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Title

Reduction of the subacromial space in athletes with and without rotator cuff tendinopathy and its association with the strength of scapular muscles

Authors

Hio Teng Leong, Sammi Sin Mei Tsui, Gabriel Yin-fat Ng, Siu Ngor Fu

Affiliations

Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong Special Administrative Region

Abstract

Objectives

To compare the reduction of subacromial space (SAS) during arm abduction between overhead athletes with and without rotator cuff (RC) tendinopathy, and to explore the relationship between the strength of scapular muscles with the SAS.

Design

Cross-sectional study.

Methods

Sixty-six athletes (33 healthy and 33 with RC tendinopathy, mean age = 22.3 years) participated in the study. Ultrasound measurement of the SAS with arm at 0°, 30° and 60° of shoulder abduction were taken, and the maximal isometric force in upper, middle and lower trapezius, and serratus anterior with manual muscle tests (MMT) were assessed using a handheld dynamometer. The change in SAS during arm abduction from 0° to 30° (SAS0°–30°), 30° to 60° (SAS30°–60°) and 0° to 60° (SAS0°–60°) was compared between groups. Differences in force produced with scapular muscles MMT between groups and relationships with reduction in SAS were explored.

Results

We found more reduction of the SAS during SAS0°–30° in athletes with RC tendinopathy (0.44 ± 1.22 mm) than healthy athletes (−0.06 ± 1.41 mm) ($p = 0.045$). Athletes with RC tendinopathy demonstrated significant decrease in all scapular muscles MMT strength when compared to their healthy counterparts ($p < 0.05$). In healthy athletes, a lower middle and lower trapezius MMT strength were moderately associated with a greater reduction in SAS during 0° to 30° ($r = -0.445$, $p = 0.016$ and $r = -0.423$, $p = 0.022$, respectively) and 0° to 60° of shoulder abduction ($r = -0.415$, $p = 0.018$ and $r = -0.504$, $p = 0.003$, respectively).

Conclusions

Athletes with RC tendinopathy demonstrated more reduction in the SAS during early arm abduction. Decreased strength of middle and lower trapezius was related to reduction of the SAS.

Keywords

Scapula; Scapular muscle strengths; Rotator cuff tendinopathy; Subacromial space; Ultrasonography; Overhead athletes

1. Introduction

Rotator cuff (RC) tendinopathy is considered to be the principal cause of shoulder pain in orthopaedics and sports medicine,1, 2 particularly in athletes with repetitive overhead activities.3 The supraspinatus tendon runs in the subacromial space (SAS) and is most commonly affected by pathological change.4, 5, 6 Reduction of the SAS during arm elevation has been proposed as one of the possible mechanisms in the aetiology of RC tendinopathy.4, 7, 8 Maintenance of the SAS during arm elevation is thus essential for prevention and rehabilitation of RC tendinopathy.9 Exploring the correlation between biomechanical factors and the SAS will enhance our understanding of the pathokinematics of this condition.

Scapular muscles are important to stabilise and control the scapula for proper position and normal kinematics during arm elevation. The relationship between the scapular position and SAS has been investigated.10, 11, 12 An early study by Solem-Bertoft et al. showed a negative relationship between SAS and scapular protraction with MRI technique.10 More recent studies using ultrasound imaging reported significant reduction of the SAS in asymptomatic elite junior tennis players with scapular dyskinesia from 0° to 60° abduction11 and an increase in the SAS with manual upward rotation and posterior tilting of the scapula.12 Weakness or imbalanced activation of the scapular muscles has been reported in people with RC tendinopathy,13, 14, 15 and these were associated with alterations in scapular kinematics.13, 14 The consequence of this alteration may compromise the SAS and render the athletes more vulnerable to RC tendinopathy.9, 16 Scapular muscle deficiency and imbalance are common implications of pathological processes of RC tendinopathy. No studies have investigated the relationship between scapular muscle strength and SAS, but such research would provide more information on the pathogenesis of RC tendinopathy and underpin preventive programmes.

Therefore, the aims of this study were to (1) compare the reduction of SAS during arm abduction in athletes with and without RC tendinopathy, and (2) explore the relationship between the strength of scapular muscles with change in SAS during arm elevation. We hypothesised that (1) athletes involved in overhead sports with RC tendinopathy would demonstrate more reduction of the SAS during arm abduction than their healthy counterparts, and (2) reduction of the SAS would be associated with weaker scapular muscles.

2. Methods

Sixty-six athletes between 18 and 40 years old participated in this study. They were volleyball and baseball players recruited from local sports clubs and universities. Players with a history of shoulder fractures, instability or dislocation, shoulder surgery or clinical treatment for a shoulder injury, frozen shoulders (more than 50% restriction in external rotation, abduction and flexion during both active and passive movements in comparison to the uninvolved shoulder) and a positive general laxity test (>5/9 Beighton Score) were excluded.

Demographic information such as age, gender, height, weight, body mass index (BMI), arm dominance (the side on which they throw a ball), number of years of involvement in overhead sports training and training hours per week were recorded. Clinical tests were conducted by an experienced physiotherapist to differentiate the participants into healthy (no shoulder pain present during training) and RC tendinopathy group. In the present study, RC tendinopathy was defined as (1) presence of shoulder pain during training for more than 3 months, (2) painful arc in flexion or abduction, (3) two or more positive impingement signs (Neers, Kennedy–Hawkins or Jobe test).5 The intensity of pain being provoked in each test should be ≥3/10 on the visual analogue scale (VAS),6 and (4) ultrasound image showed the presence of non-homogeneity or partial tear in the supraspinatus tendon. The study was approved by the Human Subjects Ethics Sub-committee of the administrative institution, and all participants gave their written informed consent before the study.

The SAS and scapular muscles strength were assessed by two examiners who were blinded to the grouping of the participants. The SAS of each participant's dominant arm was scanned using an Aixplorer® ultrasound scanning system (SuperSonic Imagine, Aix-en-Provence, France) with a bandwidth between 4 and 15 MHz and length of 55 mm linear-array transducer. Each participant was asked to sit upright on a stool with their head in a neutral position. The SAS was measured with the arm at 0°, and after static holding at 30° and 60° of abduction. Due to the constraint of the imaging technique, measurements beyond 60° of abduction were not possible.5 At 0° of arm abduction, the participant was asked to relax his/her arm with forearm in pronation and resting on the thigh. During static arm abduction at 30° and 60°, the participant would actively maintain the shoulder at the required abduction angle without flexion, elbow flexed at 90° and forearm in pronation for 10 s. The angle of shoulder abduction was measured by a goniometer (Sammons Preston, Royan, Canada). The SAS measurement was taken by placing the transducer on the lateral surface of the shoulder along the shaft of the humerus. The shoulder was scanned in the longitudinal view and the SAS was defined as the tangential distance between the humeral head and the inferolateral edge of the acromion.6 Three measurements were recorded in each arm position, and a 1-min rest was given between each measurement to avoid muscle fatigue. The averaged value of the three measurements and the change in SAS during arm abduction from 0° to 30° (SAS0°–30°), 30° to 60° (SAS30°–60°) and 0° to 60° (SAS0°–60°) were calculated for analysis. The intra-rater reliability of the SAS measurement was assessed in a pilot study with 10 healthy individuals and the intraclass correlation coefficient (ICC), ranged between 0.903 and 0.952 which represents excellent reliability.17

The peak isometric force of scapular strength during manual muscle testing (MMT) was adopted from the study of Cools et al.18 A microFET2 Digital Handheld Dynamometer (HHD) (HOGGAN Health Industries Inc., West Jordan, Utah) was used to test the MMT strengths of the upper trapezius (UT), middle trapezius (MT), lower trapezius (LT) and serratus anterior (SA) of the dominant shoulder.18 The UT strength was measured with the participant sitting upright with their head in a neutral position. The HHD was placed over the superior aspect of the shoulder and the force was applied directly downward in the direction of scapular depression. The participant was asked to perform shoulder elevation against the resistance of the examiner. For the MT and LT strength testing, the participant was positioned lying prone with a pillow underneath the abdomen. The shoulder was abducted to 90° when testing the MT; and 145° for the LT, with thumb pointing to the ceiling. The HHD was placed at 1 cm proximal to the lateral radial styloid process. Force was applied directly downward to the lateral radius and the participant was asked to perform horizontal abduction with external rotation against the resistance of the examiner. The SA strength was measured with the participant lying supine, with the shoulder at 90° forward flexion and the elbow extended. The HHD was placed over the participant's palm. Force was applied directly downward to the hand along the humeral shaft, and the participant was asked to push against the resistance of the examiner. The sequence for the MMT was: (1) UT, (2) MT, (3) LT and (4) SA. The participant was asked to maintain the position of the tested arm for 5 s as the examiner pushed against the limb until the maximal effort was overcome and the joint being tested gave way.19, 20 Standardised verbal instructions and encouragements were given. Three measurements were recorded and averaged in each muscle. One minute of rest was given between each measurement to avoid muscle fatigue. Force measurements were then normalised with the participant's body weight in N/kg.18, 21

Statistical analysis was performed using the SPSS Version 23 for Windows (SPSS Inc., Chicago, IL, USA). Distributions consistently passed the Shapiro–Wilk normality test (all $p > 0.05$). Independent t-tests were used to compare the age, body weight, height, body mass index (BMI) and years in sports training between the two groups, whereas gender was compared using the chi-square test. Univariate analysis of variance was used to compare the reduction of the SAS (SAS0°–30°, SAS30°–60° and SAS0°–60°), and the strength of scapular muscles between the two groups and demographic factors that demonstrated significant group difference as covariates, with α set at 0.05. Pearson's correlation coefficient (r) was used to determine the relationships between the scapular muscles strength and SAS in each group. Bonferroni's adjustment was used for correlation analysis in each group, and α was set at 0.025.

3. Results

Sixty-six athletes participating in either volleyball or baseball (mean age = 22.3 ± 3.7) were tested. Among them, 33 players reported pain or discomfort in the shoulder during training. Clinical tests and ultrasound imaging confirmed the presence of RC tendinopathy. Demographic data of the participants are shown in Table 1. Athletes with RC tendinopathy were older ($p = 0.000$) and had participated in sports training longer ($p = 0.002$) than the healthy athletes; thus, these two factors were used as covariates during statistical analysis.

Measurements of the SAS at different arm abduction angle between athletes with and without RC tendinopathy are shown in Fig. 1. When comparing the change in SAS at different arm positions, athletes with RC tendinopathy demonstrated more reduction of subacromial space during SAS0°–30° (0.44 ± 1.22 mm) than the healthy athletes (−0.06 ± 1.41 mm) ($p = 0.045$). No significant group difference was found in the reduction in SAS30°–60° (healthy athletes = 1.00 ± 1.36 mm and athletes with RC tendinopathy = 0.94 ± 1.70 mm, $p = 0.196$), and SAS0°–60° (healthy athletes = 0.94 ± 1.70 mm, and athletes with RC tendinopathy = 1.34 ± 1.32 mm, $p = 0.518$).

Results of UT, MT, LT and SA normalised peak isometric strength are shown in Fig. 2. There were significant differences in the normalised strength of all scapular muscles between groups ($p < 0.05$). Athletes with RC tendinopathy had weaker UT (by 9.1%), MT (by 15.7%), LT (by 24.3%) and SA (by 8.4%) than their healthy counterparts.

In the healthy athletes, significant negative correlations were found between the change in subacromial space during SAS0°–30° and MT MMT strength ($r = -0.445$, $p = 0.016$) and LT MMT strength (−0.423, $p = 0.022$), respectively, and between the change in subacromial space during SAS0°–60° and MT MMT ($r = -0.415$, $p = 0.018$) and LT MMT ($r = -0.504$, $p = 0.003$), respectively. Hence, more reduction of subacromial space during SAS0°–30° and SAS0°–60° was associated with weaker MT and weaker LT. However, such relationships could not be detected in athletes with RC tendinopathy.

4. Discussion

Our findings revealed more reduction of the subacromial space in athletes with RC tendinopathy during early abduction from 0° to 30°. Athletes in overhead sports events with RC tendinopathy demonstrated strength deficits in the scapular muscles compared with their healthy counterparts. Decreased MT and LT strengths were associated with more reduction in the SAS during arm abduction from 0° to 30° and 0° to 60°.

When comparing the change in SAS at different arm positions, athletes with RC tendinopathy demonstrated more reduction in SAS during early arm abduction from 0° to 30° than the healthy athletes, which signified some deficits in the dynamic control of the SAS in athletes with RC tendinopathy during early arm abduction. Muscle deficits or imbalance of the scapulohumeral and scapulothoracic muscles secondary to weakness, fatigue, pain-related inhibition and structural incompetence may contribute to the dynamic narrowing of the SAS.[22, 23, 24] In overhead athletes, repetitive overhead activities caused micro-trauma to the passive stabilisers of the glenohumeral joint leading to the fatigue or damage of the rotator cuff muscles. Previous studies have reported superior migration of the humeral head that contributes to the dynamic narrowing of the SAS when the rotator cuff is fatigued or damaged.[25, 26] Thus, the scapular muscles play important roles for scapular stabilisation and normal scapular and humeral kinematics during arm movements. Silva et al. found a greater reduction in the SAS in elite tennis players with scapular dyskinesis when compared to players without dyskinesis.11 Weakness or altered muscle activation of the scapular muscles may lead to abnormal scapular kinematics and reduction in SAS.13, 14, 15

We found athletes with RC tendinopathy had strength deficits in the scapular muscles in which their UT, MT and LT and SA were significantly weaker than the healthy athletes. Previous studies have used hand-held dynamometers,27 isokinetic dynamometers28 or electromyography (EMG)13, 14, 15 to assess the scapular muscle performance in people with RC tendinopathy. Similar to our findings, Celik et al. found the muscle strengths of the MT and SA to be significantly weaker in people with RC tendinopathy than their asymptomatic contralateral shoulders, and weakness of these muscles were associated with pain.27 Cools et al. examined isokinetic muscle performance in the scapular rotators in athletes with RC tendinopathy and showed a significant decrease in strength of SA during scapular protraction in the injured shoulder of the symptomatic group compared with the dominant side of a healthy control group when measured at slow velocity.28 Other studies with EMG showed decreased or delayed muscle activities of MT, LT and SA during arm elevation in people with RC tendinopathy.13, 14, 15 Seitz et al. reported LT and SA strength deficits to be moderately (r = 0.41–0.57) associated with a lack of scapular upward rotation in athletes involved in overhead sports with clinically identified scapular dyskinesis,29 and Lin et al. further demonstrated the decrease in EMG activity of SA to be correlated with the decrease in posterior tipping of scapula (r = 0.772).13 The consequence of this alteration may compromise the SAS as the anterior acromion fails to elevate during humeral elevation.3, 13, 14 Whether pain is a causal factor in terms of the development of weakness in the players with RC tendinopathy or the other way around warrants further investigations in the form of a longitudinal study.

Indeed, we found a relationship between scapular muscles strength and SAS during early arm movement. The decrease in MT and LT strength was associated with the amount of SAS reduction. A previous EMG study on shoulder muscles demonstrated the importance of the muscle activation pattern for dynamic control during early arm movement.[30] MT was activated before the movement began (onset time −0.020 s) as this was important to stabilise the scapula and to provide an initial stable base to allow the scapulohumeral muscles to generate force.[30] Recent studies have investigated the relationship between scapular control and SAS by using ultrasound imaging. Significant reduction in SAS in asymptomatic elite junior tennis players with scapular dyskinesis from 0° to 60° abduction,[11] and increase in SAS with manual upward rotating and posterior tilting of the scapula were reported.[12] Findings from the present study further confirm the relationships between the strength of the MT and LT and the SAS in the athletes without RC tendinopathy. Such findings highlight the importance of these muscles in maintaining the SAS in these athletes. Whether preserving the SAS could reduce the incidence of RC tendinopathy awaits further study.

One of the limitations of this study was the technical constraint in using ultrasound to quantify the SAS. The measurement was done with the arm abducted to 60° only. However, this study has demonstrated the importance of the control of SAS in the early phase of arm abduction and the relationship of scapular muscles strength with SAS. Measuring the effects of muscle strength on the SAS with the arm abducted beyond 60° requires other measuring tools, such as magnetic resonance imaging. Second, we identified athletes with and without RC tendinopathy by clinical tests and ultrasound imaging. However, current clinical tests used in the diagnosis of RC tendinopathy have poor specificity, and there is a lack of correlation between symptoms and contemporary methods of imaging. Thus, athletes with RC tendinopathy were included if they had experienced shoulder pain during training for more than 3 months, had positive clinical tests and ultrasound imaging showed the presence of non-homogeneity or partial tear in the supraspinatus tendon. Nevertheless, the key confounders of age and years of sports training differences between groups may have influenced the result, as these two factors were used as covariates during statistical analysis. Other factors, like the players' activity level, may also have influenced the results.

5. Conclusion

There was more reduction in SAS in athletes with RC tendinopathy than healthy athletes when the arm was abducted from 0° to 30°. Athletes with RC tendinopathy demonstrated strength deficits in the scapular muscles compared with those without RC tendinopathy. Weaker MT and LT were associated with more reduction in the SAS during early abduction. In this context, the role for scapular muscle strengthening in the rehabilitation and prevention of shoulder disorders in athletes of overhead sports merits further research.

6. Practical implications

• More reduction of the SAS in overhead athletes with RC tendinopathy during early arm abduction.

• Decreased strength of UT, MT, LT and SA in overhead athletes with RC tendinopathy.

• Decreased strength of MT and LT trapezius was associated with more reduction of the SAS.

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Table 1. Demographic data of participants.

Variables	Healthy athletes (*n* = 33)	Athletes with RC tendinopathy (*n* = 33)
Age (years)	20.7 ± 2.4	24.0 ± 4.1*
Weight (kg)	61.7 ± 10.4	65.2 ± 11.1
Height (cm)	169.4 ± 9.8	171.8 ± 10.0
BMI	21.4 ± 3.0	21.9 ± 2.4
Gender (Male/female)	14/19	19/14
Years of sports training	7.0 ± 3.2	10.2 ± 4.6*
Duration of shoulder pain (months)	–	28.7 ± 29.9
Supraspinatus tendon ultrasound imaging		
Presence of non-homogeneity	0	33/33
Presence of partial tear	0	1/33

Values are mean ± SD.

Abbreviations: BMI, body mass index; RC, rotator cuff.

*$p < 0.05$.

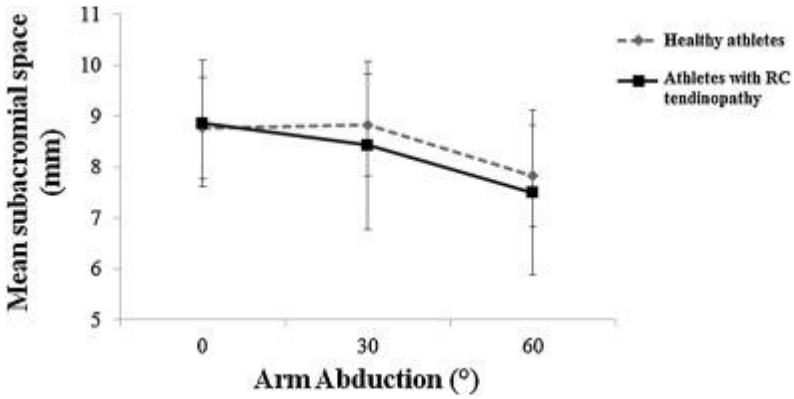

Figure 1. Mean ± SD of SAS (mm) measured by ultrasound between healthy athletes (grey-dotted line) and athletes with RC tendinopathy (black-solid line) at different arm abduction angle.

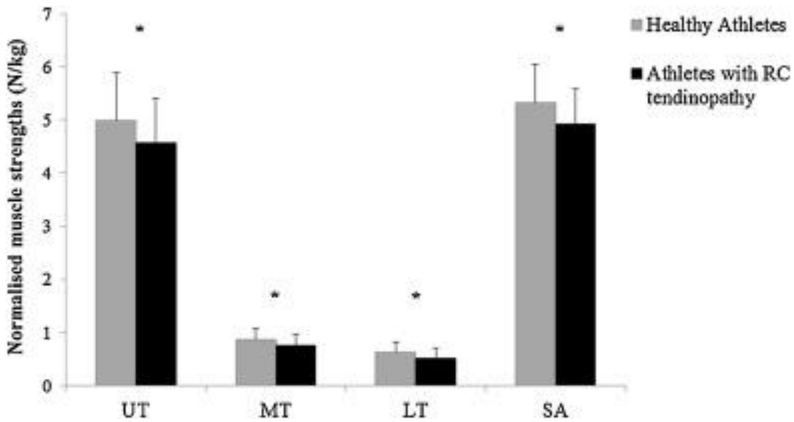

Figure 2. Normalised strength of UTMT, LT and SA between healthy athletes (grey-colour box) and athletes with RC tendinopathy (black-colour box). * denotes significant difference between groups ($p < 0.05$).