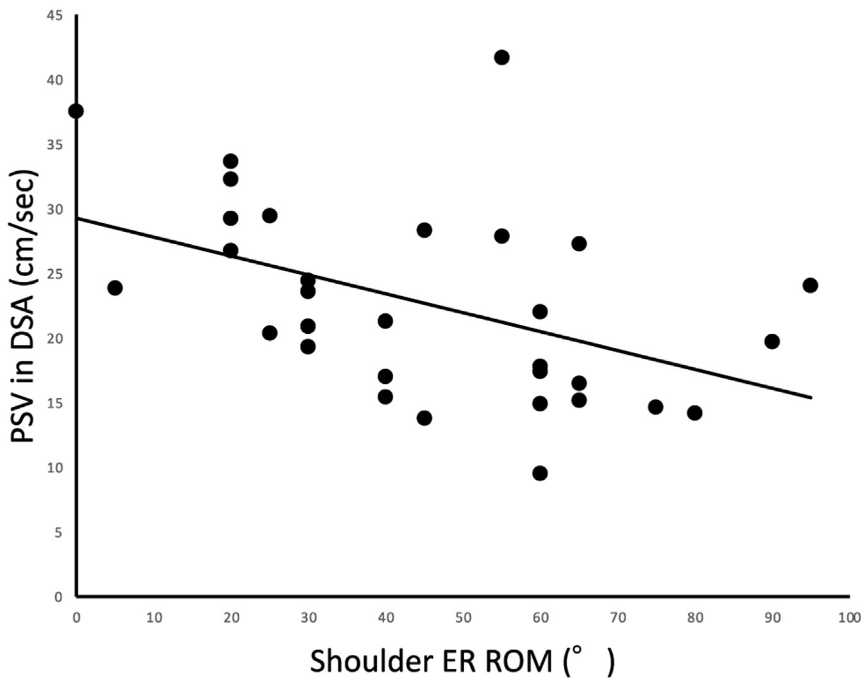

Figure 2 Correlation between the peak systolic velocity (PSV) in the dorsal scapular artery (DSA) and shoulder external rotation (ER) of range of motion (ROM).

association between the blood flow changes of DSA and pain and shoulder function. We hypothesize that blood flow is increased in DSA in patients with RCTs, which we expect as a factor reflecting shoulder joint pain and function. The results revealed a significantly increased PSV in the DSA on the tear side. This result supports our hypothesis. Additionally, results investigating the relationship with shoulder joint function revealed that PSV in the DSA on the tear side was not associated with pain but had a significant negative correlation with the ER ROM. To the best of our knowledge, reports have examined changes in PSV in the AHCA in RCT cases, but this is the first study to focus on blood flow in the DSA, which supplies the levator scapula and rhomboid muscles.[30]

The association between RCTs and blood flow has been widely reported in the AHCA, which is an artery that supplies the rotator cuff and synovium. Terabayashi et al investigated the blood flow of the AHCA in patients with RCT and healthy controls and revealed the association between night pain and PSV in the AHCA.[29] Similarly, Watanabe et al revealed the association between PSV in the AHCA and night pain severity.[31] Furthermore, Asano et al revealed that PSV in the AHCA was associated with synovial inflammation severity.[1] The increased PSV in the AHCA may be attributed to inflammation based on the above. Conversely, the DSA is not an artery that directly supplies the rotator cuff and may not be related to inflammation due to RCTs. However, the AHCA originates from a branch of the axillary artery, which in turn originates from the subclavian artery,[20] and the DSA also originates either directly from the subclavian artery or from a branch of the transverse carotid artery.[14] In particular, they both have the characteristic of branching from vessels originating in the subclavian artery. Inflammation increases blood flow to surrounding vessels because of the role of microcirculation in supplying oxygenated blood to tissues, maintaining tissue-wide blood flow despite central blood pressure changes, and linking local blood flow to local metabolic needs.[16] Therefore, the increased oxygen demand and increased local metabolic needs due to inflammation caused by the tear may increase blood flow velocity to provide sufficient blood supply to the affected area, resulting in an increased PSV response not only in the AHCA but also in the DSA originating from the subclavian artery.

More interestingly, a negative correlation was found between the DSA and the ER (Fig. 2). Sasanuma et al investigated imaging findings of blood flow changes in symptomatic RCTs using 3-dimensional dynamic magnetic resonance imaging and revealed that all RCTs had burning signs of abnormal blood flow in the RI, which were associated with pain score, tear size, and ROM.[25] Additionally, the ascending branches of the anterior circumflex humeral artery are reported to supply the subscapularis muscle (SSC), the lateral 1/3 of the superior glenohumeral ligament, and the RI.[22] As mentioned above, the PSV in the AHCA is increased in RCTs, suggesting that the AHCA reflects the inflammatory state of the RI, SSC, and synovium. These tissues are tensed in ER,[10,18] thus the tissues hypersensitized by inflammation are likely stretched and stimulated in the ER, resulting in ROM limitation. Thus, DSA reflects increased blood flow throughout the arterial blood flow originating from the subclavian artery, which may have been related to ER because it indirectly assesses inflammation in the tissues surrounding the RI. Interestingly, the DSA slightly supplies the medial border of the scapula of the SSC[32] and the supraspinatus muscle,[19] which may be related to ER, since it indirectly assesses inflammation of the peri-RI tissues. Gao et al revealed that the DSA was a feeding vessel of the brachial plexus and contributes to the blood supply of a large area located mainly at the level of the distal trunk, branches, and proximal cords of the brachial plexus.[9] Chaijaroonkhanarak et al revealed the highest frequency of DSA passage to the brachial plexus between the upper and middle trunks (63.2%).[3] Thus, DSA also supplies blood to the SSC, supraspinatus muscle, and brachial plexus, thus it may directly reflect the inflammatory state caused by these injuries and may be associated with ER. Similarly, the PSV may increase in DSA when ER is limited by contracture. However, since there was no correlation with CHL thickness, we speculate that ER restriction is primarily the result of inflammation of the RCTs. This is a cross-sectional study; we would like to examine the relationship between changes in PSV in the DSA and improvement in shoulder joint function, especially ER, by conducting an intervention study. In conclusion, the PSV in the DSA may reflect the degree of inflammation around the rotator cuff. The PSV may have increased in the highly inflamed state, resulting in ER limitation. Future studies are needed to examine the relationship between PSV in the DSA and the AHCA in patients with RCT and to examine differences in tear sites.

This study has several limitations. First, we did not measure inflammation biomarkers although PSV in the DSA is suggested to be related to inflammation. Additionally, we only compared the tear and nontear sides and not the healthy controls and asymptomatic cases. Therefore, the influence of intrinsic factors is unknown. Moreover, scapular motion is abnormal in patients with RCTs, but physical therapy has a modest effect on scapular interventions.[2] However, we hope that future investigations of the effects of periscapular interventions on blood flow velocity and shoulder joint function will allow for the development of new physiotherapy.

Conclusion

The present study revealed a significantly increased PSV in the DSA on the tear side of the RCTs which was further associated with the ER. The observed increase in PSV in the DSA may indicate an inflammatory response of RCTs, which may have been associated with the restriction of ER.

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