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Measurement of subacromial impingement of the rotator cuff

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Abstract

Objective: Recent evidence suggests that shoulder impingement syndrome arises from primary rotator cuff pathology and may be related to the inability of the rotator cuff to prevent superior humeral head migration in shoulder elevation. Impingement involves compression of subacromial structures, including the rotator cuff. Previously, clinical tests have been shown to be inaccurate in diagnosing rotator cuff impingement. A lack of anatomical validity might explain the inaccuracy of these tests. This study aimed to clarify the anatomical basis of subacromial compression of the rotator cuff by analysing the compression forces generated and observing the structures impinged in a variety of shoulder positions. *Design*: This observational case series involved the dissection of nine embalmed cadaveric shoulders.
Method: Pressure transducers were placed deep to the coracoid process, coracoacromial ligament, the anterior acromion and the posterior acromion. Shoulders were moved into internal and external rotation from the positions of flexion, abduction and extension. At each position, pressure readings were recorded and structures being compressed observed visually.
Results: Highest pressures were recorded in flexion/internal rotation at the coracoacromial ligament, in abduction/internal rotation at the coracoid process (both involving the rotator interval) and in abduction/internal rotation at the coracoacromial ligament (involving supraspinatus). Supraspinatus was also observed to be compressed in extension/external rotation (against the anterior acromion). Infraspinatus was compressed in extension/external rotation (against the posterior acromion), while subscapularis was compressed in flexion/internal rotation and flexion/external rotation (both against the coracoid process).
Conclusion: This study identifies shoulder positions likely to impinge particular rotator cuff tendons.

Keywords: Shoulder; Impingement; Rotator cuff; Diagnosis

1. Introduction

Shoulder impingement syndrome can be defined as compression of the rotator cuff and the subacromial bursa against the anteroinferior aspect of the acromion and the coracoacromial ligament.[1,2] Shoulder impingement syndrome may lead to pain and/or weakness around the shoulder, accounting for half of all patients who consult a physician for shoulder pain.[3–5]

Recent evidence suggests that subacromial impingement may result from a primary rotator cuff pathology.[6,7] As the rotator cuff tendon passes through phases of the continuum of pathology (reactive tendinopathy, tendon disrepair and degenerated tendon) the increased tendon volume and/or subacromial bursal involvement may lead to a situation of impingement.[6,7] It is thought that rotator cuff dysfunction results in upward migration of the humeral head, causing impingement against the acromion with shoulder use.[8] Physical examination, geared towards subacromial impingement, is purported to increase compression in certain parts of the shoulder, thereby eliciting pain from pathology in this region.

Two clinical tests commonly used to assess shoulder impingement are Hawkins–Kennedy test and the Neer sign.[9] The Hawkins–Kennedy test involves passively flexing the shoulder to 90° then fully internally rotating the shoulder.[10] The Neer sign involves passive flexion of the shoulder while the scapula is stabilised.[11] While some authors refer to the Neer sign as the Neer test,[2] Neer's original test involved a

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subsequent xylocaine injection to differentiate impingement lesions from other causes of shoulder pain.[11] Pain constitutes a positive sign for both procedures. However a recent systematic review has found a lack of evidence to support the accuracy of the Hawkins–Kennedy and Neer signs for diagnosing rotator cuff pathology.[12]

Uncertainty concerning the physical effects of these tests on surrounding structures in the shoulder has cast doubt on their ability to contribute to a structural diagnosis.[12] A lack of anatomical and biomechanical validity to support the use of the clinical tests may explain their poor diagnostic accuracy. Evidence of anatomical and biomechanical validity of shoulder impingement might be established by measuring shoulder joint compression forces during various shoulder movements to find out if the movements increase compression on subacromial structures, thereby placing a stress upon them. These movements that stress the subacromial structures may then become the basis of anatomically valid tests for shoulder impingement.

There has been limited research investigating the anatomical basis of subacromial impingement. Some research that has examined this topic has focussed on contact or distances between impinged structures rather than compression forces.[13–15] Previous studies have established the accuracy and reliability of using pressure transducers to measure glenohumeral contact pressure.[16,17]

A recent study has investigated only the Neer sign and Hawkins–Kennedy test specifically.[18] Eight cadavers were attached to a shoulder positioning device, compression was applied and a tactile force sensor was used to determine subacromial pressure. The tactile force sensor provided generalised subacromial pressure readings in two general areas, below the anterior acromion and the coracoacromial ligament. The relationships between the rotator cuff tendons and the overlying acromion, coracoacromial ligament and coracoid process were established after removal of the relatively large tactile force sensor. The current study aimed to investigate a wider range of movements, to measure subacromial contact pressure in a more localised manner and to observe anatomical relationships of the rotator cuff more directly, during movement.

We aimed to investigate the subacromial pressures generated between the rotator cuff and the coracoacromial arch in a variety of shoulder positions, using four small pressure transducers. It was thought that by investigating a wide range of shoulder movements a comprehensive view of the subacromial pressures acting on the shoulder would be developed. The movements used to investigate impingement were external rotation (ER) and internal rotation (IR) from the positions of flexion (F), abduction (Ab) and extension (E). We also aimed to visually identify what structures in the rotator cuff were responsible for any subacromial pressure generated during movement. The pressures and structures identified in this study might then provide insights into subacromial impingement and inform a new protocol for clinical testing irrespective of whether the rotator cuff pathology is caused by external impingement or secondary to rotator cuff tendinopathy.

2. Method

The study design was a cadaveric observational case series. The right and left shoulders of four embalmed cadavers and the left of another (three males, two females, mean age 85 years), were dissected. No rotator cuff tears could be identified in any of the cadaveric shoulders. The skin and fascia were removed from the shoulder girdle to the lower aspect of the upper arm, just above the elbow. The deltoid was cut, just above its insertion and carefully peeled back to its origin and removed to expose the acromion. This revealed the subacromial bursa and subacromial space. Any fascia on the deep surface of the coracoid process, the acromion and the coracoacromial ligament was removed to facilitate the placement of pressure-sensitive transducers on these surfaces.

Removal of the subacromial bursa allowed the insertions of teres minor, infraspinatus, supraspinatus and subscapularis to be identified. Although it is acknowledged that the subacromial bursa can be a source of pain in impingement syndrome, the aim of the current study was to investigate potential impingement of the rotator cuff. The borders of the rotator cuff tendons were identified and marked with an indelible marker to allow clear identification of the tendons and the rotator interval during the trials.

Small force sensitive resistors (Interlink electronics, Model no. 400 – diameter 5 mm) were used as the transducers to measure subacromial pressures and were attached to the specimen with adhesive. These transducers were connected to a 4-channel PowerLab unit via a custom designed 4-channel variable offset amplifier.[19] The data were then fed directly to a computer and collected using 'Labchart 6 for Windows' software (ADI Instruments, Sydney). Data were collected at a frequency of 1000 Hz. In our laboratory, preliminary testing demonstrated that subacromial pressures could be measured in a cadaver with high levels of interdevice and retest reliability (intraclass correlation coefficient $\geq$0.88).[19]

Previous studies have found a subacromial pressure range of 0–243 kPa.[20–22] Based on the surface area of the transducers (19.6 mm^2), this translated to a weight range of 0–121 g. Given that the upper range in previous studies was associated with pathological conditions, the pressure transducers were calibrated using weights ranging from 31 to 91 g, which incorporated the range of expected pressures.

Each cadaver was inserted into a vice that fixed the body of scapula. The limb was suspended in the anatomical position and the glenohumeral joint was free to move. Four transducers were attached first, deep to the coracoid process, second, to the lateral aspect of the inferior surface of the coracoacromial ligament, third, to the under-surface of the acromion, 1 cm posterior to the anterior border, and fourth, 1 cm anterior to the posterior border (Fig. 1). The three posterior transduc-

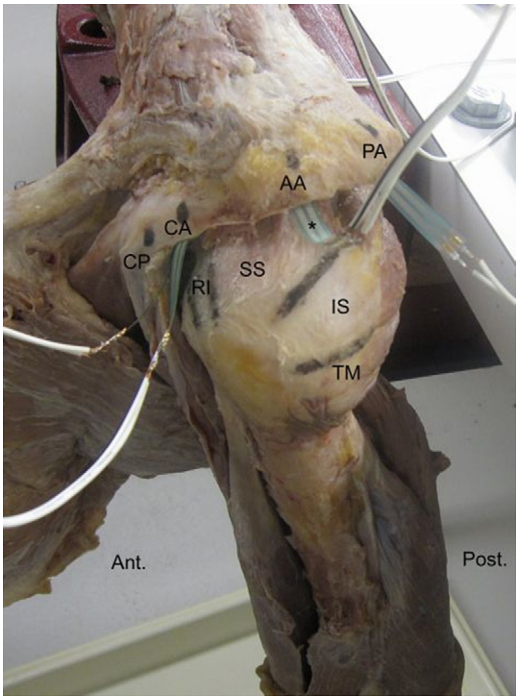

Fig. 1. Supero-lateral view of left cadaveric upper limb with borders of rotator cuff tendons traced onto the glenohumeral joint capsule (CP: coracoid process; CA: coracoacromial ligament; AA: anterior acromion; PA: posterior acromion; RI: rotator interval; SS: supraspinatus tendon; IS: infraspinatus tendon; TM: teres minor tendon; *pressure transducer fixed under AA). Note that subscapularis tendon is anterior to RI.

ers were situated in areas where the subacromial bursa would normally lie.

To investigate shoulder impingement it was considered appropriate to examine subacromial contact pressures in a wide range of shoulder positions. Six shoulder positions were evaluated. Full external and internal rotation to a point where the tissues were providing significant passive resistancefrom the positions of 90° shoulder flexion, 90° abduction and full extension were carried out in a randomised order. Recent three-dimensional studies confirm that the scapulothoracic joint contributes between 20° and 40° of the first 90° of elevation.[23,24] So for flexion and abduction, in this study, 60–70° of elevation in the cadaver with the scapula fixed was approximately equivalent to 90° shoulder elevation in a living person.[19] Pressure was recorded continuously at all sites. While one researcher manually moved the limb and held the end position, a second researcher recorded the time point at which the end position was achieved using the 'Labchart 6' software. The second researcher also measured the range of glenohumeral movement using a manual goniometer (model G300; Whitehall Manufacturing, City of Industry, CA).

While the pressures were recorded using the 'Labchart 6' software, a visual determination of contact between the rotator cuff tendons and the rotator interval with the superficial-lying acromion, coracohumeral ligament and the coracoid process was recorded.

Results were assessed in two ways. First, analysis of the endpoint pressures as recorded by the pressure transducers, and second, visual assessment of the structures that were in contact in the subacromial region. Pressure was recorded in kPa. For the purposes of this study contact pressures were considered high if pressure was above 30 kPa, moderately high if pressure was 15–30 kPa and moderate if pressure was 8–15 kPa.

Data analysis of the subacromial pressures recorded at each transducer, at the endpoint of movement was carried out by a 2-way ANOVA with the dependent variable being pressure and two independent factors being shoulder position (with three levels; flexion, abduction, and extension) and rotation (two levels; external and internal).

3. Results

Table 1 shows the mean pressures generated (and the standard deviations) at the coracoid process, coracoacromial ligament, anterior acromion and posterior acromion. It also shows the structure that was most often in contact at these points (out of a maximum possible total of 9 cadaveric shoulders).

Supraspinatus was most often in contact, at moderately high or high pressures, in Ab/IR (with the coracoacromial ligament) and E/ER (with the anterior acromion). Subscapularis was most often in contact in F/IR and F/ER (with the

Table 1
Pressures (SD) generated and structures in contact. Pressures denoted in kPa.

Transducer	Flexion		Abduction		Extension	
	IR	ER	IR	ER	IR	ER
Coracoid process	13 ± 16 Sub = 6	12 ± 14 Sub = 5	31 ± 24 RI = 7	0.5 ± 0.3 Sub = 1	3 ± 6 RI = 3	0.3 ± 0.2 Nil
Coracoacromial ligament	41 ± 46 RI = 6	3 ± 8 Sub = 5	39 ± 25 SS = 8	5 ± 10 Sub,RI,SS = 1	3 ± 8 SS = 3	1 ± 2 RI = 3
Anterior acromion	10 ± 13 SS = 6	1 ± 2 Nil	3 ± 5 IS = 6	9 ± 14 RI = 4	2 ± 2 IS = 1	17 ± 19 SS = 5
Posterior acromion	2 ± 1 IS = 1	1 ± 1 Nil	1 ± 1 IS = 1	4 ± 7 SS = 4	0.5 ± 2 IS = 1	8 ± 10 IS = 6

Sub: subscapularis; RI: rotator interval; SS: supraspinatus; IS: infraspinatus.
■ : high pressures; ■ : moderately high pressures; ■ : moderate pressures.

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Fig. 2. Internal rotation in abduction.

coracoid process). Infraspinatus was most often in contact in E/ER (with the posterior acromion).

High pressures were recorded in F/IR (at the coracoacromial ligament) and Ab/IR (coracoacromial ligament and coracoid process) (Fig. 2). Moderately high pressure was also recorded in E/ER (at the anterior acromion).

In shoulder flexion, at the coracoacromial ligament, there was significantly more pressure in IR than ER, whereas there was little difference at the other sites between IR and ER ($F[1.9, 15.0] = 4.9$, $p < 0.05$).

In abduction, at the coracoid process and coracoacromial ligament, significantly increased pressures were recorded for IR compared to ER ($F[2.5, 20.1] = 9.7$, $p < 0.01$).

In extension, at the anterior acromion, significantly greater pressures were observed during ER compared to IR ($F[3, 24] = 6.8$, $p < 0.01$).

The mean (SD) glenohumeral movements were flexion $70° \pm 12°$, abduction $74° \pm 15°$, and extension $48° \pm 10°$. Internal rotation was $79° \pm 19°$ in flexion, $58° \pm 10°$ in abduction and $35° \pm 15°$ in extension. External rotation was $43° \pm 16°$ in flexion, $84° \pm 17°$ in abduction and $67° \pm 15°$ in extension.

4. Discussion

The movement with the highest subacromial pressure generated was F/IR. This movement is the Hawkins–Kennedy test. It has been proposed that the Hawkins–Kennedy test impinges the supraspinatus tendon against the coracoacromial ligament.[25] However, we found that F/IR caused most contact anterior to the supraspinatus, at the rotator interval. Yamamoto et al.[18] in a recent study also observed contact anterior to supraspinatus, although their observed point of contact was more anterior to our results and involved the subscapularis tendon. According to these results, the Hawkins–Kennedy test may not be best able to indicate subacromial impingement involving supraspinatus. Supraspinatus contacted the anterior acromion at only moderate pressures during F/IR. Having the arm in an abducted position moved the point of compression more posteriorly within the rotator cuff to involve the supraspinatus (more often and with greater pressure). These results suggest that if supraspinatus is suspected to be implicated in impingement, then Ab/IR may be more likely to compress this tendon than the F/IR of the Hawkins–Kennedy test.

The position of E/ER involved compression of supraspinatus on the anterior acromion, at moderately high pressures. E/ER has not been previously reported as being associated with subacromial impingement of supraspinatus, or as a clinical test. In flexed or abducted positions, external rotation rolls the greater tuberosity away from the glenoid fossa, but in extension, the reverse is true.

Subscapularis was most often in contact with the coracoid process, at moderate pressures, in both F/IR and F/ER. It makes sense that flexion is bringing the anteriorly placed subscapularis into contact with the coracoid process. We also observed supraspinatus in contact with the anterior acromion at moderate pressure. These results can be compared with those of Yamamoto et al. who reported higher pressures when the Neer sign was performed with flexion and internal rotation.[18] They observed consistent contact between supraspinatus and the anterior acromion and coracoacromial ligament. However, they did not measure or observe contact at the coracoid process.[18] Flexion is the movement in the Neer test. It could be that positive findings with this test may indicate impingement involving the subscapularis or supraspinatus.

The only movement to produce moderate pressures involving infraspinatus contact was E/ER. Attaching more posteriorly, this combination of movements brings the infraspinatus insertion into contact with the acromion.

This study recorded the contact pressures at the end of the movements. However, as the arm was being moved into position, the researchers could observe that a degree of shearing contact was taking place. This was particularly evident in both internal and external rotation, in abduction. The process of moving between internal and external rotation in abduction appeared to place a shearing stress on the tendons of the rotator cuff (particularly supraspinatus and infraspinatus) and on the acromion to a much greater extent than was the case in rotation in flexion. This movement is also likely to impact on the subacromial bursa that would normally lie between the tendons and the acromion. The pressure transducers used in this experiment are designed to detect compressive pressure, not measure shearing forces, so it is possible the transducers may underestimate the total impact on tendon during the observed shoulder (end of movement) positions.

It may be that clinical tests for impingement need to incorporate some of the movements in this study. For impingement involving the supraspinatus tendon, internal rotation in abduction may be worthy of further investigation. Flexion may best illustrate impingement involving subscapularis. When infraspinatus is involved, external

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rotation in extension might be the best position to elicit pressure and hence pain. However, this movement also results in supraspinatus contact at high pressure, so, for example, if isolated infraspinatus pathology exists, it might be that pain with E/ER, combined with pain in resisted external rotation might implicate infraspinatus pathology over supraspinatus.

The subacromial bursa is an important structure that was not directly considered in this study as it was removed during dissection to allow placement of transducers and observation of the tendons of the rotator cuff. Situated superior to the rotator cuff tendons, the bursa covers a wide area and any pain arising from subacromial impingement may well be sourced from this structure. If the bursa is inflamed, with more bursal fluid present, the pressures recorded in this study would be distributed more widely, and may possibly result in high pressure values.

A limitation of this study is that it involved embalmed cadaveric as opposed to living shoulders. However, the relationships between the anatomical structures remain the same and it could be assumed the pressure relationships are similar. While there could be a difference in the passive behaviour of biological materials in these contexts and the ranges of shoulder movement in an embalmed cadaver will obviously be less than *in vivo*, the ranges of movement achieved in this study were sufficient to achieve the desired positions. The scapula was fixed in a vice and therefore there was no scapulohumeral rhythm in arm elevation. Elevation of the arm is accomplished by a combination of glenohumeral and scapulothoracic movements,[26] with the scapulothoracic joint contributing 20–40°.[23] This means the 70° of flexion reached in this study could equate with the 90° required for the Hawkins–Kennedy test.

It may be that capsular tightness is a factor in impingement, in living subjects. A recent cadaveric study, using the type of larger tactile force sensor as did Yamamoto et al.[18] found that posteroinferior capsular tightness leads to higher contact areas under the coracoacromial arch and increased contact area.[27]

Yanai et al. questioned whether subacromial pressure data from cadaveric studies should be the sole basis for determining the shoulder movements that produce impingement in living subjects.[28] They undertook an *in vivo* study that measured impingement forces by ultrasonic assessment of coracoacromial ligament deformation under load. Despite the differences in methodology, the key results of the current study are similar to those of Yanai et al. in that abduction in internal rotation and flexion in internal rotation returned the highest pressure values.

The results in this study associated with passive testing procedures also need to be seen in the context of no rotator cuff activation in cadavers. Superior humeral head migration occurs when the rotator cuff becomes fatigued and is unable to resist this upward translation.[29] This may call in to question the passive nature of impingement tests to date. Since it is often active movements that produce the pain of impingement, perhaps impingement testing *in vivo* should also involve active movements.

5. Conclusion

This cadaveric study measured subacromial pressures and observed impinged structures in internal and external rotation of the shoulder, in flexion, abduction and extension. It provides insights that suggest that clinical tests for shoulder impingement may need to be re-appraised. Rotator cuff structures most commonly implicated in subacromial impingement may not be placed under compression with current clinical testing protocols. This study identifies positions more likely to impinge particular rotator cuff tendons that could be evaluated with clinical testing.

6. Practical implications

- If supraspinatus is associated with an impingement syndrome, internal rotation in abduction may be painful.
- If subscapularis is associated with an impingement syndrome, flexion in internal or external rotation may be painful.
- If infraspinatus is associated with an impingement syndrome, external rotation in extension may be painful.

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