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Research Article

Is there a Difference between Dimensions of the Subacromial Space with Forced Adduction Pressure Measured Under Ultrasound, During Resisted Isotonic Internal and External Rotation of the Glenohumeral Joint?

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Abstract

Objective: This study investigated the effect of forced adduction pressure on the subacromial space (SAS) during isotonic shoulder internal and external rotation at 45° of shoulder abduction. Three adduction pressures (0, 40 and 60 mmHg) were assessed and controlled through a biofeedback unit.

Design: This study utilised convenience sampling. Data from 17 of 20 participants (9 women and 11 men) including those with a history of shoulder pathology were used for analysis. Ultrasound videos were taken to analyse the SAS during resisted isotonic internal and external rotation at each level of adduction pressure 0, 40 and 60 mmHg while maintaining 45° of shoulder abduction.

Results: No significant difference of the dimension of the SAS were observed at each of the three levels of forced adduction pressure (0, 40 and 60 mmHg) during resisted isotonic rotation ($p > 0.05$). Comparisons between those with and without a history of shoulder pathology also revealed no significance ($p = 0.0892$).

Conclusion: This study demonstrated the subacromial space (SAS) was not affected by forced adduction pressure during resistive isotonic shoulder internal and external rotation while maintaining a 45° abduction angle. Further research is required to determine the effects of this in those with subacromial impingement syndrome (SIS).

Keywords: Subacromial Space; Ultrasound; Shoulder Rehabilitation; Adduction Pressure

A common approach to rehabilitation exercise for the shoulder is to incorporate internal-external rotational strengthening whilst a forced adduction pressure is maintained, with the concept of increasing the SAS [1,2]. In a series of static ultrasound pictures White *et al* demonstrated the effect of this and recommend a follow-up study using video to capture this effect.

The present study is the first to assess the effect of forced adduction on the dimensions of SAS using ultrasound videos and found that no significant difference could be observed. The underlying mechanism of this rehabilitation procedure should be questioned.

Introduction

The shoulder is the third most common musculoskeletal site of complaint observed in a primary care setting [3]. It is prone to instability as it exhibits the greatest amount of motion of any articulation in the human body and relies on stabilisation from the muscles, principally those of the rotator cuff [4-6]. These muscles help to 'steer and stabilise' the glenohumeral joint and control humeral head translation during dynamic activities [7]. The subacromial space (SAS) is defined by the space between the inferior surface of the acromion and the head of the humerus [8]. A reduction of the SAS is often commonly seen in rotator cuff pathologies with subacromial impingement syndrome (SIS) being the most common disorder of the shoulder resulting in pain and overall dysfunction [9,10]. The general approach of conservative or post-surgical rehabilitation protocols for the shoulder involves the use of exercises that address the rotator cuff musculature [1,2,11,12] using internal and external rotational strengthening exercises to help strengthen the rotator cuff [1,2]. These exercises are performed using a low load with either constant resistance as demonstrated by Graichen *et al* through a resistance pulley, dumbbell, barbell or elastic resistance using elastic straps or tubes [4,11,13]. With the overall goal being to help provide stability

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to the glenohumeral head within the glenoid fossa to prevent further injury and increase the SAS in patients with SIS [11,13,14].

Several clinical studies have demonstrated a reduction of the subacromial joint space and centring of the humeral head relative to the glenoid during shoulder abduction [11,15,16]. Graichen *et al* reported a physiological increase of the width of the SAS through open MR assessment of healthy participants in vivo at 5 angles of shoulder elevation (30°, 60°, 90° and 150°) [11]. This involved achieving constant isometric muscle activity through application of a 15N abducting and adducting force to the distal humerus [11]. This study demonstrated an increase of the SAS as a result of inferior and anterior translation of the humeral head relative to the glenoid [11].

In contrast a retraction of the shoulder girdle has been shown to widen the SAS [11,17]. Studies using Electromyography (EMG) have assessed glenohumeral and scapulothoracic muscle activity during specific shoulder rehabilitation exercises and have provided information on when, how much and how often a muscle is active throughout the range of motion (ROM) of an exercise [6,7,13,18]. The involvement of adduction pressure using an object held in place by the elbow during rehabilitation exercises for the shoulder has shown through EMG to activate co-contraction of the rotator cuff musculature rather than the agonist of the movement alone [18].

Despite its operator-dependent drawback ultrasound has been shown to be a reliable mode of imaging when assessing the SAS [1,19,20]. It is a quick and efficient method of imaging that allows for real-time values when compared to radiographic examination and has been shown in previous studies to have high inter-rater reproducibility [20-22]. Observed changes in the size of the SAS have been demonstrated as a sensitive marker of rotator cuff dysfunction and have been highlighted particularly in cases of mild Neer type I lesions [23]. This mode of analysis also serves as a tool for monitoring patient progress and as a treatment outcome measure [23].

There is, however, limited research surrounding the effect of resisted internal and external rotation on the dimensions of the subacromial joint space. Previous studies have used ultrasonography to examine the effect of abduction and adduction on the subacromial space in both loaded and unloaded conditions and at different angles of shoulder elevation and reported mixed results [1,19,22]. Abduction angles below 60° are reported as favourable in those with SIS to maintain the AHD [11,12].

It is clear from the current literature that this proposed analysis involving forced adduction pressure during dynamic internal and external rotational load has not been performed despite it being a common procedure incorporated in rehabilitation protocols of the shoulder. Therefore, the focus of this research was to explore whether a difference in the parameters of the SAS can be observed through ultrasonography with forced adduction under internal and external rotation of the shoulder.

This research utilised similar methodology to a paper by White *et al* (2012) which assessed the effect of isometric shoulder internal and external rotation on the AHD through sonography at various isolated positions of glenohumeral coronal plane abduction (0°, 30° and 45°) with subjects seated in an upright position [1].

This study incorporated White *et al's* recommendation for the assessment of the SAS during isotonic shoulder exercise in order to provide greater clinical application [1].

Methods

Subjects

This study used convenience sampling and aimed to recruit 20 participants, and this methodology was chosen as similar studies on this subject were based upon similar sample sizes [1,11,19].

The research protocol was approved by AECC University College's research ethics committee (SOC-1022-008) and participants were recruited from the university population via email. Written informed consent was obtained from all participants prior to participation.

Exclusion criteria were age <18 years; Individuals with acute (within last month), current shoulder pain that precludes adduction, internal and external rotation with the humerus at less than 45° of abduction.

Those with a history of previous shoulder injury were included in the study and in such cases underwent analysis of both shoulders. Demographic information was also recorded from all participants prior to data collection through completion of a questionnaire.

Procedure

Participants were asked to read an information sheet and provide written consent to the procedure prior to participation. They were then seated upright with their hips and knees positioned to 90° of flexion. The starting position involved achieving the 45°abduction angle of the glenohumeral joint with the participants elbow at 90° of flexion whilst holding a 2kg dumbbell parallel to the floor (Figure 1). Internal and external rotation began from 45° of humeral external rotation to maximal internal rotation and back to the starting position, whilst maintaining the arm at 45° constant abduction. To standardise shoulder position and achieve the 45° abduction angle a

Figure 1: Subject set-up and positioning.

customised triangular wedge was placed in the patient's axilla and was held in position. Participants were then asked to repeat this procedure whilst maintaining an adduction pressure of 40mmHg and then for a third time at 60mmHg (measured on a blood pressure cuff for biofeedback). During this the ultrasound probe was positioned upon the participants shoulder and a video of the rotational movement at each adduction pressure was recorded. However, this resulted in not necessarily the same position analysed per individual per position. Although assuming participants moved at a uniform speed, it was considered by the researchers to be an acceptable variation between subjects.

To standardise different adduction pressures a folded sphygmomanometer, pre-inflated to 20 mmHg and previously calibrated using MicroFET 2 digital hand-held force measurement device, to measure 40 mmHg and 60 mmHg was utilised, similar to a procedure described by Vernon *et al*, in 1992 [24]. This system was used for biofeedback to achieve the two levels of adduction pressure and was positioned on the wedge at the distal third of the humerus. Participants were instructed to contract to the assessed levels of adduction pressure, 40mmHg and 60mmHg while performing the loaded isotonic movement.

A Samsung HS60 diagnostic ultrasound machine with a linear array ultrasound transducer (LA3-14AD, 3.5-13.5 MHz, resolution 1) was used to obtain all videos of the SAS and was operated by an experienced sonographer. Each participant underwent ultrasound evaluation of their dominant shoulder while those with a history of shoulder pathology underwent analysis of both. With the participants positioned as described above the ultrasound transducer was placed at a transverse view of the infraspinatus.

Best visualisation involved a posterior approach whereby the acromion, humeral head, and infraspinatus in the posterior aspect of the subacromial space were seen (Figure 2). This view was to chosen in order to utilize the uniform curvature of the humeral head rather than the distance being impacted by the greater tubercle of the humerus. It is recognized this is not a standard view of the subacromial space however, there are two standard landmarks present.

Participants were verbally instructed when to initiate the required movement once the ultrasound probe was correctly positioned. A video was then taken until participants met their end range of internal rotation (where their arm touched their chest), paused and then restarted until reaching the floor marker indicating the initial starting point. This was then repeated for each level of adduction pressure (40 & 60 mmHg).

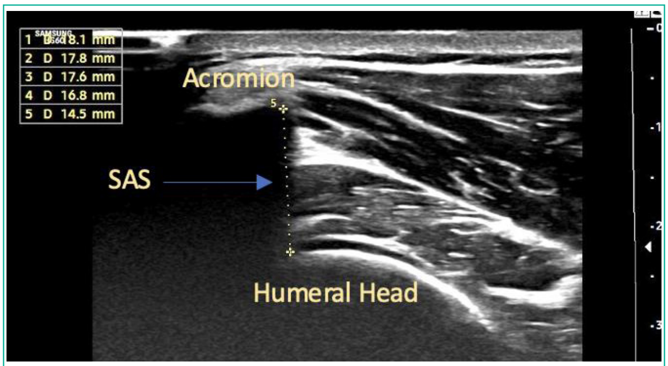

Figure 2: Image of SAS measurement. A linear measurement was taken from the inferior aspect of the tip of the acromion to the capsule of the glenohumeral joint.

Calibration of Blood Pressure Cuff

To assess adduction pressure a modified sphygmomanometer [24] was used as a biofeedback unit to achieve the two levels of desired adduction pressure 40mmHg and 60mmHg. This involved rolling the cuff into a cylindrical shape, securing it with tape and inflating it to 20mmHg. A MicroFET 2 was used to calibrate the pre-inflated blood pressure cuff (20mmHg) and determine the amount of pressure required to achieve 15N of adduction pressure was observed at 40mmHg – the proposed amount to alter the SAS [11] and again at 60mmHg. This was performed three times in order to ensure consistency. While performing isotonic internal and external rotation the patient used biofeedback to maintain a constant adduction pressure at both 40mmHg and 60mmHg whilst maintaining the 45° abduction angle.

Six videos (Internal and external rotation at each of the 3 adduction pressures) were taken per participant while twelve were generated for those who underwent analysis of both shoulders due to a history of shoulder pathology. Each ultrasound video was analysed by frame number after data collection. This involved dividing the video into one fifth of the total number of frames whereby a measurement of each subjects SAS was recorded. A linear measurement was taken from the inferior aspect of the tip of the acromion to the capsule of the glenohumeral joint (Figure 2). A total of 10 measurements were recorded for each participant at each adduction pressure (0, 40 and 60 mmHg) across isotonic shoulder internal and external rotation.

Separate to raw data collection the sonographer who captured all data was then blinded to the subject's number, arm position and level of adduction pressure and recorded all measurements.

Data Analysis

SPSS (version 29.0.0.0 241 for macOS) was used to generate all statistics. Data was inputted into GraphPad Prism (version 9.5.1 for macOS) to generate all figures accordingly. All participants underwent ultrasound analysis of their dominant arm while those with a history of previous shoulder injury underwent analysis of both.

The data was assessed for normality and equality of variance and tested with a one-way repeated measures ANOVA and an unpaired t-test in order to assay for any differences.

A one-way repeated measures analysis of variance (ANOVA) was performed to compare the effect of the three levels of adduction pressure (0, 40 and 60) during both isotonic internal and external rotation. Those with a history of shoulder injury were also compared against their non-injured shoulder respectively.

Results

A total of 20 subjects with a mean age of 30 years (range: 22-65) including 9 females and 11 males underwent ultrasound analysis of their dominant arm. Fiver of these participants had a history of shoulder pathology and therefore underwent analysis of both shoulders allowing a comparison with an uninjured side. Due to at least one image not meeting the quality criteria for ultrasound

Table 1: The Mean SAS in mm at 45° of shoulder abduction during the 3 states of adduction pressure (non-injured shoulders). A posterior imaging view was chosen whereby the acromion, humeral head, and infraspinatus in the posterior aspect of the subacromial space were seen.

State of Adduction Pressure (mmHg)	Isotonic Shoulder Internal Rotation (mm)	Isotonic Shoulder External Rotation (mm)
No Adduction Pressure	21.9	22.5
40 Adduction Pressure	22.0	22.6
60 Adduction Pressure	22.3	22.7

Table 2: The Mean SAS in mm at 45°of shoulder abduction during 3 states of adduction pressure (Injured shoulders).

State of Adduction Pressure (mmHg)	Isotonic Shoulder Internal Rotation	Isotonic Shoulder External Rotation
No Adduction Pressure	20.7	22.0
40 Adduction Pressure	21.6	22.2
60 Adduction Pressure	21.8	23.0

analysis three participants were excluded. This resulted in the data of 17 subjects (8 women and 9 men) a total of 22 shoulders being included for analysis.

The mean SAS during isotonic shoulder internal and external rotation across the three assessed adduction pressures are summarised for those with (Table 2) and without a history of shoulder pathology (Table 1). Box and whisker plots were used to describe the statistics accordingly (See Figure 3). It is considered the normal size of the SAS from an anteroposterior view is between 10-15mm in healthy subjects [1,25].

A repeated measures one-way ANOVA was performed to compare the effect of the three levels of adduction pressure at both positions of resisted isotonic internal and external rotation (Internal 0mmHg, 40mmHg & 60mmHg; p= 0.5769, External 0, 40 & 60; p= 0.9146). This determined all p-values > 0.05, therefore indicating no significance between them.

An un-paired two tailed t-test was performed to analyse internal vs external rotation at each individual adduction pressure (no pressure internal vs external; p= 0.6583, 40 internal vs external; p= 0.6608, 60 internal vs external; p= 0.7971). This test was also used to analyse the effect of adduction pressure during isolated internal rotation (0 vs 40 internal; p= 0.9302, 0 vs 60 internal; p= 0.7526) and external rotation (0 vs 40 external; p= 0.9162, 0 vs 60 external; p=0.8823). This also showed there to be no significant difference between the groups of data as the p-value was > 0.05.

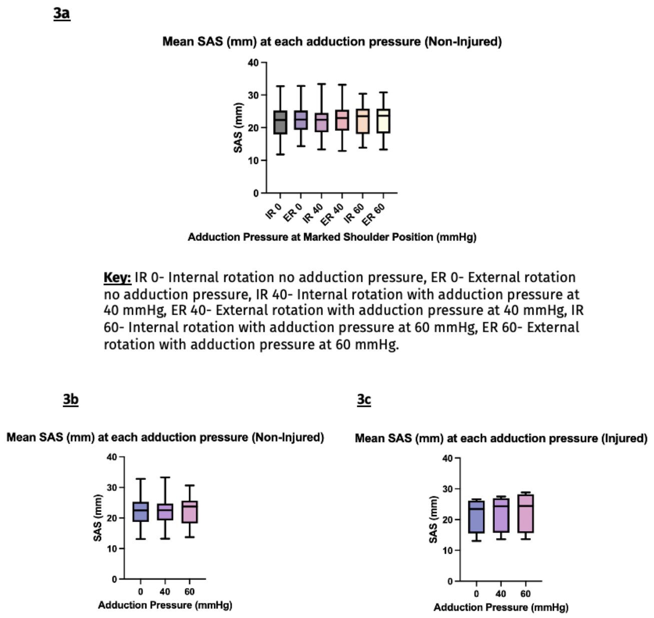

Figure 3: Box & Whisker Plot displaying the average SAS (mm) at each level of adduction pressure (0, 40 & 60 mmHg):
3a: Across each position (resisted isometric internal & external rotation) in healthy shoulders.
3b: Healthy shoulders.
3c: Injured shoulders.

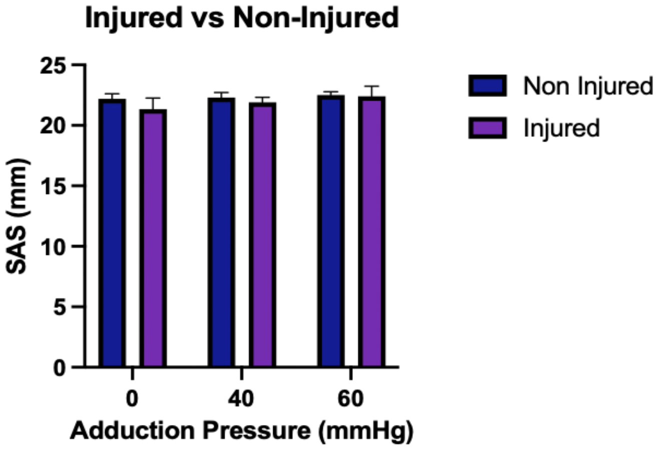

Figure 4: Bar chart displaying the mean SAS (mm) of the 5 participants with a history of shoulder pathology against their non-injured arm at each adduction pressure.

Analysis of participants with known shoulder pathology also involved a repeated measures one-way ANOVA to compare the effect of the three levels of adduction pressure (Internal 0, 40 & 60; p= 0.1210, External 0, 40 & 60; p= 0.2994). When compared against their non-injured shoulder no significance was determined between the three-adduction pressures analysed (p= 0.0892).

Discussion

The focus of this research was to explore the concept of the effect of forced adduction pressure on the SAS during resisted internal and external rotation. The aim was to identify whether a decrease in the SAS could be observed during resisted isotonic internal and external rotation when performed with forced adduction pressure. Three adduction pressures were chosen for analysis: 0mmHg, 40mmHg and 60 mmHg and were achieved through the use of a biofeedback unit.

This study followed similar methodology to the study by White *et al* incorporating their follow up recommendation for further investigation into the effect of isotonic shoulder exercise on the SAS during dynamic real-time movements rather than static movements.

The findings in this study do not correlate with those presented by White *et al* as no significance was observed during isotonic external rotation at 45° of abduction without forced adduction pressure (Figure 3a). White *et al* reported resistive isometric shoulder external rotation performed in an upright position at 45° of shoulder abduction significantly reduced the size of the AHD (1.06 mm) when compared with isometric shoulder internal rotation or no muscle contraction at 45° of shoulder abduction [1]. Questioning whether this is an appropriate approach for those with shoulder pathology. Whilst our study failed to agree with this finding, it is recognised that we did not incorporate a horizontal force of resistance to the shoulder during the procedure, and it is perhaps this along with the adduction pressure which introduces the decreasing SAS previously seen, not the adduction pressure alone.

The results for those with a history of shoulder pathology (Fig. 3c) displayed little variation in the size of the SAS when compared to those without (Figure 3b) at each level of adduction pressure during resistive isotonic internal and external rotation at 45° of shoulder abduction. The Mean SAS in participants with a history of shoulder pathology was seen to be highest under 60 mmHg of forced adduction pressure during isotonic shoulder external rotation compared to that of internal rotation at 60 mmHg (Table 2). However, this was not statistically significant ($p = 0.7845$).

It is unclear why there is such disparity between our data when compared to that shown in previous studies and reported by White *et al* [1,19,22]. Despite reaching significance, the study by White *et al* observed a minimal reduction of the SAS (1.06 mm) during isometric shoulder external rotation [1]. Disparity in results may be due to the use of a non-standard view for the purpose of video capture, or the resisted rotational force in the presence of the adduction pressure which our study lacked. We can postulate that assessment of the dimensions of the SAS during dynamic motion differs to results obtained from static views.

Adduction pressure achieved through a wedge has shown to provide assistance to patients when performing resistive shoulder exercise [6]. Ensuring the elbow is kept to the side through reciprocal inhibition and correct technique is observed [6]. It has also shown to improve coordination between the infraspinatus (IS) muscle (agonist of external rotation) and the adductor muscles including pectoralis major, latissimus dorsi and teres major [6]. However, the effect of adduction on muscle activation remains controversial. As demonstrated by Bascour *et al* who assessed the effect of different adduction pressures on the activity of IS, middle (MD) and posterior deltoid (PD) muscles through EMG during isotonic shoulder external rotation [18]. Demonstrating muscle activity during adduction is a result of muscle co-contraction [18].

It remains clear from the current literature there is lack of consensus surrounding the most effective type and dosage of exercise prescribed in shoulder rehabilitation protocols to maintain the AHD [26]. Although supported theoretically the effect of the adduction strategy during resistive glenohumeral internal and external rotation remains controversial and is not definitive on whether changes of the width of the SAS are primarily as a result of humeral head translation, muscle activation and/or alterations of scapular kinematics. Limitations of this study include the assessment of young asymptomatic individuals, the loss of subjects as a result of image quality and the use of a non-standard view of the SAS to facilitate dynamic assessment and the fact we did not incorporate a horizontal force of resistance to the shoulder during the procedure. Modifications of the protocol utilised have been acknowledged throughout in order to refine the procedure to aid future investigation. However, the assumption that the SAS changes with forced adduction pressure during loaded internal and external rotational exercises is not supported by these data.

Conclusion

Despite being incorporated into many rehabilitation programmes and the success of such protocols our concept of the mechanism falls into question and is likely to be one of muscle tone and stabilisation, not one of changing the dimension of the joint space. Future assessment should incorporate analysis of the SAS through a standard view while also analysing the corresponding effect on muscle activation. A focus on those with diagnosed SIS would also provide greater understanding for clinical implementation of the prescription of shoulder rehabilitation exercises.

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