Differences in supraspinatus occupation ratio between the symptomatic, the contralateral asymptomatic shoulder and control subjects

A cross-sectional study

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Abstract

The relationship between supraspinatus tendon thickness and the acromiohumeral distance (AHD) at both rest position and shoulder elevation is still to be explored in those with chronic shoulder pain. The aim is to compare supraspinatus occupation ratio (OR) at 0° and 60° of shoulder elevation measured by ultrasound imaging in the symptomatic shoulder, the contralateral asymptomatic shoulder and in healthy subjects. This was across-sectional, observational study. A sample of 56 participants with subacromial pain syndrome in their dominant arm was recruited in 3 different primary care centres. Forty participants without shoulder pain were also recruited. The AHD at 0° and 60° of active shoulder abduction as well as the supraspinatus tendon thickness were measured by ultrasound in these groups. Supraspinatus OR at 60° was significantly greater in symptomatic compared to asymptomatic shoulders (P = .04) and healthy shoulders (P = .008). The percentage of change in supraspinatus OR from rest position to 60° was also greater in symptomatic shoulders when comparing with asymptomatic (P = .01) and healthy shoulders (P = .03). No other statistically significant differences for the rest of comparisons were found. Supraspinatus OR may explain shoulder pain in chronic conditions. Further studies at acute and chronic conditions after a physiotherapy treatment are needed to explore its usefulness in clinical practice.

Abbreviations: AHD = acromiohumeral distance, MRI = magnetic resonance imaging, OR = occupation ratio, RC = rotator cuff, SAPS = subacromial pain syndrome, US = ultrasound imaging

Keywords: chronic pain, occupation ratio, rotator cuff, shoulder pain, supraspinatus, ultrasonography

1. Introduction

Shoulder pain is a multifactorial and a prevalent musculoskeletal condition, presenting ranges from 4.7% to 46.7% for 1-year prevalence and 6.7% to 66.7% for lifetime prevalence.[1] Rotator cuff (RC) disorders have been recognized as one of the main causes of shoulder pain in both athletic and non-athletic populations,[2] with subacromial pain syndrome (SAPS) being one of the most common diagnosis,[3] and with the supraspinatus tendon as the main affected structure.[4] Patients with SAPS are traditionally evaluated by radiographs, magnetic resonance imaging (MRI), computed tomography and electromyography. The use of ultrasound imaging (US) is becoming popular,[5] with their results being comparable to those obtained by MRI,[6] although less costly and with the possibility of carrying out dynamic evaluations.[7]

Supraspinatus tendon thickness[8,9] and the subacromial space, measured by acromiohumeral distance (AHD),[10–12] are external factors that have been commonly investigated in patients with SAPS. There are contradictory findings regarding their influence on this syndrome and its mechanisms. While some studies have found differences between patients and controls in supraspinatus tendon thickness,[8,9,13] others have reported an absence of them.[14] Likewise, there are the same contradictory findings related to the AHD.[15] In a systematic review, Seitz et al showed that AHD can be greater in people with a full thickness RC tear compared with healthy individuals and patients with subacromial impingement, whereas AHD is also greater when the arm is actively elevated in patients with less severe RC tendinopathy compared with healthy individuals.[16] Nevertheless, other studies have concluded the contrary.[9,11,17,18]

The supraspinatus occupation ratio (OR) has emerged to provide more information on the relationship between the supraspinatus tendon thickness and the subacromial space. It is defined as the percentage of the subacromial space (AHD) that occupies supraspinatus tendon thickness.[16] It has been
evaluated by MRI and computed tomography, in studies evaluating fatty degeneration in relation to RC tears,\(^\text{[19]}\) as well as supraspinatus muscle atrophy.\(^\text{[20]}\) Specifically in subacromial impingement syndrome patients reported a less available unoccupied AHD at the rest position, compared to healthy controls.\(^\text{[9]}\) However, differences with the arm in elevation or how the supraspinatus OR changes from rest to the elevation position is still challenging. To our knowledge, there are not studies comparing the supraspinatus OR at 0° and 60° of shoulder elevation, in the symptomatic shoulder and the contralateral asymptomatic shoulder, in patients suffering from chronic SAPS, and compared to healthy subjects. This information may help to understand the underlying mechanisms of SAPS.

Hence, the aim of this study is 2-fold: (i) to compare supraspinatus OR at 0° and 60° of shoulder elevation measured by US between the symptomatic shoulder, the contralateral asymptomatic shoulder and those with shoulders free of pain, and; (ii) to study how the supraspinatus OR changes from rest position to 60° of elevation in these 3 groups.

2. Material and methods

2.1. Study design

This was an cross-sectional, observational study, conducted according to the Declaration of Helsinki. It was developed in 3 different primary care centers, and Ethical approval was obtained from the Ethics Committee of the Health Care District where the primary care centers were located (PI9/012014). The study has been reported following the recommendations of STROBE statement for observational studies, and it has been registered in www.protocols.io (46238).

2.2. Sample size calculation

Based on previous studies,\(^\text{[8,9,13,21]}\) we used an expected 0.8 mm supraspinatus tendon thickness difference between the painful shoulder and the contralateral shoulder, and a standard deviation of 1 mm, significance test at \( \alpha = 0.05 \), and a power of 90%, a sample of 27 participants was needed. Additionally, for the AHD distance, a sample size of 29 participants was necessary based on the preliminary expectation to achieve a difference between painful shoulder and contralateral shoulder of 1.10 mm, with a standard deviation of 1.43 mm, significance test at \( \alpha = 0.05 \), and a power of 90%. Thus, a total sample of 56 participants was recruited.

2.3. Participants

General practitioners (GPs) carried out the recruitment and research assistants screened all participants for eligibility, who were aged between 18 to 55 years. Participants had to meet at least 3 of the following inclusion criteria: (i) unilateral shoulder pain in their dominant arm;\(^\text{[22]}\); (ii) 2 out of 3 positive clinical tests (Hawkins–Kennedy; Jobe; Neer)\(^\text{[23]}\); (iii) pain with normal activity 2+4/10 on a visual analogue scale; (iv) shoulder pain lasting more than 3 months; (v) a history of non-traumatic onset of shoulder pain. Participants were ineligible to participate in this study if any of these conditions were present: (i) history of significant shoulder trauma, such as fracture or ultrasonography-clinically suspected full thickness cuff tear, following the classification of Wiener and Seitz, 1993\(^\text{[24]}\); (ii) recent shoulder dislocation in the past 2 years; (iii) systemic illnesses such as rheumatoid arthritis; (iv) adhesive capsulitis; (v) shoulder pain originating from the neck or if there was a neurological impairment, osteoporosis, haemophilia and/or malignancies; (vi) shoulder pain in the non-dominant arm.

A convenience sample of 40 participants with both shoulders free of pain for the last year was recruited in order to compare with participants with shoulder pain, and was assessed by the same examiner who evaluated patients. Asymptomatic participants were specifically age and gender matched to the symptomatic group.

2.4. Outcome measures

Images in grey scale using a B-mode were captured, and an US system, Sonosite M-turbo (GE Healthcare, Wauwatosa, WI) with a 6 to 13 MHz linear transducer, was used. Images were obtained by a physiotherapist with 8 years of experience on rehabilitative ultrasound imaging (RUSI).

Integrity of both shoulders was assessed in patients with unilateral chronic SAPS, where the standard III, IV and V views according to the modified 5-grade Wiener and Seitz classification\(^\text{[24]}\) were supposed to be an exclusion criteria. In healthy subjects, the dominant arm was assessed, where the presence of asymptomatic RC abnormality was understood as exclusion criteria. Three measurements were taken for all the structures and spaces by the examiner. An interval of 1 minute was provided between the 3 measurements, during which the patient was encouraged to move freely. Patients were then repositioned and the second and third set of measurements was successively taken. The ultrasound examiner was blind to all measurements (values were obscured by placing a shield on the ultrasound screen, meanwhile a research assistant registered the data), and was blind to the previous condition of each patient (shoulder function and pain severity) as well as to the affected side and dominant upper limb. All the ultrasound measurements were expressed in centimeters.

2.5. Primary outcome

2.5.1. Tendon thickness as a percentage of subacromial space: supraspinatus occupation ratio. Mean supraspinatus tendon thickness was measured as a percentage of the mean AHD using the following formula: OR = [tendon thickness/AHD] × 100. The tendon thickness percentage of AHD was calculated for each of the 3 trials for each participant\(^\text{[9]}\). To calculate this ratio, AHD and supraspinatus tendon thickness were calculated as follows:

2.5.2. Acromiohumeral distance. AHD was measured with the shoulder in rest with the participant seated in an upright position. The process to evaluate AHD has been previously used in different populations, such as healthy volunteers\(^\text{[25]}\) and patients with shoulder pain.\(^\text{[9]}\) Patients were seated upright without back support, their feet flat on the ground. AHD was defined as the shortest linear distance between the most inferior aspect of the acromion and the adjacent humeral head.\(^\text{[12]}\) The ultrasound transducer was placed on the most anterior aspect of the acromion edge, with the long axis of the transducer placed in the plane of the scapula and parallel to the flat surface of the acromion. To measure the AHD at 60° of active shoulder elevation, a hydro-goniometer was placed on the patient’s arm. This angle was chosen since elevation greater than 60° hinders the ultrasound measurements because of the acoustic shadow of the
acromion, and also this is when the pain usually appears. The measurements were expressed in centimeters, using the calipers on the ultrasounds’ screen. (Fig. 1)

2.5.3. Supraspinatus tendon thickness. The supraspinatus tendon thickness was evaluated using the same position as used in the AHD measurement to guarantee the exact supraspinatus OR (Fig. 2). The transducer was placed over the anterior aspect of the shoulder, just anterior to the anterior-lateral margin of the acromion. Then the exact position where the observer evaluated tendon thickness to be at its maximum was determined and 3 measurements were taken.

2.6. Secondary outcome
2.6.1. Shoulder pain and disability index (SPADI). The shoulder pain and disability index (SPADI)\(^{[26]}\) is a self-administered questionnaire that consists of 2 scales, one for pain and the other for functional activities. SPADI total score fluctuates from 0 to 100, where 0 is the best and 100 is the worst. The SPADI has shown a good internal consistency with a Cronbach’s alpha of 0.95 for the total score, 0.92 for the pain subscale and 0.93 for the disability subscale as well as the ability to detect change over time.\(^{[27]}\) An adapted version of the SPADI was obtained following the International recommendations\(^{[28]}\) since English was not the native language for all the participants.

2.7. Data analysis
Normality for all ultrasound variables was analyzed using the Kolmogorov-Smirnov test for the 2 groups of participants with shoulder pain (affected and non-affected), and the Shapiro-Wilk test for healthy group (controls). Comparisons between the affected (group A) and non-affected side (group B) of the participants with shoulder pain were calculated using non parametric tests since the normality was violated. Wilcoxon test was used for related samples and Mann–Whitney U test for independent samples.\(^{[29]}\)

A \( P \) value <0.05 was considered statistically significant. Intra-rater reliability was calculated for all ultrasonography measurements. This was necessary in order to determine whether differences between groups surpassed the minimal detectable change (MDC). A result was considered significant if it reached the 5% level of probability (\( P < 0.05 \)). Finally, a new outcome measure was created, as the percentage of change in supraspinatus OR from rest to 60° of shoulder elevation, for all the groups studied.

3. Results
3.1. Sample characteristics
A sample of 73 patients with chronic unilateral shoulder pain in their dominant arm was recruited from 3 different primary care centres, with a final sample size of 56 participants obtained after applying the inclusion criteria.

Sample characteristics are shown in Table 1. There were no significant differences between the study groups for demographic characteristics. Regarding the duration of symptoms, 29.7% of the participants presented shoulder pain lasting 3 to 6 months; 12.73% between 6 and 12 months; and 58.19% greater than 1 year.

The ICC was 0.88 (0.83–0.92) for AHD measurements at 0°, and 0.98 (0.97–0.99) at 60°. The SEM was 0.05 at 0° and 0.003 at 60°. The MDC based on a 95% confidence interval was 0.13 at 0° and 0.01 at 60°.

3.2. Mean values of all measurements
Mean values of the supraspinatus tendon, AHD and supraspinatus OR are shown in Table 2.
3.3. Mean differences in supraspinatus occupation ratio between groups

Mean differences in supraspinatus OR between groups are shown in Table 3. There were statistically significant differences in supraspinatus OR measurements at 60° of shoulder elevation when comparing the symptomatic group with both the asymptomatic and healthy groups. We did not find statistically significant differences between the asymptomatic and the healthy groups. When analyzing the percentage of change in supraspinatus OR from rest to 60° of shoulder elevation, there were statistical significant differences when comparing the symptomatic group with both the asymptomatic and healthy groups, and there were not significant differences when comparing the asymptomatic and the healthy groups.

4. Discussion

This study aims to compare supraspinatus OR at 0° and 60° of shoulder elevation measured by US between the symptomatic shoulder, the contralateral asymptomatic shoulder and those with shoulders free of pain, and how the supraspinatus OR changes from rest position to 60° of elevation in these 3 groups. Supraspinatus OR at 60° was significantly greater in symptomatic compared to asymptomatic shoulders (P = .04) and healthy shoulders (P = .008). The percentage of change in supraspinatus OR from rest to 60° was also greater in symptomatic shoulders when comparing with asymptomatic (P = .01) and healthy shoulders (P = .03). No other statistically significant differences for the rest of comparisons were found.

Comparisons with others studies are difficult since only Michener et al studied the relationship between the AHD and the supraspinatus tendon thickness. Their results regarding the supraspinatus OR were 61.7% ± 10.3% in patients with subacromial impingement syndrome and 54.2% ± 7.9% in healthy subjects. Our results showed a supraspinatus OR of 55.44% ± 15.87% in the symptomatic shoulder, 54.62% ± 12.64% in the asymptomatic and 53.48% ± 10.64% in healthy people. Other studies have analyzed the supraspinatus OR to evaluate fatty degeneration and supraspinatus muscle atrophy, obtaining values of 59% ± 15% and 42.39% ± 10.10% respectively, as well as differences in supraspinatus thickness activation ratio between subjects who had history of shoulder injury and matched controls. The differences between studies can be explained by the different conditions analysed (RC tears vs SAPS) and the different imaging tools used (MRI vs US). Differences can be also explained by the chosen position during the assessment. Michener et al took 3 measurements along the tendon, with the hand of the patient on the ipsilateral posterior hip with the humerus in extension, and then the average was collected. In contrast, we took 3 measurements of the supraspinatus tendon at the same position as that used in AHD, since the supraspinatus can lead to a different depth of position because of shoulder movement. This was chosen to ensure the most accurate relationship between the AHD and the supraspinatus tendon thickness by measuring both at the same position.

Interestingly, the results obtained in the present study show absence of differences in the supraspinatus OR between groups at rest position, whereas statistically significant differences were found at 60° of shoulder elevation, which is in contrast with Michener et al. Again, the explanation may be the different US approach used when assessing the supraspinatus tendon, which has been explained previously. On the other hand, our results

### Table 1

**Characteristics of the study group (standard error).**

|                  | Affected       | Healthy       | Total          | P value |
|------------------|----------------|---------------|----------------|---------|
| Age              | 45.52 (1.40)   | 46.42 (1.11)  | 48.95 (1.04)   | 0.96    |
| Gender           |                |               |                |         |
| Female           | 36             | 19            | 56             | 0.10    |
| Male             | 20             | 21            |                |         |
| SPADI            | 57.20 (2.58)   | –             |                |         |
| Duration of symptoms (mo) | 3–6 = 29.7% | 6–12 = 12.73% | 1 yr = 58.19 |         |

A P value < .05 was considered significant.

SPADI = shoulder pain and disability index.

### Table 2

**Ultrasound measurements of the study groups.**

|                  | Symptomatic shoulder | Asymptomatic shoulder | Healthy subject |
|------------------|----------------------|-----------------------|-----------------|
| Supraspinatus    | 0.52 (0.01)          | 0.52 (0.01)           | 0.50 (0.01)     |
| AHD              | 0.97 (0.01)          | 0.97 (0.1)            | 0.95 (0.01)     |
| AHD at 60° of shoulder elevation | 0.62 (0.01) | 0.68 (0.01) | 0.67 (0.01) |
| Supraspinatus OR at rest position (%) | 55.44 (2.12) | 54.62 (1.62) | 53.48 (1.68) |
| Supraspinatus OR at 60° of shoulder elevation (%) | 86.10 (3.21) | 80.53 (3.46) | 77.08 (3.07) |
| Percentage of change in supraspinatus OR from 0° to 60° | 30.66 (2.30) | 25.59 (3.03) | 22.81 (2.80) |

Values are given as mean (standard error) and expressed in centimeters.

AHD = acromiohumeral distance, OR = occupation ratio.

### Table 3

**Differences in supraspinatus OR between the groups.**

|                  | Symptomatic-asymptomatica | Symptomatic-asymptomaticb | Asymptomatic-healthya |
|------------------|---------------------------|---------------------------|-----------------------|
| Supraspinatus OR at rest position (%) | 0.47 (1.97) | 0.34 (2.89) | 1.47 (0.05) |
| Supraspinatus OR at 60° of shoulder elevation (%) | 7.51 (3.61) | 12.54 (4.60) | -4.25 (6.72) |
| Percentage of change in supraspinatus OR from rest to 60° (%) | 6.53 (5.96) | 10.33 (3.60) | -4.36 (5.91) |

OR = occupation ratio.

a Mean differences (standard error).
b Wilcoxon test.
c Mann-Whitney U test.

∗ Statistically significant (P < .05).
showed significant differences in supraspinatus OR groups at 60° of active shoulder elevation when comparing the symptomatic group with both the asymptomatic and healthy groups, as well as in the percentage of change in supraspinatus OR from rest position to 60° of arm elevation. However, absence of differences were found between asymptomatic and healthy shoulders. To date, this has not been studied, but in this context Navarro et al. found significant differences in AHD at 60° of shoulder elevation between the symptomatic and the contralateral asymptomatic shoulder when compared the same 3 groups, which is line with the present results.[11] Additionally, Muething et al. studied muscle-activation differences between the previously injured limb of individuals with a history of GH-joint injury and healthy matched controls during functional isometric contractions. They showed significant decreases in muscle activation in the anterior deltoid between previously injured and healthy people, as well as in the lower trapezius, in previously injured subjects.[29]

The presented results may support the existence of compressive mechanisms during shoulder elevation up to 60° in subjects with SAPS, showing that patients have a greater occupied space in the symptomatic shoulder than the asymptomatic or patients with healthy shoulders.

The differences in the percentage of change in supraspinatus OR from rest to 60° of arm elevation when comparing symptomatic shoulders with both asymptomatic and healthy shoulders were also statistically significant. This is in line with other studies that suggest a direct supraspinatus tendon compression during arm elevation.[9,11] Thus, the benefit of studying the OR is that it allows the interpretation of the AHD relative to the tendon thickness; otherwise, a large AHD may be interpreted as favourable even though the tendon thickness is large and therefore counteracts the large AHD, or vice versa, which would be a small AHD being interpreted as dangerous even though the tendon is thin. Thus, given the wider perspective of supraspinatus OR it may be more suitable to use than those measurements carried out to assess shoulder pain currently, such as the AHD and tendon thicknesses in isolation, avoiding the existing controversy.

This study has some strengths. This is the first study analyzing the supraspinatus OR at rest position, 60° of shoulder elevation and the percentage of change in supraspinatus OR from rest to 60° of arm elevation for both shoulders in patients with unilateral chronic SAPS, and healthy people, measured by US, which increases the body of knowledge in the potential underlying mechanisms for people with SAPS. Additionally, the US assessment was carried out by an expert examiner with 8 years of experience on US, following rigorous criteria, to avoid RC injuries when patients were screened to participate in the study.[24] On the other hand, there are some limitations to be considered. Ultrasound imaging is a highly operator dependent tool and therefore results should be taken with caution. The subacromial space is a tridimensional space which has been measured through the AHD, which is bidimensional; hence, it is difficult to assess the space entirely. Furthermore, the acoustic shadow from the acromion may make the measurement of the whole tendon thickness difficult when measuring at 60° of shoulder elevation.

From the clinical point of view, the use of the supraspinatus OR could be used as predictor of shoulder conditions, and possibly as an improvement indicator measurement after a treatment program. Furthermore, others factors such as the intrinsic properties of tendons, hormonal status, genetics, central and peripheral sensitization, and psychological factors should be taken into account when explaining shoulder pain. More studies following a longitudinal design which analyses changes in the supraspinatus OR after a physiotherapy treatment programme would be necessary, not only in chronic conditions but also in an acute stage. This would determine the real usefulness of supraspinatus OR within clinical practice, and the level of improvement that would be necessary to be clinically and functionally meaningful.

In conclusion, the supraspinatus OR has been found to be statistically significantly different when comparing the symptomatic shoulder with both asymptomatic and healthy shoulders at 60° of shoulder elevation and in the percentage of change from rest to an elevated arm position. This may explain a part of the total shoulder pain and dysfunction of the patient, and may serve as a distinguishing factor in the assessment of chronic SAPS, as well as being as an outcome measure for therapeutic programmes. Thus, its use should be corroborated with longitudinal studies, and others factors such as central/peripheral sensitization, genetics or intrinsic properties of tissue should also be considered.

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