ROTATOR CUFF FUNCTION
IN THE IMPINGEMENT SYNDROME

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Thirty-three patients with impingement syndrome of the rotator cuff were studied before and at operation. It was shown that the rotator cuff lengthens and twists during elevation of the arm. Elevation is achieved by early glenohumeral abduction and continuous flexion and external rotation. The range of free rotation at the glenohumeral joint diminishes progressively during elevation.

Rotator cuff impingement occurs towards the end of the early glenohumeral abduction. Excision arthroplasty of the acromioclavicular joint and anterior acromioplasty is highly effective for impingement under the acromion, but only moderately effective where impingement is under the acromioclavicular joint.

The function of the rotator cuff is important in the treatment of the impingement syndrome, cuff rupture and shoulder arthroplasty (Neer 1972; Cofield 1984; Watson 1985). Cuff function has been discussed in some detail (Poppen and Walker 1976; Himeno and Tsumura 1984): it stabilises the glenohumeral joint while the deltoid elevates the arm, but its precise excursion has not been well described, either in disease or in health.

Since elevation is normal (although painful) in the impingement syndrome, it is likely that cuff function also is normal. Thus a study of cuff function in patients with impingement syndrome affords an opportunity to define normal values and refine our understanding of impingement and its sequel, rupture.

Definitions. The rotator cuff affects the glenohumeral joint only, so scapular movement on the thorax was not studied, all measurements being made with reference to the scapula. The neutral position was the anatomical one, except that in zero rotation the humerus lay in such a position that elbow flexion moved the forearm in a plane perpendicular to that of the scapula.

Flexion at the glenohumeral joint brought the humerus forwards perpendicular to the scapular plane abduction brought it laterally in the scapular plane and external rotation took the flexion arc of the forearm outwards. The general term for lifting the arm is elevation in order to avoid prejudice as to the mechanism of the movement.

PATIENTS

Thirty-three consecutive patients were studied, 11 men and 22 women. Their ages ranged from 41 to 64 years and the dominant arm was affected in 26.

All had the refractory impingement syndrome, in which the shoulder is fully mobile actively and passively, with no weakness. Pain is felt only during part of the excursion, but there is demonstrable tenderness over the humeral head. Complete relief of this tenderness by injection of local anaesthetic abolishes the pain and localises its source (Kessel and Watson 1977). Radiographs reveal no gross glenohumeral disorder and arthrography shows no gross abnormality. All 33 patients had failed to respond to non-operative treatment.

METHODS

Pre-operative. Palpable bony points on the scapula and the humerus were identified. The positions of the tip of the coracoid, the angle of the acromion and the medial and lateral epicondyles of the elbow at the two extremes of active rotation were recorded in the neutral position, in mid-elevation (arm horizontal) and in full elevation. The angular excursion of the glenohumeral joint was calculated from these measurements. The position at which the greatest pain was felt was recorded, using the same technique and convention.
Table I. Active rotation in three positions of the humerus, given as average and range in degrees

<table>
<thead>
<tr>
<th></th>
<th>Neutral</th>
<th>Mid-elevation</th>
<th>Full elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>External rotation</td>
<td>85 (65 to 100)</td>
<td>70 (70 to 90)</td>
<td>90 (85 to 100)</td>
</tr>
<tr>
<td>Internal rotation</td>
<td>80 (70 to 90)</td>
<td>30 (20 to 40)</td>
<td>-70 (-90 to -60)</td>
</tr>
<tr>
<td>Total rotation</td>
<td>165</td>
<td>100</td>
<td>20</td>
</tr>
</tbody>
</table>

Table II. The position of greatest pain in impingement syndrome in 33 patients given as average and range in degrees

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abduction</td>
<td>45</td>
<td>(40 to 60)</td>
</tr>
<tr>
<td>External rotation</td>
<td>50</td>
<td>(40 to 60)</td>
</tr>
<tr>
<td>Flexion</td>
<td>45</td>
<td>(40 to 60)</td>
</tr>
</tbody>
</table>

Radiographs perpendicular to the scapular plane were taken in the neutral position, in mid-elevation and in full elevation. Apparent movement of the tuberosities with respect to each other and to the acromion gave a measure of rotation, flexion/extension and abduction/adduction (Fig. 1).

Operation. After induction of anaesthesia, the joint was put through its passive excursion and the location of the bony landmarks was recorded in a similar manner to that used pre-operatively. Another set of radiographs were taken as detailed above.

Through a deltoid split the cuff was inspected and the positions of any lesions were recorded. The arm was moved through its full passive range and the locations of the scapular and humeral landmarks were recorded by the pre-operative method in relation to the position and course of movement of each cuff lesion.

The deltoid split was then extended proximally and the outer centimetre of the clavicle was excised through an acromioclavicular capsulotomy. The deep bony projections on either side of the joint and the coracoacromial ligament were excised (Fig. 2). This included an
anterior acromioplasty. Cuff lesions were trimmed or repaired. The wound was closed by acromioclavicular capsule repair. Gentle active and passive movement was encouraged postoperatively.

**Postoperative.** Glenohumeral excursion and pain relief were recorded at regular intervals and a final assessment for this study was made at six months.

**FINDINGS**

**Pre-operative movement.** Placing the hand in the overhead position caused a stereotyped movement which was reproducible: the humerus was lifted forwards and upwards, rotating externally by 80 to 110°. At the same time, the glenohumeral joint flexed 110 to 130°. The initial half of the movement included 40 to 60° of abduction. Most patients had learned trick movements to reduce pain when elevating their arm, usually involving early external rotation followed by late abduction and flexion.

The possible range of active rotation diminished with elevation in all cases. At full elevation an average of 20° of total rotation was available, compared with 100° in mid-elevation and 165° in the neutral position (Table I).

**The painful lesion.** The source of pain within the cuff was in the region of the lesser tuberosity in four cases and in the region of the greater tuberosity in the other 29. The position at which the greatest pain was felt was remarkably constant: in all patients it was between 40 and 60° of glenohumeral abduction, with some flexion and nearly full external rotation (Table II).

**Radiology.** Measurement of the distances between bony points on the pre-operative radiographs showed proximal and lateral migration of the lesser tuberosity and proximal migration of the greater tuberosity in the first half of elevation, indicating flexion, external rotation and abduction. During the second half of the movement to full elevation no further abduction took place; continued flexion was indicated by proximal migration of the lesser tuberosity and continued external rotation by migration of the tuberosities around the long axis of the humerus.

**At operation**

**Movement.** During passive elevation the tuberosities passed along an S-shaped path which was directed at

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**Table III.** The position of the lesions in 33 patients with impingement syndrome

<table>
<thead>
<tr>
<th></th>
<th>Full thickness</th>
<th>Partial thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subscapularis</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>4*</td>
<td>25</td>
</tr>
</tbody>
</table>

* all less than 5 mm in diameter

**Table IV.** The impinging structures in 33 patients

<table>
<thead>
<tr>
<th></th>
<th>Coracoacromial ligament</th>
<th>Acromioclavicular joint</th>
<th>Acromion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subscapularis</td>
<td>2</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>-</td>
<td>14</td>
<td>15</td>
</tr>
</tbody>
</table>

**Table V.** Excursion in degrees for each of the three planes measured on the radiographs taken before and at operation

<table>
<thead>
<tr>
<th></th>
<th>Flexion</th>
<th>External rotation</th>
<th>Abduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-operative</td>
<td>110 to 130</td>
<td>80 to 100</td>
<td>40 to 60</td>
</tr>
<tr>
<td>Operative</td>
<td>100 to 130</td>
<td>75 to 105</td>
<td>40 to 70</td>
</tr>
</tbody>
</table>

**Table VI.** Result at six months in 33 patients related to site of impingement. No patients were unchanged or made worse

<table>
<thead>
<tr>
<th></th>
<th>Subscapularis</th>
<th>Subscapularis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain</td>
<td>Coracoacromial ligament</td>
<td>Acromioclavicular joint</td>
</tr>
<tr>
<td>None</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Mild</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

VOL. 71-B, No. 3, MAY 1989
Figure 4 - Drawings of the shoulder based on the integration of radiological and clinical findings. Anterior, lateral and superior views are shown for each of three positions of the humerus. The scapula and clavicle remain in the anatomical position.

Figure 4a - Neutral position.

Figure 4b - Partial elevation. In the normal patient the elevation would be greater at this glenohumeral position, because of the addition of scapular excursion. The humerus is fully abducted and is in partial external rotation and flexion. The cuff tendons wind posteriorly around the free edges of the spine of the scapula and the coracoid process. In the superior view the coracoacromial ligament has been turned down to expose the cuff tendons.

Figure 4c - Full elevation. The arm would be against the ear in a normal patient. The cuff tendons are fully wound up and are tightly stretched beneath the coracoacromial arch. The supraspinatus tendon passes to the lowest part of the humeral head, and the subscapularis tendon passes to the most posterior part. In the superior view the coracoacromial ligament has been turned back.
first medially and then laterally (Fig. 3). During the first half of the movement, abduction brought the tuberosities under the coracoacromial arch. In the second half, on cessation of abduction, continuing flexion and external rotation brought the tuberosities out from beneath the acromion in a posterolateral direction. At full elevation the tuberosities had moved 3 to 4 cm from their resting position (Fig. 4).

The painful lesion. All the patients had an identifiable lesion on the rotator cuff. These were either small full thickness ruptures (less than 5 mm) or partial thickness localised ruptures on the bursal surface of the cuff. In four cases there were partial thickness ruptures on the bursal surface of the upper half of the subscapularis tendon, and in all other cases the lesions lay on the anterior half of the supraspinatus tendon. There were four full-thickness ruptures; the rest were partial-thickness lesions. There was complete correlation between the pre-operative and the operative localisation of the lesions: all the patients with lesser tuberosity tenderness had subscapularis lesions and all the patients with greater tuberosity tenderness had supraspinatus lesions (Table III).

Impingement. At the end of the abduction phase of elevation, when the arm was horizontal, all the cuff lesions lay beneath the coracoacromial arch. This position was associated with partial flexion and external rotation at the glenohumeral joint. The supraspinatus and subscapularis tendons were then under tension, as they angled posteriorly around the free lateral margins of the scapular spine and the coracoid process respectively (Fig. 4b).

Impingement of the lesions could be reproduced by passive movement of the arm into the position of greatest pain; this was towards the end of glenohumeral abduction as the tuberosities approached the coracoacromial arch. All the lesions were compressed most tightly between these structures as external rotation and flexion overtook abduction; in this position the tendons buckled around the coracoid process and the scapular spine, thus increasing the pressure of impingement. The impinging structures were revealed by placing the arm in the painful position. Of the four subscapularis lesions, two were compressed against the free anterior margin of the coracoacromial ligament by the lesser tuberosity at the end of the glenohumeral abduction phase. The other two were compressed similarly on the deep surface of a degenerate and enlarged acromioclavicular joint (Fig. 5).

The supraspinatus lesions were compressed similarly. In 14 cases impingement was against a degenerative swelling of the acromioclavicular joint; deep osteophytes on either side of the joint distorted and compressed the tendon at the end of the abduction phase. In 15 cases the swelling was purely acromial, the normal anterior projection being enlarged and projecting down into the subacromial space. The coracoacromial ligament was distorted by these swellings, but no cases of ligament thickening or stiffening were seen (Table IV).

Radiology. Passive reproduction of the trick movement used by the patient to avoid painful elevation showed its mechanism. Early external rotation moved the cuff lesion laterally so that subsequent flexion and glenohumeral abduction failed to bring it beneath the coracoacromial arch.

Pre-operative and operative radiographs were virtually indistinguishable: the amount of passive abduction, flexion and external rotation was similar to the active amount in all cases (Table V).

CLINICAL RESULTS

No patient had any residual weakness or stiffness, and no improvement was seen beyond six months after the operation. There was no apparent difference between the results in patients with small full-thickness ruptures and those with partial-thickness ruptures.

Of the four patients with subscapularis lesions, two were painless within six months. Two had permanent residual pain on movement, though this was less severe than before operation: one had had coracoacromial ligament impingement and the other acromioclavicular joint impingement.

Of the 14 patients with supraspinatus impingement beneath the acromioclavicular joint, 11 became pain-free and three had mild residual pain. All 15 patients with supraspinatus impingement on the deep surface of acromion were pain-free at six months (Table VI). There
was no correlation between the result and age, sex or limb dominance of the patient.

DISCUSSION

Cuff function. No radiological difference was found between the active and the passive excursion of the cuff so it appears that its function is principally passive: the cuff lengthens and twists during elevation of the arm. The electromyographic activity of the cuff muscles noted during elevation of the arm (Basmajian and Bazant 1959; Laumann 1984; Glousman et al. 1988) must therefore represent reeling out under tension rather than true contraction. This leads to the conclusion that the chief function of the muscle bellies attached to the cuff is to maintain tension on it during elevation and descent of the arm; this prevents rucking of the cuff and subsequent jamming. Furthermore it follows that tension in the cuff is greatest in full elevation of the arm, not at the other extreme of movement, as most surgeons imagine.

Glenohumeral movement. This study has clarified the mechanism whereby the arm is elevated over the head. As the arm ascends the humerus rotates externally and flexes at the glenohumeral joint; about 60° of abduction takes place in the first half of the movement. With more elevation, increasing tension in the cuff progressively limits rotation, and movement can take place only within a narrowing range until the cuff is fully wound up. The neck of the humerus then abuts on the coracacromial ligament and only scapular movements are available to adjust the position of the arm, since little or no movement can take place at the glenohumeral joint. In lesser degrees of elevation more glenohumeral freedom is available and less scapular excursion is required to place the arm in any desired position.

Cuff decompression. The effectiveness of anterior acromioplasty, acromioclavicular excision arthroplasty and excision of the coracacromial ligament for cuff impingement on the abnormal anterior acromion is borne out by this study. The operation is less effective for patients with impingement on the deep surface of the acromioclavicular joint and has even worse results for impingement on the coracacromial ligament, with only a 50% cure rate. These differences were not due to variations in the severity of the disorder in the series, since the patients were selected to prevent this. It seems possible that residual impingement against the inferior acromioclavicular ligament and the coracoid process caused the relative failure.

Cuff impingement. Elevation of the arm is associated with two distinct cuff movements, continuous flexion/external rotation and early glenohumeral abduction. The initial glenohumeral abduction moves the tuberosities and their attached cuff tendons towards the coracacromial arch. Normally, simultaneous flexion and external rotation prevent collision between the arch and the tuberosities, but, if flexion/external rotation is prevented, elevation leads to collision and prevents further glenohumeral abduction. Any projection on the deep surface of the coracacromial arch will cause repeated and inevitable collisions which flexion/external rotation cannot prevent. These lead to degeneration and rupture of the cuff.

The commonest type of impingement seems to be between the greater tuberosity and the acromion, as pointed out by Neer (1972). However, impingement between the greater tuberosity and an enlarged degenerate acromioclavicular joint is almost as common and is less amenable to the operation described above. In such cases, the nature of the acromioclavicular disorder varies, but most are post-traumatic (Watson 1984). It is not known what proportion of injured acromioclavicular joints lead to an impingement syndrome.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

REFERENCES


