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ORIGINAL ARTICLE

Functional study of glenohumeral ligaments

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Abstract

Background The glenohumeral ligaments are passive stabilising anatomical structures of the shoulder which, in synergy with the other active and passive stabilising structures, enable joint movement and cohesion. The purpose of this study is to analyse the isolated and synergic function of the glenohumeral ligaments by using a tetrapolar detection system with computer analysis.

Methods In a study performed on cadavers after anatomical dissection, detector electrodes were positioned on the individual ligaments and recordings were made of bioelectric impedance and, consequently, the resistance, which is an indicator of the state of tension or relaxation of the ligamentous complex. Predefined positions of the upper limb were adopted—neutral adduction, adduction with external rotation, abduction at 45° with neutral and external rotation, and abduction at 90° with neutral and external rotation.

Results The superior glenohumeral ligament is important in stabilisation of the glenohumeral joint in adduction and external rotation. The middle glenohumeral ligament is an important stabilising structure in the positions of adduction and external rotation and abduction up to 45° in external rotation. The resistance, and therefore tension, of the inferior glenohumeral ligament, which is negligible in positions of neutral adduction and adduction in external rotation, increases in value for angles between 45° and 90°, indicating the important stabilising function of this ligament in those positions.

Conclusion Our experimental study on cadavers, which involved evaluating the resistance of the glenohumeral ligaments by means of tetrapolar detection and computer analysis of the results, contributes to our knowledge of the functional activity of the anterior portion of the joint capsule.

Introduction

The glenohumeral joint is the most mobile joint in the human body, owing to the large size of the humeral head compared with the small size of the glenoid cavity. The capsular, ligamentous, and muscular structures have the task of conferring stability to the joint without negatively affecting the range of movement. Passive stabilisers include the bony structures, the glenoid labrum, negative intra-articular pressure, the capsule, and the glenohumeral ligaments. Active stabilisers include the periarticular muscles and, in particular, the rotator cuff.

Many authors, including Moseley, Hoffmeyer, Jerosch, and Lee, have performed studies to identify the function of the different structures of the glenohumeral joint, thus adding to our knowledge of this complex joint [1–4]. In a biomechanical study, Lugo [5] emphasised the importance of the interaction between the different anatomical structures for correct functioning of the glenohumeral joint. Yang [6] studied the in-vivo three-dimensional kinematics of the normal shoulder joint by means of a markerless bone-registration technique. In our study, which was

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performed on cadavers, we analysed the isolated and synergic function of the glenohumeral ligaments. The purpose of the study was to evaluate the function of the three glenohumeral ligaments in both the static and dynamic humeral phases by analysing the time of major stabilizing activity, expressed by the level of tensioning, in different positions. To this end, we measured the impedance of electrical current by means of a tetrapolar detection system with computer analysis.

Materials and methods

For ten shoulders of whole fresh cadavers, after dissection of the pectoral and deltoid regions and complete reflection of the subscapular muscle to prevent stabilizing activity of the muscle, the anterior capsule was exposed and the superior, middle, and inferior glenohumeral ligaments were arthroscopically identified. Cases in which the normal anatomy was compromised by trauma or malformation were excluded. To harmonise the data collected, our study was conducted on shoulders with type-1 features of the glenohumeral ligaments in accordance with the classification proposed by Morgan et al. [7] (the three ligaments are present and distinct). We excluded other anatomical variants: type 2 (inferior glenohumeral ligament (IGHL) and middle glenohumeral ligament (MGHL) merged at the distal end); type 3 (MGHL has a cord-shape); and type 4 (the three ligaments are unidentifiable and capsular thickening is present).

A ligamentous structure can be likened to a cylinder; by measuring the bioelectric impedance, the resistance and, therefore, the state of tension or relaxation, can be evaluated. The relationship between potential difference (V) and current (I) is subject to Ohm's law:

$$R = \frac{V}{I}$$

where R is the electrical resistance of the segment. The resistance is directly proportional to the length of the segment (l), inversely proportional to its cross section (S) and will have resistivity, ρ, which will be constant for the conductor. This gives:

$$R = \rho \frac{l}{S}$$

Therefore, an increase in length or a decrease in cross section will be accompanied by an increase in resistance. Conversely, the resistance of the cylinder in question will decrease with increasing cross section and decreasing length. This means that when our measurement systems detect high resistance, the ligamentous structure is a state of extension, whereas low resistance is indicative of relaxation.

To obtain the bioelectric impedance measurements, and therefore the resistance of the ligament, we used a modified Cip Plus plethysmograph (Akern, Florence) [8]. For tetrapolar detection, the clip leads were applied to two needle electrodes. The needles were positioned along the fibres of the superior glenohumeral ligament (SGHL), MGHL, and the anterior band of the IGHL at a constant distance of 1.5 cm at the level of the capsular ligament junction and perpendicular to the capsular plane in the middle third of the width of the ligaments. The supply of current was kept constant. The measurements were analysed by use of appropriate software.

Two types of measurement were taken:

1. with two pairs of short-circuited electrodes producing a parallel resistance of 82 Ohms; and
2. with isolation of the two electrodes.

This was done so that the results obtained could be cross-checked with each other.

Resistance values of the superior, middle, and inferior glenohumeral ligaments were evaluated in the following positions:

1. upper limb adducted in the neutral position (0° of rotation);
2. upper limb adducted in maximum external rotation;
3. upper limb abducted at 45° in the neutral position;
4. upper limb abducted at 45° in maximum external rotation;
5. upper limb abducted at 90° in the neutral position; and
6. upper limb abducted at 90° in maximum external rotation.

The neutral position was evaluated with the cadaver's arm lying parallel to the table with the elbow flexed at 90° and with the forearm perpendicular to the dissection table.

In addition, measurements of the resistance of the three ligaments were taken during a dynamic test, beginning from a position of adduction and neutral rotation up to abduction at 90° and external rotation and return to the initial position. The tension of the three ligaments was then considered simultaneously in the different standardised positions, to evaluate the effective activity of each ligament in relation to the others.

Statistical analysis

One-way ANOVA was used to evaluate differences between the superior, medial, and inferior ligaments in the adduction and abduction positions with different degrees of rotation. Post-hoc comparisons were assessed by means of the Bonferroni test.

A P value of 0.05 was considered statistically significant. SPSS (IBM) was used for computation.

Results

The results of the resistance measurements of the three ligaments, and therefore of their state of tension or relaxation, are reported in the figures; the standard positions are indicated on the *x* axis and the measured resistance values are indicated on the *y* axis with variations of ±10 %.

The SGHL was tense in adduction and neutral rotation, with the tension increasing during external rotation while still in adduction. In the subsequent positions studied, changes of the resistance values, and therefore of the ligamentous tension, were minimal, such that the ligament could be regarded as being in constant tension. This means the SGHL is important in stabilising the glenohumeral joint in adduction and external rotation (Fig. 1).

The tension of the MGHL increased when passing from the initial position of adduction with neutral rotation and external rotation to abduction to 45° with external rotation. The tension remained constant during abduction to 90°. Therefore, the MGHL is an important stabilising structure in the positions of adduction and external rotation and abduction up to 45° in external rotation (Fig. 2).

The resistance of the IGHL, and therefore the tension, was negligible in positions of neutral adduction and adduction in external rotation. The resistance increased between 45° and 90°, indicating the important stabilising function of this ligament in those positions (Fig. 3).

The resistance of the three ligaments under dynamic conditions (from neutral adduction to abduction at 90° in external rotation and return to the initial position) closely followed those obtained during the static measurements. It is interesting to note that the values of the resistance measured at each position in the anterograde half are very similar to those obtained in the retrograde half (Fig. 4).

The resistance (which correlated with the extension) obtained for each ligament in the different positions studied once again demonstrated the functional relationships of the three ligaments, which take part in joint stabilisation in different ways (Table 1). Significant differences between glenohumeral ligaments were obtained for all positions ($P < 0.001$). For adduction and abduction at 90° (external and neutral rotation), all comparisons between ligaments were statistically significant ($P < 0.001$). For abduction at 45° with external rotation, no differences between the superior and inferior ligaments were noted; likewise, no differences emerged between the superior and middle ligament on abduction at 45° with neutral rotation.

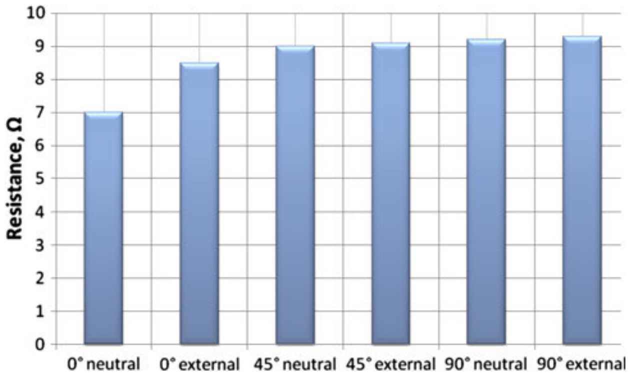

Fig. 1 Superior glenohumeral ligament

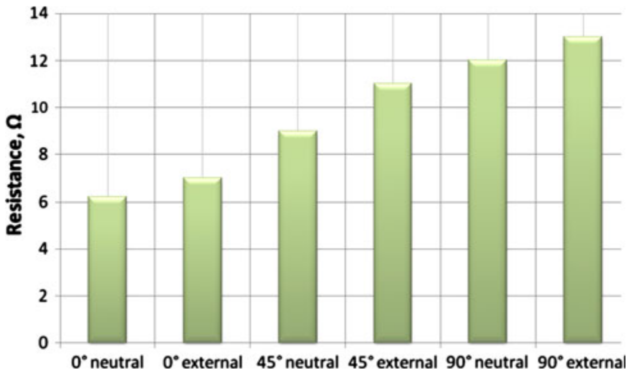

Fig. 2 Middle glenohumeral ligament

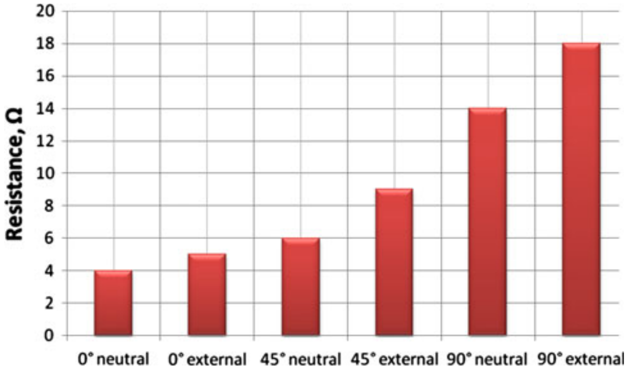

Fig. 3 Inferior glenohumeral ligament

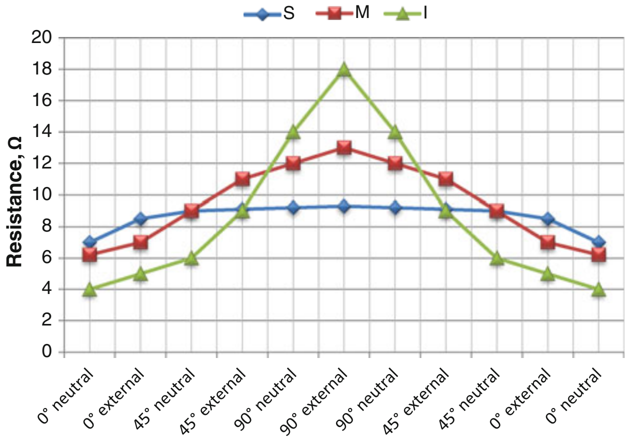

Fig. 4 Dynamic evaluation of the glenohumeral ligaments

Table 1 Resistance (Ω, with standard deviation in parentheses) of glenohumeral ligaments in different positions

Position	Glenohumeral ligament		
	Superior	Middle	Inferior
Adduction with neutral rotation	7.00 (0.213)	6.21 (0.248)	4.00 (0.175)
Adduction with external rotation	8.50 (0.240)	7.00 (0.274)	5.00 (0.224)
Abduction at 45° with neutral rotation	9.00 (0.334)	9.00 (0.399)	6.00 (0.261)
Abduction at 45° with external rotation	9.10 (0.340)	11.00 (0.440)	9.00 (0.402)
Abduction at 90° with neutral rotation	9.20 (0.348)	12.00 (0.475)	14.00 (0.637)
Abduction at 90° with external rotation	9.30 (0.357)	13.00 (0.524)	18.00 (0.814)

Discussion

The different anatomical structures of the shoulder—both passive and active stabilisers—work together to achieve correct joint function and cohesion. Nonetheless, each structure has a specific function. Our experimental study on cadavers, in which the resistance of the glenohumeral ligaments was evaluated by means of tetrapolar detection and computer analysis of the results, contributes to our knowledge of the functional activity of the anterior portion of the joint capsule. As described by O'Connell [9], the SGHL is important in stabilisation of the joint in the position of neutral adduction and external rotation, with resistance of 7.00 Ω (SD 0.213) and 8.50 Ω (SD 0.240), respectively. For the MGHL, by contrast, a functional increase is observed at 45° of abduction, both in the neutral and the external rotation positions, with measured resistance values of 9.00 Ω (SD 0.399) and 11.00 Ω (SD 0.440), in agreement with Ferrari [10]. The IGHL, which has the greatest resistance, is particularly active at 90° of abduction, both in the neutral rotation (14.00 Ω; SD 0.637) and in external rotation (18.00 Ω; SD 0.814), as reported by Turkel and Cain [11, 12].

The results obtained shed light on the functions of the glenohumeral ligaments of the shoulder during the different phases of movement. Such knowledge has implications for assessment of injuries involving the anterior portion of the joint, and may suggest the correct treatment. One limitation of this study is that other factors, for example bone shape, the glenoid labrum, and the muscle–tendon structures, also contribute to joint stability.

The definition of functional anatomy for this joint, as for others, enables us to thoroughly analyse diagnostic techniques and to more accurately establish treatment for congenital disease or trauma.

Conflict of interest None.

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