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Local pressures in the subacromial space

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Abstract We recorded pressures in the subacromial space with various degrees of humeral abduction. The recordings were made during open surgery and under general anaesthesia using a 2-mm-thick piezo-electric pressure transducer. The pressures were recorded in 14 patients with shoulder impingement syndrome (Neer's stage II) and in eight patients with acromioclavicular dislocation serving as controls. The pressures were higher in the impingement group than in the control group. In both groups the highest pressures were recorded antero-laterally under acromion. In patients with impingement syndrome, the pressures increased significantly with abduction.

Résumé Nous avons enregistré les pressions dans l'espace subacromial avec plusieurs degrés d'abduction humérale. Les enregistrements ont été faits pendant une chirurgie ouverte et sous anesthésie générale en utilisant un transducteur de pression piézoélectrique de 2 mm d'épaisseur. Les pressions ont été enregistrées chez 14 malades avec un syndrome d'accrochage de l'épaule (Neer stade II) et chez 8 malades témoins, présentant une luxation acromioclaviculaire. Les pressions étaient plus hautes dans le groupe d'accrochage de l'épaule que dans le groupe de commande. Dans les deux groupes les plus hautes pressions ont été enregistrées dans la région antéro-externe, sous l'acromion. Chez les malades avec un syndrome d'accrochage de l'épaule les pressions augmentaient significativement avec l'abduction.

Introduction

Encroachment of the rotator cuff tendons in the subacromial compartment, which is bound by the coracoacromial arch above and the humeral head below, has been suggested to be a major factor in the pathogenesis of impingement syndrome [10, 13, 16, 20, 23]. The compression, leading gradually to various stages of impingement lesion, i.e. tendinitis, partial and full thickness rotator cuff tear and rotator cuff arthropathy [3, 14, 18], is thought to be caused by the curved and hooked shape of the acromion or by bony protuberances from the anterior undersurface of the acromion [12, 13]. The importance of these factors is supported by the fact that elimination of the anterior undersurface of the acromion by acromioplasty frequently results in pain relief [1, 2, 5, 6, 8, 13, 18].

This concept has not been completely proven yet [16]. Recent literature contains only some papers dealing with subacromial pressure recordings, but they deal with contact area, are made in cadaveric models, have not measured local pressures or have used crude techniques in pressure measurement [16, 21, 24].

We measured the pressures between the acromion and the rotator cuff with a small sensor in four subacromial locations at various abduction angles of the humerus in patients with tendinitis stage impingement syndrome using cases of acromioclavicular dislocation as controls.

Patients and methods

The system used for pressure measurement consisted of a power source (9-V battery) and a RMS multimeter connected to a pressure transducer based on a piezo-resistive-type sensor (Entran International, Les Clayes-sous-Bois, France) operating in a fully active Wheatstone Bridge. Many different types of pressure sensors, ranging from piezo-resistive semiconductors (silicon) to piezo-electric polymer (PVDF), were in fact tested. The results reported here were measured with a sensor based on a silicon strain gauge in an active bridge configuration encapsulated in a stainless steel case. Sensor pressure values were referenced to 1 atmosphere pressure sealed within the sensor structure. Sensor sensitivity was

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35 mV/bar and the maximum range continued up to 5 bar. Combined non-linearity and hysteresis were about $\pm 1\%$ FS up to 1.5 bar when external circuitry was used for thermal compensation. The sensor in the form of a flat disc of 3 mm diameter and 1 mm thickness was mounted in a flat, flexible rod with a 2 mm thickness and length about 30 cm (thus the thickness of the head of our pressure gauge was 2 mm). A metal spike 1 mm long was fused to the tip of the rod in order to fix the rod against the acromion when the pressure was being recorded.

The study group consisted of 14 patients—seven men and seven women; mean age 45 (33–55) years—who underwent acromioplasty for stage II impingement syndrome [3, 14]. All had positional discomfort and night pain for at least 1 year despite effective conservative treatment and showed a positive impingement sign and a subacromial injection test. Single contrast arthrography and ultrasonography examinations were performed without any evidence of either partial-thickness or full-thickness rotator cuff tear. The shape of the acromion was determined as type 2 (curved) in all cases with supraspinatus outlet view [7, 15].

Eight patients—seven men and one woman; mean age 36 (27–45) years—undergoing surgery for complete acromioclavicular dislocation [9], of which seven were acute and one chronic with no previous history of shoulder complaints, served as controls.

All 22 operations were performed under general anaesthesia with the patient lying supine, using a curved longitudinal incision along the anterior border of the acromion and acromioclavicular joint. After detaching the deltoid muscle from the anterior margin of the acromion, the subacromial space was exposed by incising the coracoacromial ligament in both groups. Recordings were made at this stage before the operation proper.

Pressures were recorded at four locations in the subacromial space (Fig. 1): (1) Anterolateral—tip of the acromion as near to the borders as possible, 6 mm from the lateral and anterior borders; (2) Anteromedial—6 mm distal to the acromioclavicular joint and posterior to the anterior border of the acromion; (3) Posterolateral—25 mm posterior to point 1; and (4) Posteromedial—25 mm posterior to point 2.

At each measurement point the recordings were made with the arm abducted in the coronal plane at 0°, 30°, 60° and 90° in neutral rotation. Arm position was achieved passively without traction by an assisting person. Pressure values are expressed in relative pressure units, with one unit corresponding to one bar. Measurements were repeated and the averages used in the final analysis.

Informed consent was obtained from all patients and the protocol was approved by the Ethical Committee of the Medical Faculty of the University of Oulu. Data was processed and analysed by a statistician using SPSS version 10.0 package. Because data included excess zeros, the two-part model described by Lachenbruch was applied [11]. Fischer's exact test was used for dichotomous data, and Student's *t*-test or Mann-Whitney *U*-test for continuous data. Friedman's non-parametric test (using averages of recordings at different abduction angles) or Fischer's exact test was used in the evaluation of differences between measurement locations.

Results

The highest subacromial pressures were found in both groups under the anterior part of the acromion (Fig. 2). In the impingement group the pressure under the anterolateral acromion was significantly ($p < 0.001$, Friedman's test) higher than under the anteromedial, posterolateral and posteromedial acromion, and under the anteromedial acromion significantly ($p < 0.001$) higher than under the posterolateral and posteromedial parts. In the control group, comparison of averages with Friedman's test could not be applied due to excess zeros (7/32 zeros in the anterolateral

Fig. 1 Schematic diagram of the subacromial measurement points. 1 = anterolateral; 2 = anteromedial; 3 = posterolateral; 4 = posteromedial

location, 15/32 zeros at the anteromedial location, 23/32 at the posterolateral and 26/32 at the posteromedial location). Therefore Fischer's exact test was used. This showed that pressures were significantly higher under the anterolateral acromion than under the anteromedial, posterolateral and posteromedial acromion ($p < 0.001$), and under the anteromedial acromion than under the posterolateral and posteromedial acromion ($p < 0.01$) in controls, too.

Pressures were significantly higher in the impingement group than in the control group under the anterolateral acromion at 60° ($p = 0.016$, Mann-Whitney *U*-test) and 90° ($p = 0.015$) of abduction and under the anteromedial acromion at 90° ($p = 0.046$) of abduction (Fig. 2).

Pressures under the anterolateral acromion increased during abduction in the impingement group (Fig. 2). The differences were significant between 0° and 30° ($p = 0.007$, Student's *t*-test), 0° and 60° ($p = 0.006$) and 0° and 90° ($p = 0.004$). Similar significant increases were seen under the anteromedial acromion between 0° and 60° ($p = 0.044$) and 0° and 90° ($p = 0.046$). An increase of abduction angle had no significant effect on subacromial pressures in the control group.

Discussion

Our results suggest that the subacromial pressure is highest under the anterior acromion, especially anterolaterally, increases during abduction in impingement patients and is elevated in the impingement shoulders. These findings further define the earlier knowledge and are by large in agreement with previous studies.

Flatow et al. [4], with the use of stereo-photogrammetric analysis, demonstrated that acromion undersur-

Fig. 2 Relative pressures in four locations of the of subacromial space at different abduction angles in the study and control groups (median, 25% and 75% quartiles)

face and rotator cuff tendons are in closest proximity between 60° and 120° of elevation in cadaveric shoulders and that the main area of increased contact is the antero-inferior part of the acromion. However, they did not measure the pressure quantitatively.

Zuckermann et al. [25] evaluated the subacromial pressure indirectly with use of three-dimensional computer modelling, which showed that the volume of the subacromial space was decreased when the anterior aspect of the acromion was more prominent. Wuelker et al. [24], using dynamic cadaveric model, found that peak forces under the coracoacromial arch occurred between 51° and 82° of elevation and were most pronounced underneath the acromion. They pointed out that measurements obtained in anatomic specimens may not be fully applicable to the clinical situation. Jerosch et al. [10] suggest, based on their cadaveric study, that where the measurement was carried out with a compression film a mechanical subacromial compression only occurs in shoulder joints with a Bigliani acromion type III acromion [12] or in joints with an imbalance of the deltoid/rotator cuff relation. In our study acromions were classified as type II, and we could not consider the muscular imbalance because of the anaesthesia.

Sigholm et al. [21] studied subacromial bursal pressures in healthy volunteers using the microcapillary infusion method. Pressure averaging at rest 8 mmHg increased when the arm was lifted to 39 mmHg and with 1 kg weight to 56 mmHg. Their method reflects only the total pressure of the bursal pouch [16], not local pressures under the acromion, as does our method.

Nordt et al. [16] measured the subacromial pressures with a balloon catheter and showed that fully abducted and cross-reach positions generate the highest impingement pressures, and that acromioplasty decreased significantly (60–100%) anterior edge subacromial pressures. These results are also very much in accordance with our findings, showing the rise of pressures with abduction and highest pressures in the anterior part of the subacromial space.

These papers, as do our findings, lend support the use of Neer's acromioplasty in the treatment of impingement syndrome [13]. Excision of the anterior undersurface of the acromion, under which the subacromial pressure is concentrated, decreases the pressure and explains the good effect of acromioplasty in this disease.

There are aspects of this study that may cause some bias. The pressures observed between the acromion and rotator cuff proved to be surprisingly high. It must be considered that the sensor, although not more than 2 mm thick, interferes with the recording by stretching the subacromial space, which may increase the real pressure value. However, our sensor was markedly thinner than that of the balloon used by Nordt et al. [16], which was 4 mm thick. We give the measured pressures in relative values, which are sufficient for our purposes. To obtain pressure values near to the real, a transducer as thin as possible should be developed. Another source of error might be that the measurements were performed under general an-

aesthesia. It is possible that under normal conditions the co-ordination of muscle function and arm torque would have an effect on the pressures in the subacromial space.

Furthermore, it has to be emphasised that it is difficult to find a valid control group for this kind of measurement. Here we performed the control measurements during repair of the dislocated acromioclavicular joint, which is nevertheless the only frequently performed operation in our hospital during which the subacromial space can be reached without unnecessarily widening the approach. Also, some biomechanical error which might relate to the random position of the scapula might occur [19]. These weaknesses have to be accepted because it is impossible to make measurements used in this study in a completely non-affected shoulder or under local anaesthesia, as was stated also by Nordt et al. [16] after some preliminary attempts in a study design similar to ours. We believe that these sources of error are not decisive and that our results reflect the real pressure conditions in the subacromial space.

Our findings support the "extrinsic" theory [12, 14] of the pathogenesis of impingement syndrome. It should be considered, however, that increased subacromial pressure may also be of secondary origin, i.e. caused by spur formation secondary to the primary degenerative process in the cuff, as suggested by the supporters of the "intrinsic" theory [17, 22].

The steady increase in subacromial pressure observed under the anterolateral part of the acromion during abduction as up to 90° in the impingement syndrome shoulders fits very well with the classical clinical symptom of this disease, i.e. a painful arc.

In conclusion, the subacromial pressure seems to concentrate under the anterior acromion, especially laterally. Pressures are elevated in impingement shoulders and increase with abduction up to 90°.

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