SHOULDER ABDUCTION STRENGTH IS CORRELATED WITH ACROMIOHUMERAL DISTANCE IN PATIENTS WITH ACUTE SUBACROMIAL IMPINGEMENT SYNDROME SYMPTOMS BUT NOT WITH SUPRASPINATUS TENDON THICKNESS REGARDLESS OF DISEASE STAGE

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Abstract:

We aimed to investigate the relationships of isometric and eccentric shoulder abduction strength with acromiohumeral distance and supraspinatus tendon thickness based on the disease stage in patients with subacromial impingement syndrome. Eighty-two patients with subacromial impingement syndrome were assessed. Acromiohumeral distance and supraspinatus tendon thickness were measured using ultrasonography. Isometric and eccentric shoulder abduction strength were measured with a hand-held dynamometer. Spearman's correlation coefficients were calculated. Isometric (rho = 0.428, p=.021) and eccentric (rho = 0.487, p=.007) shoulder abduction strength showed moderate correlations with acromiohumeral distance in patients with acute symptoms (n = 29). There was no relationship between acromiohumeral distance and abduction strength in patients with chronic symptoms (n = 53) (p>.050). Supraspinatus tendon thickness showed no significant correlation with abduction strength (p>.050). These findings suggest that the relationship between acromiohumeral distance and abduction strength differs according to disease stage. However, supraspinatus tendon thickness was not correlated with abduction strength regardless of disease stage. In patients with acute subacromial impingement syndrome symptoms increasing shoulder abduction strength may be a potential strategy to improve acromiohumeral distance.

Key words: *muscle strength, rotator cuff, rehabilitation, ultrasonography*

Introduction

Subacromial impingement syndrome (SIS) is a common cause of shoulder pain and dysfunction (Ostör, Richards, Prevost, Speed, & Hazleman, 2005). The rotator cuff (RC) muscles play an essential role in shoulder stabilization and prevention of anterosuperior migration of the humeral head during shoulder abduction (Sangwan, Green, & Taylor, 2015). The supraspinatus, the most commonly involved muscle in SIS, is active during arm abduction (Ellis & Mahadevan, 2013; Reed, Cathers, Halaki, & Ginn, 2013) and is of the greatest practical importance among the RC muscles (Ellis & Mahadevan, 2013). Accordingly, decreased supraspinatus muscle activity (Reddy, Mohr, Pink, & Jobe, 2000) and shoulder abduction strength (Celik, Sirmen, & Demirhan, 2011; Miller, et al., 2016) and pathological changes in the supraspinatus tendon (Cholewinski, Kusz, Wojciechowski, Cielinski, & Zoladz, 2008; Leong, Tsui, Ying, Leung, & Fu, 2012; Michener, et al., 2015; Seitz, McClure, Finucane, Boardman, & Michener, 2011) are common in patients with SIS.

Although the general opinion is that the subacromial space (SAS) decreases (Graichen, et al., 1999; Hébert, Moffet, Dufour, & Moisan, 2003; Mackenzie, Herrington, Horlsey, & Cools, 2015) and supraspinatus tendon thickness (SsTT) increases (Leong, et al., 2012; Michener, et al., 2015) in patients with SIS, some studies reported no change (Leong, et al., 2012; Michener, et al.,

2015) or a decrease (Cholewinski, et al., 2008) in those parameters, compared to healthy controls. These conflicting results have been attributed to the stage of the disease (Mackenzie, et al., 2015; Seitz, et al., 2011).

There is some evidence of a possible relationship between shoulder muscle strength with SAS (Leong, et al., 2012; Leong, Tsui, Ng, & Fu, 2016; Schmidt, Engelhardt, Cools, Magnusson, & Couppé, 2021) and supraspinatus tendon morphology (Joensen, Couppe, & Bjordal, 2009). These relationships are often demonstrated by isometric muscle strength (Joensen, et al., 2009; Leong, et al., 2016; Schmidt, et al., 2021). Although assessment of the maximal isometric shoulder strength is an important component of the physiotherapy examination in clinical and research settings (Celik, et al., 2011; Cools, et al., 2014), none of these studies has investigated the relationship between SAS and SsTT with the maximal isometric or eccentric strength of RC muscles in patients with SIS. Besides, since pain often occurs also during the eccentric phase of the shoulder abduction (Camargo, Avila, Asso, & Salvini, 2010), and not only isometric strength deficits (Celik, et al., 2011; Miller, et al., 2016) but also eccentric strength deficits were demonstrated in shoulders with SIS (MacDermid, Ramos, Drosdowech, Faber, & Patterson, 2004), examining the eccentric strength may also be important. Determining these relationships and revealing whether they differ depending on the stage of the disease appears worth investigating (Mackenzie, et al., 2015). This can assist healthcare professionals in clinical decision-making while creating individual treatment programs tailored to the needs of patients at different disease stages.

We aimed to investigate the relationships of isometric and eccentric shoulder abduction strength with SAS measured by acromiohumeral distance (AHD) and SsTT based on the disease stage in patients with SIS. We hypothesized that the correlations between shoulder abduction strength and AHD and SsTT would be different for acute and chronic SIS.

Methods

Setting and participants

Eighty-two patients with SIS (45 females and 37 males) from Dokuz Eylul University Hospital volunteered to participate in this observational study. All participants provided written and oral informed consent, and the study was approved by the Ethics Committee of Dokuz Eylul University (Number: 4268-GOA). We performed sample selection and data collection at Dokuz Eylul University, School of Physical Therapy and Rehabilitation between August 2017 and September 2019. No previous study presented correlation data between isometric and eccentric shoulder abduction strength and SsTT and the SAS. Considering the findings of the previous studies, which investigated the relationships between the AHD and the strength of scapular muscles (Leong, et al., 2016) and shoulder external rotator muscles (Leong, et al., 2012), we anticipated medium correlations between variables and we used 0.50 value for correlation to calculate the number of patients (n=29 per group) required to determine a significant correlation with 80% power and 5% Type-I error level (GPower, version 3.1.7, Heinrich-Heine-Universität, Düsseldorf, Germany). Inclusion criteria were: (1) SIS diagnosis, (2) ≥18 years of age, (3) ≥three positives in five shoulder impingement tests: Neer's sign, Hawkins and Kennedy test, Empty Can test, painful arc of abduction, and external rotation (ER) resistance test (Michener, Walsworth, Doukas, & Murphy, 2009), (4) ability to complete the entire study procedure. The exclusion criteria were: (1) diagnosis of the adhesive capsulitis, (2) shoulder pain > 7/10 according to the Visual Analogue Scale (Timmons, Ericksen, Yesilyaprak, & Michener, 2016), (3) history of fracture in the upper extremity, (4) systemic musculoskeletal disease, (5) history of shoulder or cervical surgery, (6) glenohumeral instability (positive apprehension, relocation, or positive sulcus test), (7) positive findings for a full-thickness RC tear (positive lag sign, positive drop arm test or marked weakness with shoulder external rotation), (8) shoulder pain with cervical spine movement (Michener, et al., 2015) (9) diagnosis of chest deformity or scoliosis. Patients who had shoulder pain ≥ three months were classified as patients with chronic SIS symptoms and others as patients with acute SIS symptoms.

Procedures

Strength tests were performed by two physiotherapists who were experienced in the field of shoulder examination (five and four years for testers 1 and 2, respectively). Ultrasound imaging was performed by the first author who was experienced in the field of musculoskeletal ultrasound examination (nine years).

To measure SAS, a diagnostic ultrasound unit, LOGIQe (GE Healthcare, Wauwatosa, WI, USA) with a 7–12-MHz linear transducer set at 8 MHz was used to capture two-dimensional images in greyscale B-mode. Images were obtained while the patient was seated feet flat on the floor, with neutral trunk posture, head straight, and arms resting at the side (Michener, et al., 2015). We measured SAS twice at two locations and averaged the results for data analysis: 1. on the most anterior part of the acromial margin with the long axis of the transducer placed in the plane of the scapula and parallel to the flat surface of the acromion and 2. 1-cm behind the first measure. SAS was operationally defined as the AHD, the two-dimensional shortest linear distance between the anterior–inferior tip of the acromion and the humeral head (Desmeules, Minville, Riederer, Côté, & Frémont, 2004; Luque-Suarez, Navarro-Ledesma, Petocz, Hancock, & Hush, 2013; Mackenzie, et al., 2015). The AHD was measured (in mm) using the ultrasound unit's on-screen calipers by visually locating the superior aspect of the humeral head and the inferior aspect of acromion, and then measuring the linear distance (Figure 1A) (Michener, et al., 2015). As a result of test-retest measurements in ten patients, our intra-rater reliability for this method was excellent (ICC=0.99).

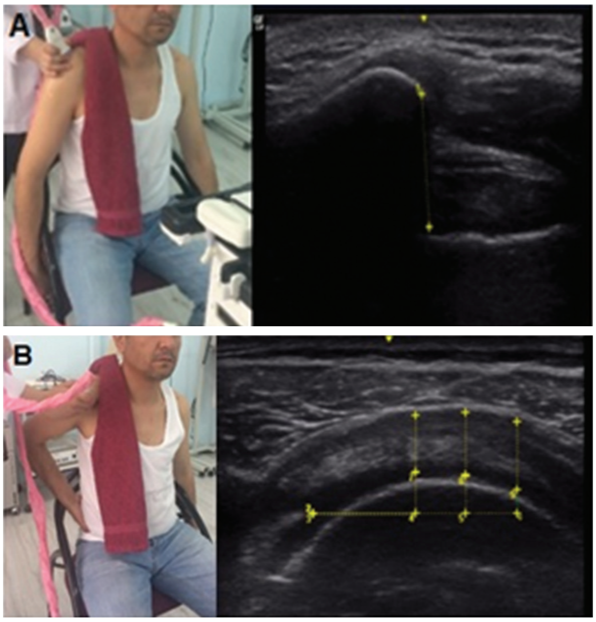

Figure 1. Ultrasonography measurement. A. Acromiohumeral distance assessment with ultrasonography, and ultrasound measurement of the acromiohumeral distance from the acromial tip to the humeral head. B. Supraspinatus tendon thickness assessment with ultrasonography and ultrasound measurement of the tendon thickness taken at 10, 15, and 20 mm lateral to the biceps tendon (transverse view).

SsTT measurement was performed using the same ultrasound unit with the same settings while the patient seated feet flat on the floor, with a neutral trunk posture and head straight. We asked the patients to place their hand of the involved side on the ipsilateral posterior hip with the humerus in extension. The transducer was placed on the anterior aspect of the shoulder, perpendicular to the supraspinatus tendon, and just anterior to the anterior-lateral margin of the acromion, and both the supraspinatus tendon and long head of the bicep's tendon were captured laterally in the transverse axis. Then, the transducer was tilted in the mediolateral direction, visualizing the long biceps brachii tendon, and the maximum tendon thickness was obtained. The lateral margin of the hyperechogenicity of the bicep's tendon was taken as the reference point. Three positions along the tendon were measured for thickness (in mm) at 10, 15, and 20 mm lateral to this reference point (Figure 1B).

First, we averaged the results of the three measurements for each of the two ultrasound images and then the average values for each image were averaged for data analysis. We measured the SsTT using the ultrasound unit's on-screen callipers via tendon borders, from the first hyperechoic region above the anechoic articular cartilage of the humeral head to the hyperechoic superior border of the tendon before the anechoic subdeltoid bursa (Cholewinski, et al., 2008; Joensen, et al., 2009; Michener, et al., 2015). Our intra-rater reliability for this method was excellent (ICC=0.93). In AHD and SsTT assessments, after the completion of capturing images of all the participants, AHD and SsTT measurements by the ultrasound on-screen callipers were performed without the strength results being known. An author who was not involved with the data collection performed the analysis.

We performed the strength tests with a hand-held dynamometer (HHD) (MicroFET®3, Hoggan Health Industries, West Jordan, UT, USA). The patients sat with their feet flat on the floor. We placed the patient's arm into the scapular plane using a plastic goniometer (Universal Baseline® 12" Plastic Goniometer 360°, NY, USA). The participants were instructed to maintain this plane during the test, and the researcher monitored the arm position. Each test was conducted three times, and the results were averaged. We provided 30 seconds of rest between the tests (Schrama, Stenneberg, Lucas, & van Trijffel, 2014). To avoid bias, the author that performed the strength assessments was not allowed to read the results of the HHD throughout the testing period. A trained assistant read and recorded the results.

To measure the isometric strength of shoulder abduction, we positioned the shoulder at 90° abduction in the scapular plane and external rotation (thumb pointing up) and the elbow at full extension (Figure 2). The bubble inclinometer was attached to the arm to ensure 90° shoulder abduction. After the explanation of the test, the participant performed one sub-maximal test for familiar-

Figure 2. Measurement of the isometric strength of shoulder abduction

ization. Then, the participant performed maximal isometric shoulder abduction effort while the tester gave downward resistance over the wrist with the HHD for 5-seconds (Dollings, Sandford, O'conaire, & Lewis, 2012). Our intra-rater (ICC=0.970 for both testers) and inter-rater reliability for this method were excellent (ICC=0.980).

To measure the eccentric strength of shoulder abduction, the starting position was 120° of abduction of the shoulder in the scapular plane, with the thumb pointing up and full extension of the elbow. The bubble inclinometer was attached to the arm to monitor humeral abduction angles throughout the test (Figure 3). Participants performed one sub-maximal testing for familiarization. Then, the participant performed the maximal eccentric effort, while the researcher pushed the arm just above the wrist from 120° to 30° of shoulder abduction at 30°/s (controlled with a metronome) using the HHD. Standardized verbal encouragement was provided during testing (Karabay, Yesilyaprak, & Sahiner Picak, 2020). Our intra-rater (ICC=0.976 and 0.978 for testers 1 and 2, respectively) and inter-rater (ICC = 0.940) reliability were excellent for this procedure. During the strength tests, some pain was allowed, however, this did not lead to not completing the test. Additionally, no patient reported increased pain on the test day and days following the test.

Figure 3. Measurement of the eccentric strength of shoulder abduction. A. Starting position. B. Ending position.

Statistical analysis

The normality of the distributions of the continuous data was analyzed with the Shapiro-Wilk test. Data are expressed as mean followed by standard deviation and median followed by interquartile range or percentages as appropriate. The distribution of sex, dominant side, and affected side between patients with acute SIS and chronic SIS were compared with the Chi-square test. Age, height, mass, and body mass index of the acute and chronic SIS patients were compared with the independent samples *t*-test. Duration of symptoms and pain intensity were compared with the Mann-Whitney U test. The association of isometric and eccentric muscle strength values with ultrasonographic data was analyzed by Spearman's rank correlation analysis. Correlation was classified as strong (rho ≥ 0.70), moderate (rho= 0.40 - 0.69), or weak (rho ≤ 0.39) (Guilford, 1956; Rowntree, 1981). The significance level was set at $p<.050$.

Results

Eighty-two patients with SIS were tested. Twenty-nine of those were classified as patients with acute SIS symptoms and fifty-three were patients with chronic SIS symptoms. Demographic, anthropometric, and clinical characteristics were similar (except for pain duration) between patients with acute and chronic symptoms (Table 1).

The results of ultrasonography and strength measurements are shown in Table 2. The AHD showed moderate correlation with both isometric (rho = 0.428, p=.021) and eccentric (rho = 0.487, p=.007) shoulder abduction strength in patients with acute SIS symptoms. However, abduction strength was not correlated with the AHD in patients with chronic SIS (p>.050). Moreover, there was no correlation between the SsTT and abduction strength in patients with both acute and chronic SIS (Table 3).

Discussion and conclusions

To our knowledge, this is the first study investigating the relationships between shoulder abduction strength and AHD and SsTT based on the stage of the SIS and examining the relationship of eccentric shoulder abduction strength with these ultrasonographic measurements. We found that, in patients with acute SIS symptoms, AHD was positively correlated with both isometric and eccentric shoulder abduction strength. AHD was not correlated with abduction strength in patients with chronic symptoms. SsTT was not correlated with abduction strength.

The literature emphasizes the importance of RC muscles in maintaining the SAS via depressing the humeral head to counteract the deltoid action to prevent superior migration of the humeral head (Leong, et al., 2012; Page, 2011). The supraspinatus is the most commonly involved muscle in SIS, and it is considered to be of the greatest practical importance among the RC muscles (Ellis & Mahadevan, 2013). Isometric shoulder abduction muscle strength, which is often referred to as supraspinatus muscle strength (Celik, et al., 2011; Habechian, Van Malderen, Camargo, & Cools, 2018; Kibler, Sciascia, & Dome, 2006), is frequently evaluated in patients with SIS for clinical and research aims (Celik, et al., 2011; Cools, et al., 2014; Makhni, et al., 2015). Celik et al. (2011) found that isometric shoulder abduction muscle strength (tested in the same position that we performed in this study) of the shoulder with SIS was significantly lower than the healthy opposite side and supraspinatus weakness

Table 1. Demographic, anthropometric, and clinical data of participants

Variables	Patients with acute SIS (n = 29)	Patients with chronic SIS (n = 53)	
Sex, n (%)			
Female	16 (55.2)	29 (54.7)	$p = 0.968$
Male	13 (44.8)	24 (45.3)	$X^2 = 0.002$
Dominant side, n (%)			
Right	26 (89.7)	49 (92.5)	$p = 0.668$
Left	3 (10.3)	4 (7.5)	$X^2 = 0.188$
Affected side, n (%)			
Right	17 (58.6)	25 (47.2)	$p = 0.312$
Left	12 (41.4)	28 (52.8)	$X^2 = 0.984$
	Mean (SD)	Mean (SD)	
Age, year	51.55 (12.47)	47.74 (13.64)	$p = 0.868$ t = 1.281
Height, m	1.66 (0.10)	1.68 (0.10)	$p = 0.821$ t = -0.836
Mass, kg	72.10 (14.00)	77.28 (14.43)	$p = 0.865$ t = -1.584
Body mass index, kg/m^2	26.25 (4.47)	27.50 (4.63)	$p = 0.998$ t = -1.197
	Median (interquartile range)	Median (interquartile range)	
Duration of pain, months	2.00 (1.00 – 2.00)	6.00 (3.75 – 11.00)	$p < 0.001$ * Z = -7.511
Pain intensity at rest, cm	1.00 (0.00 – 2.25)	2.00 (0.00 – 3.00)	$p = 0.286$ Z = -1.066
Pain intensity during overhead reaching, cm	4.80 (3.05 – 5.80)	6.00 (4.00 – 6.00)	$p = 0.141$ Z = -1.473

Note. * – significant difference between the groups; t – paired samples t-test; X^2 – chi-squared test; Z – Mann-Whitney U test.

Table 2. Ultrasonographic and strength data of the participants

Variables	Patients with acute SIS (n = 29)	Patients with chronic SIS (n = 53)
	Mean (SD)	Mean (SD)
AHD, mm	10.61 (1.34)	11.00 (1.24)
SsTT, mm	5.53 (1.22)	5.65 (0.92)
Shoulder abduction strength, kg	Median (interquartile range)	Median (interquartile range)
Isometric	5.90 (4.87 – 7.94)	6.87 (5.60 – 8.72)
Eccentric	7.00 (5.55 – 10.13)	8.03 (6.22 – 10.20)

Note. AHD – acromiohumeral distance; SsTT – supraspinatus tendon thickness.

Table 3. Correlations between ultrasonographic and strength measurements

	Patients with acute SIS (n = 29)				Patients with chronic SIS (n = 53)			
	Isometric strength		Eccentric strength		Isometric strength		Eccentric strength	
	rho	*p*	rho	*p*	Rho	*p*	rho	*p*
AHD, mm	0.428	.021	0.487	.007	-0.053	.709	0.076	.590
SsTT, mm	0.167	.387	0.083	.668	0.148	.291	0.212	.128

Note. AHD – acromiohumeral distance; rho – Spearman's correlation coefficients; SsTT – supraspinatus tendon thickness.

was related to the symptoms of SIS. Although they did not report the duration of symptoms for their population, the authors highlighted the importance of assessing supraspinatus strength and, if necessary, strengthening it during the treatment of SIS. Similarly, our findings highlight the importance of isometric shoulder abduction muscle strength in maintaining the SAS in patients with acute SIS symptoms.

SIS complaints often occur also during the eccentric phase of the shoulder abduction (Camargo, et al., 2010). Furthermore, lower electromyographic activity of the glenohumeral muscles has been demonstrated during the eccentric phase of the shoulder abduction (Hawkes, Khaiyat, Howard, Kemp, & Frostick, 2019). Reduced eccentric muscle control, as well as reduced isometric muscle control, may potentially increase superior humeral head translations, possibly leading to narrowing the SAS (Ludewig & Braman, 2011). However, to date, no study investigated the humeral head migration during the lowering phase of the shoulder abduction or the relationship between eccentric muscle strength and SAS. Despite the lower shoulder muscle activation, eccentric contractions create greater excitability in the motor cortex than concentric and isometric ones (Lepley, Lepley, Onate, & Grooms, 2017). High cortical activation levels in brain centers that are responsible for neuromuscular control have been reported during eccentric contractions (Kwon & Park, 2011; Lepley, et al., 2017). Perhaps this is why eccentric strength also plays a critical role in controlling the SAS. Overall, our findings support and further the Celik et al.'s (2011) suggestion. Increasing both isometric and eccentric shoulder abduction strength may be beneficial to improve SAS in patients with acute symptoms. In practice, while muscle strength measurement is generally performed as isometric strength testing (Celik, et al., 2011; Dollings, et al., 2012; Miller, et al., 2016), our results suggest that eccentric abduction strength should also be measured in patients with SIS and should be considered in strengthening programs in the presence of a deficit. Future longitudinal studies should be conducted on patients with acute SIS symptoms to investigate the ultrasonographic and clinical effects of shoulder abductors' strength training that targets both isometric and eccentric strength improvement.

The correlation found between shoulder abduction strength and AHD in patients with acute SIS symptoms was not demonstrated in patients with chronic SIS symptoms. Similarly, Leong et al. (2016) reported no correlation between scapular muscle strength and the AHD in athletes with RC tendinopathy with 29 months mean symptom duration. However, they did not discuss possible mechanisms underlying their finding. Increased scapular upward rotation in patients with chronic SIS symptoms is thought to be a compensatory mechanism used to maintain the width of the SAS and to reduce the shoulder pain experienced during movement in patients with SIS (Navarro-Ledesma, et al., 2019; Timmons, et al., 2016). In the present study, the patients with chronic SIS might have developed such compensatory biomechanical changes to avoid compression of the tendon in the SAS. However, our proposition should be interpreted with caution since we did not investigate scapular motions. In patients with chronic SIS symptoms, other factors that may affect the width of the SAS and the mechanisms that may explain the changes in SAS should be investigated. Nevertheless, the results of two studies that investigated the relationship between AHD and shoulder pain and function in patients with SIS may be consistent with our proposition (Desmeules, et al., 2004; Navarro-Ledesma, et al., 2017). Desmeules et al. (2004) found a significant correlation between increases in the AHD and shoulder function after a physiotherapy program in patients with SIS who were at the acute-subacute stage. In contrast, Navarro-Ledesma et al. (2017) found no correlation between AHD and shoulder pain and function in patients with chronic RC related shoulder pain. According to the combination of our findings and the abovementioned findings, the role of muscle strength and therefore AHD in the explanation of shoulder pain and disability may be different in patients at different SIS stages. The clinical implications of our findings are not yet fully understood, and further research is needed to examine the relationship between muscle strength and AHD in acute and chronic SIS, taking shoulder pain and disability into account.

Joensen et al. (2009) reported that side differences in SsTT and pain-free isometric abduction strength were weakly related ($r = 0.24$) in patients with unilateral SIS. We did not find a relationship between SsTT and abduction strength. The conflicting results may be explained by methodologic differences between the studies. Joensen et al. (2009) analyzed side differences for pain-free isometric strength and SsTT and they did not analyze their data based on the disease stage (their participants were a mixed population composed of patients in acute and chronic stages), but we assessed maximal strength of the symptomatic shoulder of the participants and analyzed the data of patients with acute and chronic symptoms separately. It should also be noticed that the strength of the correlation determined by Joensen et al. (2009) was weak. In line with our result, increased shoulder strength but no change in SsTT was reported in male recruits after 14 weeks of elite infantry training (Milgrom, Moran, Safran, & Finsestone, 2012). Moreover, Dischler, Baumer, Finkelstein, Siegal, & Bey (2018) reported that years of competition were positively correlated with SsTT and not correlated with isometric shoulder strength in swimmers. Accordingly, changes in SsTT might be related to long-term loadings, such as sports participation, work, or repetitive activities of daily living rather than abduction muscle strength in patients with SIS (Schmidt, et al., 2021; Seynnes, et al., 2009).

The limitation of our study is that as a mutual limitation of ultrasonography studies, although two-dimensional ultrasonography measures are frequently used in the literature, the SAS and tendon are three-dimensional structures, and for this reason, we did not fully capture these structures. The fact that this study is the first to examine (a) the relationship of eccentric shoulder abduction strength with the AHD and SsTT, and (b) the relationships between abduction strength and AHD and SsTT based on the disease stage is one of the strengths of our study. Other strengths of this study are that we used valid and reliable measurement methods, and anthropometric and demographic characteristics of patients in acute and chronic stages of the disease were similar.

In conclusion, in patients with acute SIS symptoms, AHD was positively correlated with both isometric and eccentric shoulder abduction strength. AHD was not correlated with abduction strength in patients with chronic symptoms. These findings suggest that the relationship between AHD and abduction strength differs according to disease stage. SsTT was not correlated with abduction strength regardless of disease stage. In patients with acute SIS symptoms, increasing both isometric and eccentric shoulder abduction strength may be a potential strategy to improve the width of the SAS.

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