J Shoulder Elbow Surg (2020) 29, 2043–2050

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Comparison of shoulder muscle strength, cross-sectional area, acromiohumeral distance, and thickness of the supraspinatus tendon between symptomatic and asymptomatic patients with rotator cuff tears

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Background: The purpose of this study was to demonstrate the differences in shoulder muscle strength, cross-sectional area of the rotator cuff muscles, acromiohumeral distance, and supraspinatus tendon thickness between symptomatic and asymptomatic patients with rotator cuff tears.
Methods: Thirty-two symptomatic patients and 23 asymptomatic patients with rotator cuff tears participated in this study. Data of the patients with any type of tear and supraspinatus tear were analyzed. We evaluated the isometric torque, cross-sectional area of the rotator cuff muscles, supraspinatus tendon thickness, acromiohumeral distance, range of motion, and Western Ontario Rotator Cuff Index.
Results: Asymptomatic patients showed greater isometric torque of shoulder abduction and internal rotation than symptomatic patients with any type of tear ($P \leq .01$). Asymptomatic patients also demonstrated greater cross-sectional area of the supraspinatus ($P < .01$); however, there was no significant difference in the cross-sectional area of the other cuff muscles. There was also no significant difference in the supraspinatus tendon thickness ($P = .10$). The acromiohumeral distance at 90° of shoulder abduction was larger ($P = .04$) in asymptomatic patients. Additionally, similar tendencies were observed in the results of patients with supraspinatus tears, except for the isometric torque of shoulder external rotation. This torque was greater ($P < .01$) in asymptomatic patients.
Conclusion: Asymptomatic patients showed greater shoulder range of motion, muscle strength of shoulder abduction and internal rotation, small occupation ratio of supraspinatus tendon thickness as a percentage of acromiohumeral distance, and large cross-sectional area of supraspinatus.
Level of Evidence: Level III; Case-Control Design; Prognosis Study
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Keywords: rotator cuff tear; asymptomatic patients; acromiohumeral distance; cross-sectional area; tendon thickness; isometric torque

Institutional review board approval was received from Nobuhara Hospital and Institute of Biomechanics (no. 188) Ethics Committee, Kyoto University Graduate School of Medicine (no. R1277).

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https://doi.org/10.1016/j.jse.2020.02.017

Rotator cuff tear (RCT) is a degenerative disease associated with pain and muscle weakness due to a deficit in the function of the rotator cuff, and it occurs in 50% of the population aged 65 years and older.[23,31] It has been reported that some patients experience no pain despite the RCT.[5,9,23,30,31] Previous studies have demonstrated that the tear size, atrophy, and fatty degeneration deteriorate over time after the RCT.[3,6,18,20,25] Therefore, the goal of conservative rehabilitation for symptomatic patients with RCT could be set to improve shoulder function to the level of the asymptomatic patients, because it would be difficult to expect recovery of full function after a torn rotator cuff. In the context of the difference in shoulder function between symptomatic and asymptomatic patients with RCT, prior studies have reported that asymptomatic patients exhibited greater muscle strength for shoulder flexion, abduction, and external rotation than symptomatic patients.[1,30] Kelly et al[11] measured muscle contraction during shoulder flexion, and their results showed that asymptomatic patients exhibited less muscle contraction of the supraspinatus (SSP), infraspinatus (ISP), and upper fibers of the trapezius. Moreover, Shinozaki et al[27] reported that asymptomatic patients demonstrated greater muscle contraction of the anterior and middle fibers of deltoid and less muscle contraction of the upper fibers of the trapezius during arm elevation in the scapular plane. Relative to the scapular movement, Kijima et al[12] and Yamaguchi et al[29] revealed that there was no significant difference in the scapular kinematics during arm elevation between symptomatic and asymptomatic patients. Additionally, according to the prospective cohort studies, analyzing the factors related to the pain development in asymptomatic shoulder with RCT, Mall et al[17] found that shoulder external rotation strength did not correlate with pain development. Moosmayer et al[24] reported that asymptomatic patients showed weak shoulder strength of flexion and abduction, which were similar to that of symptomatic patients. However, it is unclear whether the shoulder strength of the symptomatic patients with RCT was truly weaker or not, compared with the asymptomatic patients, because the pain would affect the measurements of the muscle strength and muscle contraction. The unaffected rotator cuff in RCT patients hypertrophied to compensate the lost function caused by RCT.[13,21] Hence, it is thought that this is a compensatory mechanism aiming the improvement of shoulder function in asymptomatic patients. Therefore, it is necessary to evaluate not only the shoulder strength but also the cross-sectional area (CSA) of rotator cuff in symptomatic and asymptomatic patients with RCT. As far as we know, there is no study conducted yet to evaluate these parameters.

Subacromial impingement is one of the mechanisms of shoulder pain in RCT patients as it leads the pressure on the rotator cuff tendon and subacromial bursa. Baumer et al[1] investigated the acromiohumeral distance (AHD) during arm elevation in asymptomatic patients with RCT and compared it to that of healthy people in a control group. Their results showed that the AHD of the asymptomatic patients was smaller, but this difference was not of any statistical significance. However, they did not compare the AHD of asymptomatic and symptomatic patients with RCT. Likewise, the swelling of the SSP tendon might cause subacromial impingement syndrome. Michener et al[22] examined the tendon thickness of SSP in shoulder impingement patients and healthy subjects and found that patients with impingement syndrome showed swelling of the SSP tendon. However, there has been no previous study comparing the tendon thickness of SSP between asymptomatic and symptomatic patients with RCT.

The purpose of the present study was to evaluate the shoulder strength, CSA of the rotator cuff muscles, AHD, and tendon thickness of the SSP in asymptomatic patients with RCT and to compare them to those of symptomatic patients. We hypothesized that the asymptomatic patients showed larger CSA of the unaffected rotator cuff, thinner tendon thickness of SSP, and greater AHD, which could all contribute to the condition of having no pain.

Materials and methods

Participants

Symptomatic patients with RCT were recruited at the Nobuhara Hospital from August 2017 to May 2018. We included patients with more than 90° of active shoulder abduction. The exclusion criteria were surgical history, rheumatoid arthritis, cervical spine disease, and neurologic lesions. Besides, we excluded the patients with the SSP tendon retracted to the medial side of the anatomic neck of humerus. Asymptomatic shoulders were the unaffected side in patients who received medical treatment for their shoulder disease at the Nobuhara Hospital. Additionally, an asymptomatic shoulder was defined as a shoulder without any pain at all during the previous 3 months before the measurements. All RCTs were examined with MRI (APERTO Eterna; Hitachi Medical Corporation, Tokyo, Japan). We calculated the sample size using G* power 3.1 software (Heinrich Heine University, Duesseldorf, Germany), and the results showed that 52 subjects were required for our study (effect size = 0.8, $\alpha = 0.05$, power = 0.8). We also examined data of the patients with SSP tear to normalize the size of the torn rotator cuff.

CSA and muscle strength

The CSA of rotator cuff muscles was analyzed by T2-weighted oblique sagittal-plane MRI, in which the scapular spine and coracoid process lead to the Y-section, following experience of previous studies (Fig. 1).[10,28,32] We calculated the CSA of the SSP, ISP, subscapularis (SSC), and teres minor (TM) using ImageJ (National Institutes of Health, Bethesda, MD, USA). To normalize the data for body size, we used the ratio of the SSP muscle CSA divided by the CSA of the SSP fossa for data analysis, following the Fuch et al method.[4] Shoulder isometric strength was assessed using μ-tas F1 (Anima Corporation, Tokyo, Japan) with a belt, which was reported in the previous studies.[2,7,14] We used the

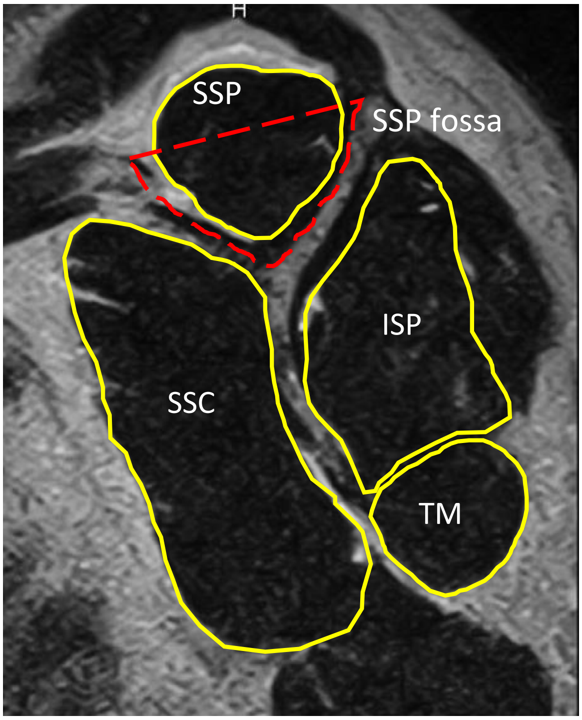

Figure 1 CSA measurements in the rotator cuff muscles. The CSA of rotator cuff muscles is indicated with yellow *solid lines*, and the CSA of the supraspinatus fossa is marked by the *red dotted line*. *CSA*, cross-sectional area; *SSP*, supraspinatus; *ISP*, infraspinatus; *SSC*, subscapularis; *TM*, teres minor.

average data of 3 trials of isometric contractions for 3 seconds. Muscle strength was measured in 30° of shoulder abduction, shoulder external rotation, and internal rotation at an arm-dependent position with the forearm kept neutrally. To calculate the isometric torque, we multiplied shoulder strength and length of the upper limb (from the acromion to the radial styloid process) for shoulder abduction, and shoulder strength and length of the forearm (from the lateral epicondyle of the humerus to the radial styloid process) for shoulder rotation. Additionally, shoulder isometric torque was divided by the body weight for data analyses.

Enlargement of SSP tendon and AHD

The tendon thickness of the SSP was measured as the length of the perpendicular line at the anatomic neck of the humerus on a T2-weighted oblique coronal-plane MRI at the middle point of the acromion (Fig. 2). We quantified the AHD in the B-mode images taken by ultrasonography (UF-450AX Bettius, Fukuda Denshi Co. Ltd., Tokyo, Japan), equipped with a 38-mm linear array transducer (7 MHz), following prior studies' experiences.[15,19,26] Measurements were done twice; the average of the values was calculated and used for the subsequent analysis. For this measurement, subjects were asked to relax and place their hand on the lap (resting position; ABD 0°), and then subjects held their arm at 90° in shoulder abduction and external rotation (ABD 90°). To scan the images, the probe was set vertical to the lateral side of the acromion, at the middle point between the anterior edge of the acromion and the acromial edge. We evaluated the occupation ratio of SSP tendon thickness as a percentage of AHD (ABD 90°), which was calculated in reference to a previous study.[22]

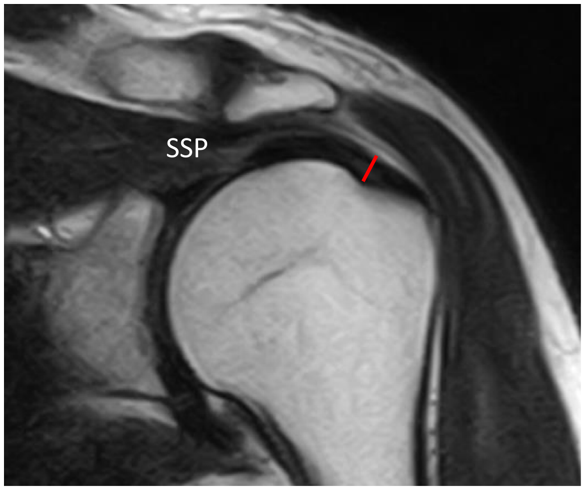

Figure 2 Measurement of SSP tendon thickness. The tendon thickness of the SSP is defined as the length of the *vertical line (red line)* at the anatomic neck of the humerus on T2-weighted oblique sagittal-plane magnetic resonance image at the middle point of the acromion. *SSP*, supraspinatus.

This ratio was calculated by the following formula: (tendon thickness / AHD) $\times$ 100.

Clinical outcomes

We measured the active shoulder range of motion (ROM) in flexion, abduction, external rotation (arm-dependent position), and the distance between the spinous process of C7 to thumb, with the patient's hand behind the back (C7 to thumb). Pain was also evaluated during these examinations. The subjective shoulder function was assessed by Western Ontario Rotator Cuff (WORC) Index. This index consists of 21 questions in 5 domains (physical symptoms, sports and recreation, work, lifestyle, and emotion), which score 0-100 (highest score is 2100, which indicates worst shoulder function). It is reported that the WORC index is a valid and reliable measurement scale.[16]

Intraclass correlation coefficients

To demonstrate the intraclass correlation coefficients (ICC) for the measurement in this study, we calculated the intrarater reliability and standard error of measurement (SEM) in 12 shoulders of 6 healthy male subjects (age 25.8 $\pm$ 3.2 years). ICC calculation used the average data for ROM in 1 measurement, isometric muscle strength measured 3 times, tendon thickness of SSP measured twice, and AHD measured twice, with a 1-week period in between. The SEM was calculated using the following formula: $SEM = SD\sqrt{1 - ICC}$. All the measurements were performed by a physical therapist, who had been working at an orthopedic hospital for 12 years and was experienced in musculoskeletal ultrasonographic scanning.

Statistical analysis

We used the SPSS version 22 (IBM, Armonk, NY, USA) for all statistical analyses. The normal distribution of all data was

Table I Comparison of the characteristics between asymptomatic and symptomatic RCT patients

	Asymptomatic RCT (n = 23)	Symptomatic RCT (n = 32)	*P* value
Sex,* n			.37
Male	15	17	
Female	8	15	
Age, yr, mean ± SD	67.0 ± 6.5	65.7 ± 6.5	.45
Height, cm, mean ± SD	160.6 ± 9.6	161.0 ± 7.4	.85
Body mass, kg, mean ± SD	58.6 ± 16.8	60.9 ± 9.6	.55
Partial-thickness tear,* n	13	10	.06
Involved tendon tear in rotator cuff,* n			.31
SSP	19	21	
SSP + ISP	3	4	
SSC + SSP	0	3	
SSC + SSP + ISP	1	4	

RCT, rotator cuff tear; *SD*, standard deviation; *SSP*, supraspinatus; *ISP*, infraspinatus; *SSC*, subscapularis.
* Chi-square test (other differences were analyzed with a Student *t* test).

checked using the Shapiro-Wilk test. The measurement data between symptomatic and asymptomatic RCT patients were compared using Student *t* test and Mann-Whitney *U* test. To indicate the difference in the 2 groups, we calculated the average values, standard deviation, 95% confidence interval for differences, *P* values, and effect size (Cohen d[8]). An effect size of 0.2 was considered a "small" effect, 0.5 was considered a "medium" effect, and more than 0.8 was considered a "large" effect. The level of statistical significance was set at .05.

Results

Thirty-two symptomatic RCT patients and 23 asymptomatic RCT patients met our inclusion criteria (Table I). There were 19 shoulders (82%) with SSP tears, 3 shoulders (13%) with SSP and ISP tears, and 1 shoulder with SSC, SSP, and ISP tears in the symptomatic RCT group. In contrast, there were 21 shoulders (65%) with SSP tears, 4 shoulders (12%) with SSP and ISP tears, 3 shoulders (9%) with SSC and SSP tears, and 4 shoulders (12%) with SSC, SSP, and ISP tears in the asymptomatic RCT group. As for the tear type, partial-thickness tear was described in 10 asymptomatic (31%) and 13 symptomatic (56%) patients ($P = .06$). In the symptomatic RCT group, the average duration of symptoms was 11.8 months (range 1-120 months), and 20 patients (63%) had a history of trauma. Furthermore, there were 11 patients (34%) who experienced pain at rest, 26 patients (81%) with pain at night, and 30 patients (93%) with movement-evoked pain.

To normalize the tear size of the rotator cuff, we analyzed the data in patients with SSP tear. There were 21 symptomatic patients (age: 64.0 ± 6.2 years; sex: 10 male and 11 female; height: 161.3 ± 7.7 cm; body mass: 62.8 ± 9.6 kg) and 19 asymptomatic patients (age: 67.1 ± 6.1 years; sex: 14 male and 5 female; height: 161.6 ± 10.0 cm; body mass: 58.5 ± 18.4 kg). Partial-thickness tear was described in 10 symptomatic (47%) and 5 asymptomatic (26%) patients ($P = .16$). In symptomatic patients with SSP tear, the average duration of symptoms was 11.3 months (range 1-120 months), and 13 patients (61%) had history of trauma. Seven patients (33%) suffered from pain at rest, 16 patients (76%) suffered from pain at night, and 20 patients (95%) suffered from movement-evoked pain.

Intraclass correlation coefficients

The ICC and SEM for all measurements are shown in Table II. The ICC values for ROM measurements varied from 0.77 to 0.95, and for the isometric muscle strength measurements from 0.86 to 0.97. The ICC values for AHD measurements (ABD 0° and ABD 90°) were 0.85.

The SEM for ROM measurements ranged from 1.9-3.5 degrees, and for C7 to thumb SEM was 1.7 cm. For the isometric muscle strength measurements, SEM was between 3.6 and 5.6 N. Lastly, the SEM for AHD measurements (ABD 0° and ABD 90°) was 0.4 and 0.5 mm, respectively.

Comparison between asymptomatic and symptomatic patients with any type of RCT

The measurement data of patients with any type of RCT are shown in Table III. Symptomatic patients demonstrated less range of motion compared with the asymptomatic patients in all directions ($P \leq .03$), and they reported movement-evoked pain in shoulder flexion (n = 8, 25%), shoulder abduction (n = 24, 75%), shoulder external rotation (n = 1, 3%), and C7 to thumb (n = 10, 31%). Conversely, no subjects from the asymptomatic group had movement-evoked pain.

As for the isometric torque, asymptomatic patients showed greater torque in shoulder abduction and shoulder

Table II Intrarater reliability for all measurements

	ICC	SEM
ROM		
Flexion	0.77°	2.9°
Abduction	0.95°	1.9°
External rotation	0.78°	3.5°
C7 to thumb, cm	0.87	1.7
Isometric muscle strength, N		
Abduction	0.86	4.7
External rotation	0.93	3.6
Internal rotation	0.97	5.6
AHD, mm		
AHD (ABD 0°)	0.85	0.4
AHD (ABD 90°)	0.85	0.5

ROM, range of motion; *ABD*, abduction; *AHD*, acromiohumeral distance; *ICC*, intraclass correlation coefficients; *SEM*, standard error for measurements.

internal rotation compared with the symptomatic patients ($P \leq .01$). There was no significant difference in isometric torque in shoulder external rotation between 2 groups ($P =$ .06, effect size = 0.41).

Likewise, symptomatic patients reported pain during muscle strength examination in shoulder abduction (n = 19, 59%), shoulder external rotation (n = 8, 25%), and shoulder internal rotation (n = 5, 15%). No asymptomatic patients reported pain during the muscle strength examination.

The CSA of SSP in the asymptomatic group was greater (asymptomatic vs. symptomatic patients, 0.90 vs. 0.72; $P <$ .01). However, no significant differences were found in the CSA of ISP, SSC, and TM (effect size: ISP 0.23, SSC 0.15, TM 0.04).

The tendon thickness of SSP was 4.9 mm in asymptomatic patients and 5.5 mm in symptomatic patients. This difference did not reach the statistical level ($P = .10$, effect size = 0.44).

There was no significant difference in AHD (ABD 0°) ($P = .69$); however, symptomatic patients showed smaller AHD (ABD 90°) (symptomatic vs. asymptomatic; 8.0 vs. 8.8 mm, $P = .04$).

In regard to the occupation ratio of the SSP tendon thickness as a percentage of AHD (ABD 90°), there was a significant difference between the asymptomatic (56.4%) and symptomatic groups (71.4%) ($P < .01$).

Comparison between asymptomatic and symptomatic patients with SSP tear

The results for SSP tear patients are shown in Table IV. In the ROM measurements, some of the symptomatic patients had movement-evoked pain in shoulder flexion (n = 5, 23%), shoulder abduction (n = 16, 76%), and C7 to thumb (n = 7, 33%). Also, while measuring isometric torque, the pain occurred in shoulder abduction (n = 13, 61%), shoulder external rotation (n = 7, 33%), and shoulder internal rotation (n = 3, 14%).

The results in the patients with SSP tear demonstrated the same tendency as those of the patients with any type of RCT, except for isometric torque of shoulder external rotation. The isometric torque of shoulder external rotation in asymptomatic patients was greater compared with the symptomatic patients ($P < .01$).

Discussion

We compared the shoulder isometric strength, CSA, AHD, tendon thickness, ROM, and shoulder function score between symptomatic and asymptomatic patients with RCT. This is the first study to clarify the differences in CSA, AHD, and SSP tendon thickness in RCT groups with and without pain.

In this study, the symptomatic patients exhibited lower isometric strength in shoulder abduction and shoulder internal rotation compared with the asymptomatic patients. Baumer et al[1] reported that the isometric strength in shoulder flexion and abduction of symptomatic RCT patients was smaller than that of asymptomatic patients; however, they could not find significant differences in shoulder external rotation and internal rotation (ABD 0°). Yamamoto et al[30] demonstrated that muscle strength of shoulder abduction and external rotation, evaluated by manual muscle testing in symptomatic RCT patients, were lower than those in asymptomatic patients. This discrepancy regarding muscle strength could be explained by the method used for measuring pain. The possible reasons for the weak muscle strength of shoulder abduction and internal rotation in the symptomatic group were considered to be atrophy of the SSP muscle and the high rate of patients with SSC tear in the symptomatic group. Furthermore, our hypothesis that the unaffected rotator cuff muscles could be hypertrophied was not supported by the results in this study. In previous studies, Kikukawa et al[13] reported that TM muscles in patients presented ISP tear hypertrophy. Melis et al[21] presented a study according to which the TM muscle hypertrophied in patients with SSC and SSP tears and it hypotrophied in patients with SSP, ISP, and TM tears. We included only 8 (25%) RCT patients with ISP tear in the symptomatic group and 4 (17%) RCT patients in the asymptomatic group. Patients with various types of RCT participated in this study. These facts could explain why our hypothesis was not confirmed by the results of our study.

To confirm our hypothesis that asymptomatic patients had hypertrophy in the unaffected rotator cuff, we analyzed the data of patients with an SSP tear. The results presented a similar tendency as in analyses of patients with any type of RCT, except for the isometric torque of shoulder external rotation. The isometric torque in all directions in symptomatic patients with an SSP tear were weak compared with

Table III Comparison of the clinical outcome between asymptomatic and symptomatic patients with all sizes of RCT tears

	Asymptomatic RCT (n = 23)	Symptomatic RCT (n = 32)	95% CI of the difference	*P* value	Effect size
ROM					
Flexion*	152° ± 8°	137° ± 16°	8°, 21°	<.01†	1.18
Abduction	130° ± 16°	102° ± 19°	17°, 37°	<.01†	1.59
External rotation	56° ± 13°	46° ± 17°	0°, 18°	.03‡	0.66
C7 to thumb, cm	19 ± 7	29 ± 11	4, 15	<.01†	1.08
Isometric torque, Nm/kg					
Abduction*	0.79 ± 1.16	0.36 ± 0.18	0.00, 0.84	<.01†	0.54
External rotation*	0.35 ± 0.44	0.22 ± 0.07	−0.02, 0.29	.06	0.41
Internal rotation*	0.46 ± 0.54	0.26 ± 0.10	0.00, 0.39	<.01†	0.51
CSA of rotator cuff muscle					
SSP	0.90 ± 0.28	0.72 ± 0.23	0.03, 0.31	.01†	0.70
ISP	1.61 ± 0.41	1.51 ± 0.43	−0.13, 0.32	.41	0.23
SSC*	2.99 ± 0.90	2.86 ± 0.74	−0.32, 0.57	.57	0.15
TM*	0.54 ± 0.19	0.55 ± 0.21	−0.12, 0.09	.79	0.04
Thickness of the SSP tendon, mm*	4.9 ± 1.4	5.5 ± 1.3	−1.3, 0.1	.10	0.44
AHD, mm					
AHD (ABD 0°)	11.0 ± 1.5	11.2 ± 1.8	−1.1, 0.7	.69	0.12
AHD (ABD 90°)	8.8 ± 1.1	8.0 ± 1.5	0.0, 1.5	.04‡	0.60
SSP tendon thickness as % of AHD (ABD 90°)	56.4 ± 15.3	71.4 ± 22.7	−25.9, −3.9	<.01†	0.77
WORC*	159 ± 213	1052 ± 388	−1057, −728	<.01†	2.85

CSA, cross-sectional area; *ROM*, range of motion; *ABD*, abduction; *SSP*, supraspinatus; *ISP*, infraspinatus; *SSC*, subscapularis; *TM*, teres minor; *AHD*, acromiohumeral distance; *WORC*, Western Ontario Rotator Cuff Index; *RCT*, rotator cuff tear; *CI*, confidence interval.
Values of CSA of rotator cuff muscle were normalized by the CSA of supraspinatus fossa.
* Mann-Whitney *U* test (other differences were analyzed with a Student *t* test).
† $P < .01$.
‡ $P < .05$.

that in asymptomatic patients. Nevertheless, no significant differences were found in the CSA of unaffected rotator cuff muscles between the 2 groups. Based on these results, we concluded that the unaffected rotator cuff muscles did not hypertrophy in the asymptomatic group with SSP tear, and that the atrophy of the SSP might be the reason for the pain in patients with SSP tear. Further studies are needed to clarify the difference in CSA between symptomatic and asymptomatic patients with large or massive RCT and to demonstrate the benefits of conservative treatment for RCT patients with the atrophy of SSP.

In relation to AHD, this study revealed that the AHD (ABD 90°) of the symptomatic group was small (0.8 mm) compared with that of the asymptomatic group, and their difference was larger than the SEM (0.5 mm) of AHD (ABD 90°) in this study. Moreover, the occupation ratio of the SSP tendon thickness as a percentage of AHD (ABD 90°) was greater in symptomatic patients. Michener et al[22] established this percentage to be 61.7% at the arm-dependent position in subacromial impingement patients. The decreases in AHD as the arm was elevated led to the high occupation ratio of the SSP tendon thickness of AHD (71.4%) in symptomatic patients in this study. Hence, pain might have been caused by the narrowing of AHD, which compressed the SSP tendon under the acromion in symptomatic patients with RCT.

In regard to the range of shoulder motion, prior studies have not identified significant differences in any direction between symptomatic and asymptomatic RCT patients.[1,30] These results were inconsistent with our study. One of the possible reasons could be the difference in the severity of symptomatic RCT patients. Baumer et al[1] reported that symptomatic RCT patients showed no limitation in the shoulder motion and also presented good patient-reported outcomes (WORC index: 93.1), although there was no information of the tear type in the subjects. Thus, the severity of the RCT might have a certain influence on our results. Another possible reason was thought to be the pain during the examination of the ROM. Previous studies have clarified that the decrease in the range of shoulder motion was related to the pain presented by RCT patients.[17,24] Similarly, in our study we observed that the limitation in shoulder motion in symptomatic patients might correlate with their pain. However, it is unclear whether pain causes the limitation in shoulder motion or if the limitation in shoulder motion increases the pain. Further study will have to identify the mechanisms of pain development in RCT patients.

One limitation of this study is that it included RCT patients with various types of tears and both partial- or full-thickness tears. Although we confirmed that there were no

Table IV Comparison of the clinical outcome between asymptomatic and symptomatic patients with SSP tear

	Asymptomatic SSP tear (n = 19)	Symptomatic SSP tear (n = 21)	95% CI of the difference	*P* value	Effect size
ROM					
Flexion*	152° ± 9°	139° ± 16°	4°, 21°	<.01†	1.00
Abduction	129° ± 16°	104° ± 21°	12°, 37°	<.01†	1.33
External rotation	56° ± 14°	44° ± 19°	0°, 22°	.03‡	0.71
C7 to thumb, cm	19 ± 7	29 ± 12	−16, −3	<.01†	1.01
Isometric torque, Nm/kg					
Abduction*	0.87 ± 1.27	0.35 ± 0.20	−0.05, 1.08	<.01†	0.57
External rotation*	0.39 ± 0.47	0.21 ± 0.07	−0.03, 0.39	<.01†	0.53
Internal rotation*	0.50 ± 0.58	0.26 ± 0.10	−0.02, 0.50	<.01†	0.57
CSA of rotator cuff muscle					
SSP	0.91 ± 0.21	0.73 ± 0.22	0.04, 0.32	.01‡	0.83
ISP	1.61 ± 0.32	1.49 ± 0.46	−0.14, 0.37	.36	0.30
SSC*	3.09 ± 0.68	2.94 ± 0.78	−0.32, 0.61	.53	0.20
TM*	0.51 ± 0.13	0.56 ± 0.22	−0.16, 0.07	.46	0.27
Thickness of the SSP tendon, mm*	4.9 ± 1.5	5.6 ± 1.4	−1.5, 0.3	.42	0.48
AHD, mm					
AHD (ABD 0°)	10.9 ± 1.6	11.5 ± 1.7	−1.7, 0.4	.25	0.36
AHD (ABD 90°)	8.8 ± 1.0	8.0 ± 1.4	0, 1.6	.02‡	0.72
SSP tendon thickness as % of AHD (ABD 90°)	56.1 ± 16.4	72.4 ± 25.2	−30.1, −2.5	.02‡	0.76
WORC*	160 ± 224	1124 ± 374	−1160, −767	<.01†	3.12

CSA, cross-sectional area; *ROM*, range of motion; *ABD*, abduction; *SSP*, supraspinatus; *ISP*, infraspinatus; *SSC*, subscapularis; *TM*, teres minor; *AHD*, acromiohumeral distance; *WORC*, Western Ontario Rotator Cuff Index; *CI*, confidence interval.
Values of CSA of rotator cuff muscle were normalized by the CSA of supraspinatus fossa.
* Mann-Whitney *U* test (other differences were analyzed with a Student *t* test).
† $P < .01$.
‡ $P < .05$.

significant differences in the tear size and tear type between the asymptomatic and symptomatic RCT groups, they might have affected the results. For example, we might have measured the CSA in the rotator cuff muscles and tendon thickness of the SSP at different positions between patients with partial- and full-thickness tears because of the retraction of torn rotator cuff muscles. In the second place, the tendon thickness of the SSP was measured at the arm-dependent position. This value was then used for the calculation of the occupation ratio of the SSP tendon thickness as a percentage of AHD (ABD 90°). The tendon thickness should have been measured at ABD 90°; however, it was difficult to measure the tendon thickness in this position because the tendon insertion was moving underneath the acromion. Another limitation came from the fact that this study did not identify which factors were responsible for the differences in ROM, muscle strength, CSA, and AHD between the asymptomatic and symptomatic patients because we did not measure the electromyogram of the shoulder muscles, scapular movement, and spine posture. In the future, longitudinal studies with large sample sizes should focus on the mechanism of pain reduction in patients with RCT according to the tear size, using multiple regression analysis. This would help determine the efficacy of conservative treatment that can improve the range of shoulder motion and AHD (ABD90°) for symptomatic RCT patients.

Conclusion

This study demonstrated the differences in the shoulder ROM, muscle strength, CSA in rotator cuff muscles, AHD, and the tendon thickness of the SSP in symptomatic and asymptomatic RCT patients. Asymptomatic patients showed greater shoulder range of motion, muscle strength of shoulder abduction and internal rotation, small occupation ratio of the SSP tendon thickness as a percentage of acromiohumeral distance, and large CSA of SSP. Further analyses of the patients with SSP tear demonstrated a similar tendency in the results of patients with any type of RCT, except for the isometric torque of shoulder external rotation.

Disclaimer

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Baumer TG, Dischler J, Mende V, Zauel R, van Holsbeeck M, Siegal DS, et al. Effects of asymptomatic rotator cuff pathology on in vivo shoulder motion and clinical outcomes. J Shoulder Elbow Surg 2017;26:1064-72. https://doi.org/10.1016/j.jse.2016.11.048
2. Cools AM, De Wilde L, van Tongel A, Ceyssens C, Ryckewaert R, Cambier DC. Measuring shoulder external and internal rotation strength and range of motion: comprehensive intra-rater and inter-rater reliability study of several testing protocols. J Shoulder Elbow Surg 2014;23:1454-61. https://doi.org/10.1016/j.jse.2014.01.006
3. Fucentese SF, von Roll AL, Pfirrmann CW, Gerber C, Jost B. Evolution of nonoperatively treated symptomatic isolated full-thickness supraspinatus tears. J Bone Joint Surg Am 2012;94:801-8. https://doi.org/10.2106/jbjs.i.01286
4. Fuchs B, Weishaupt D, Zanetti M, Hodler J, Gerber C. Fatty degeneration of the muscles of the rotator cuff: assessment by computed tomography versus magnetic resonance imaging. J Shoulder Elbow Surg 1999;8:599-605.
5. Gill TK, Shanahan EM, Allison D, Alcorn D, Hill CL. Prevalence of abnormalities on shoulder MRI in symptomatic and asymptomatic older adults. Int J Rheum Dis 2014;17:863-71. https://doi.org/10.1111/1756-185X.12476
6. Hebert-Davies J, Teefey SA, Steger-May K, Chamberlain AM, Middleton W, Robinson K, et al. Progression of fatty muscle degeneration in atraumatic rotator cuff tears. J Bone Joint Surg Am 2017;99:832-9. https://doi.org/10.2106/JBJS.16.00030
7. Holt KL, Raper DP, Boettcher CE, Waddington GS, Drew MK. Hand-held dynamometry strength measures for internal and external rotation demonstrate superior reliability, lower minimal detectable change and higher correlation to isokinetic dynamometry than externally-fixed dynamometry of the shoulder. Phys Ther Sport 2016;21:75-81. https://doi.org/10.1016/j.ptsp.2016.07.001
8. Cohen J. Statistical power analysis. Curr Dir Psychol Sci 1992;1:98-101.
9. Jeong J, Shin DC, Kim TH, Kim K. Prevalence of asymptomatic rotator cuff tear and their related factors in the Korean population. J Shoulder Elbow Surg 2017;26:30-5. https://doi.org/10.1016/j.jse.2016.05.003
10. Jo CH, Shin JS. Cross-sectional area of the supraspinatus muscle after rotator cuff repair: an anatomic measure of outcome. J Bone Joint Surg Am 2013;95:1785-91. https://doi.org/10.2106/JBJS.L.00938
11. Kelly BT, Williams RJ, Cordasco FA, Backus SI, Otis JC, Weiland DE, et al. Differential patterns of muscle activation in patients with symptomatic and asymptomatic rotator cuff tears. J Shoulder Elbow Surg 2005;14:165-71. https://doi.org/10.1016/j.jse.2004.06.010
12. Kijima T, Matsuki K, Ochiai N, Yamaguchi T, Sasaki Y, Hashimoto E, et al. In vivo 3-dimensional analysis of scapular and glenohumeral kinematics: comparison of symptomatic or asymptomatic shoulders with rotator cuff tears and healthy shoulders. J Shoulder Elbow Surg 2015;24:1817-26. https://doi.org/10.1016/j.jse.2015.06.003
13. Kikukawa K, Ide J, Kikuchi K, Morita M, Mizuta H, Ogata H. Hypertrophic changes of the teres minor muscle in rotator cuff tears: quantitative evaluation by magnetic resonance imaging. J Shoulder Elbow Surg 2014;23:1800-5. https://doi.org/10.1016/j.jse.2014.03.014
14. Kim HM, Teefey SA, Zelig A, Galatz LM, Keener JD, Yamaguchi K. Shoulder strength in asymptomatic individuals with intact compared with torn rotator cuffs. J Bone Joint Surg Am 2009;91:289-96. https://doi.org/10.2106/JBJS.H.00219
15. Kim K, Kim HG, Song D, Yoon JY, Chung ME. Ultrasound dimensions of the rotator cuff and other associated structures in Korean healthy adults. J Korean Med Sci 2016;31:1472-8. https://doi.org/10.3346/jkms.2016.31.9.1472
16. Kirkley A, Alvarez C, Griffin S. The development and evaluation of a disease-specific quality-of-life questionnaire for disorders of the rotator cuff: The Western Ontario Rotator Cuff Index. Clin J Sport Med 2003;13:84-92. https://doi.org/10.1097/00042752-200303000-00004
17. Mall NA, Kim HM, Keener JD, Steger-May K, Teefey SA, Middleton WD, et al. Symptomatic progression of asymptomatic rotator cuff tears: a prospective study of clinical and sonographic variables. J Bone Joint Surg Am 2010;92:2623-33. https://doi.org/10.2106/JBJS.I.00506
18. Maman E, Harris C, White L, Tomlinson G, Shashank M, Boynton E. Outcome of nonoperative treatment of symptomatic rotator cuff tears monitored by magnetic resonance imaging. J Bone Joint Surg Am 2009;91:1898-906. https://doi.org/10.2106/JBJS.G.01335
19. McCreesh KM, Anjum S, Crotty JM, Lewis JS. Ultrasound measures of supraspinatus tendon thickness and acromiohumeral distance in rotator cuff tendinopathy are reliable. J Clin Ultrasound 2016;44:159-66. https://doi.org/10.1002/jcu.22318
20. Melis B, DeFranco MJ, Chuinard C, Walch G. Natural history of fatty infiltration and atrophy of the supraspinatus muscle in rotator cuff tears. Clin Orthop Relat Res 2010;468:1498-505. https://doi.org/10.1007/s11999-009-1207-x
21. Melis B, DeFranco MJ, Lädermann A, Barthelemy R, Walch G. The teres minor muscle in rotator cuff tendon tears. Skeletal Radiol 2011;40:1335-44. https://doi.org/10.1007/s00256-011-1178-3
22. Michener LA, Subasi Yesilyaprak SS, Seitz AL, Timmons MK, Walsworth MK. Supraspinatus tendon and subacromial space parameters measured on ultrasonographic imaging in subacromial impingement syndrome. Knee Surg Sport Traumatol Arthrosc 2015;23:363-9. https://doi.org/10.1007/s00167-013-2542-8
23. Milgrom C, Schaffler M, Gilbert S, van Holsbeeck M. Rotator-cuff changes in asymptomatic adults: the effect of age, hand dominance and gender. J Bone Joint Surg Br 1995;77:296-8.
24. Moosmayer S, Tariq R, Stiris M, Smith HJ. The natural history of asymptomatic rotator cuff tears: a three-year follow-up of fifty cases. J Bone Joint Surg Am 2013;95:1249-55. https://doi.org/10.2106/JBJS.L.00185
25. Safran O, Schroeder J, Bloom R, Weil Y, Milgrom C. Natural history of nonoperatively treated symptomatic rotator cuff tears in patients 60 years old or younger. Am J Sports Med 2011;39:710-4. https://doi.org/10.1177/0363546510393944
26. Schneebeli A, Egloff M, Giampietro A, Clijsen R, Barbero M. Rehabilitative ultrasound imaging of the supraspinatus muscle: intra- and inter-rater reliability of thickness and cross-sectional area. J Bodyw Mov Ther 2014;18:266-72. https://doi.org/10.1016/j.jbmt.2013.09.009
27. Shinozaki N, Sano H, Omi R, Kishimoto KN, Yamamoto N, Tashiro M, et al. Differences in muscle activities during shoulder elevation in patients with symptomatic and asymptomatic rotator cuff tears: analysis by positron emission tomography. J Shoulder Elbow Surg 2014;23:e61-7. https://doi.org/10.1016/j.jse.2013.06.009
28. Thomazeau H, Rolland Y, Lucas C, Duval JM, Langlais F. Atrophy of the supraspinatus belly: assessment by MRI in 55 patients with rotator cuff pathology. Acta Orthop Scand 1996;67:264-8.
29. Yamaguchi K, Sher JS, Andersen WK, Garretson R, Uribe JW, Hechtman K, et al. Glenohumeral motion in patients with rotator cuff tears: a comparison of asymptomatic and symptomatic shoulders. J Shoulder Elbow Surg 2000;9:6-11.
30. Yamamoto A, Takagishi K, Kobayashi T, Shitara H, Osawa T. Factors involved in the presence of symptoms associated with rotator cuff tears: a comparison of asymptomatic and symptomatic rotator cuff tears in the general population. J Shoulder Elbow Surg 2011;20:1133-7. https://doi.org/10.1016/j.jse.2011.01.011
31. Yamamoto A, Takagishi K, Osawa T, Yanagawa T, Nakajima D, Shitara H, et al. Prevalence and risk factors of a rotator cuff tear in the general population. J Shoulder Elbow Surg 2010;19:116-20. https://doi.org/10.1016/j.jse.2009.04.006
32. Zanetti M, Gerber C, Hodler J. Quantitative assessment of the muscles of the rotator cuff with magnetic resonance imaging. Invest Radiol 1998;33:163-70.