Position of the rotator cuff footprint in relation to the centre of rotation of the humeral head

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Abstract

Background: The objective of the present study was to determine the size and position of the rotator cuff moment arms constructed from the cuff footprints, incident on the line of force acting through the humeral head.

Methods: Five humeri were dissected, leaving the footprints of the rotator cuff intact. Each of the rotator cuff footprints and the cartilage/calcar interface were digitized and the articular surface was scanned using a high precision surface laser scanner. All of the data were merged into the same coordinate system. The centroid of each cuff footprint, centroid of the articular surface of the humerus (G) and the centroid of the articular surface of the glenoid (P) were calculated. Moment arms were measured as the intersection of a perpendicular line of force from each footprint centroid onto the resultant line of force to the centroid of the Glenoid (P).

Results: The mean moment arms of the supraspinatus, infraspinatus and subscapularis muscles were incident close to the centroid (G), whereas teres minor was lateral to the centroid, consistently.

Conclusions: The teres minor moment arm aligned distal to the centroid of the sphere, consistently. The results may provide an understanding of the function of each muscle as a mobilizer or stabilizer of the glenohumeral joint. Further investigation is necessary.

Keywords

biomechanics, rotator cuff, shoulder

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Introduction

The rotator cuff muscles, acting as force couples, stabilize the glenohumeral joint and enable glenohumeral motion. Several studies have been conducted on this muscle group to determine the biomechanics of the rotator cuff in shoulder motion^{1,2} and to determine the moment arm and relative strength of each muscle. Several authors have assumed that the articular portion of the humeral head is spherical³ and that the centre of the humeral head acts as the centre of rotation. However, it has been shown that only around 80% of the articular surface can be regarded as spherical^{3,4} but with the rotator cuff footprints falling outside this area. Hence, we predict that the radius of such sphere cannot be adequately used to describe the moment arm for these muscles. Further, several studies have reported that there is very little translational motion between the glenoid articular surface and humeral articular

surface.^{5,6} This would imply that the centre of rotation should lay at the articular surface of the humeral head in contact with the centroid of the glenoid articular surface.

The objective of the present study was to measure the moment arm of each of the rotator cuff muscles from three-dimensional (3D) reconstructed models by calculating the distance of each moment arm from the centre of the articular surface of the glenoid.

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Figure 1. Shoulder specimen setup with Microscribe 3D-X digitizer (in red). Bottom left: a close up of the shoulder with the reference cubes attached on the greater tuberosity of the humerus and on the acromion of the scapula.

Materials and methods

Five human cadaveric full arms, preserved in formalin, with an intact shoulder complex and without skeletal deformity, were selected for the present study. All soft tissues were removed from the shoulder complex to expose an intact rotator cuff and joint capsule. Precision Perspex reference cubes were attached to the greater tuberosity of the humerus and to the acromion of the scapula on each specimen (Fig. 1). Each shoulder was mounted, rigidly, in a custom-built jig with the arm fixed in the neutral position. A Microscribe 3D-X digitizer (Immersion Corp., San Jose, CA, USA) was fixed to the custom-built jig and used to digitize three faces of each precision cube. The shoulder joint was then disarticulated and both the humerus and scapula re-mounted on the same custom-built jig, independently. The cube faces were re-digitized and the following points, lines and surfaces were identified and digitized on each humerus and scapula: the circumference of the anatomical neck of the humerus; the rotator cuff footprint for infraspinatus, teres minor, subscapularis and supraspinatus; and the glenoid articular surface and the boundary of the glenoid articular surface.

Each humerus and attached reference cube, sprayed with photographic developer, was mounted rigidly and scanned using a high precision surface laser scanner (Kestrel 3D, Dundee, UK) at a resolution of 500 μm .

Figure 2. Three-dimensional model of a single specimen showing rotator cuff footprints and resultant line of force. (G) the centroid of a best fit sphere in contact with the glenoid surface; (P) the centroid of the glenoid surface; (ISc) the centroid of the Infraspinatus footprint; (TMc) the centroid of the footprint for teres minor; (SSc) the centroid of the supraspinatus footprint; and (SUBc) the centroid of the subscapularis footprint.

The data collected from both digitizing tools were imported into Focus engineering analysis software (Metris Inc, Rochester Hills, MI, USA) and the reference cubes were used to merge the data into the same coordinate system. The data were imported into Rhinoceros NURBS modelling software (McNeal and Assoc., Seattle, WA, USA) and represented graphically. The following parameters, calculated from the model, were used to describe the geometry (Fig. 2): (G) as the centroid of a best fit sphere created from points on the surface of the humerus in contact with the glenoid surface; (P) as the centroid of the glenoid surface; (ISc) as the centroid of the Infraspinatus footprint; (TMc) as the centroid of the footprint for teres minor; (SSc) as the centroid of the supraspinatus footprint; and (SUBc) as the centroid of the subscapularis footprint.

The moment arm for each rotator muscle was calculated as the intersection of a perpendicular line of force from each footprint centroid onto the resultant line of force created through to the centroid of the glenoid (P) and humeral head (G).

Accuracy and precision

Data collection with the Microscribe 3D digitizer was determined to be repeatable to within 0.5° for angular data and 0.4 mm for linear data, representing an experimental design error of less than 1%.⁴

Results

The data were collated for all four rotator cuff muscles in each of the five specimens and descriptive statistics calculated (Table 1). The mean (SD) moment arms of

Table 1. Moment arm: distance (mm) from the intersection of each moment arm on the resultant line of force to the centre of rotation.

<i>n</i> = 5	Supraspinatus (mm)	Subscapularis (mm)	Infraspinatus (mm)	Teres minor (mm)
Mean	24.9	30.1	26.3	38.2
SD	2.7	2.6	2.0	3.3
Minimum	20.8	27.5	24.5	35.6
Maximum	27.8	34.4	29.5	42.7

the supraspinatus [24.9 (2.7) mm], infraspinatus [26.3 (2) mm] and subscapularis [30.1 (2.6) mm] muscles were incident close to the centroid (G), whereas teres minor [38. (3.3) mm] was further posteriorly and distal to the centroid, consistently.

Discussion

The articular surface of the humeral head was found to be spherical, reflecting the previous literature; 88.2% of the humeral head is spherical.³ However, the reconstructed models suggest that the rotator cuff footprints do not lie on this sphere but, instead, at variable distances from the centre of the humeral head, therefore, variable moment arms.

An increased length of teres minor moment arm, compared to the other three muscles was noted. Supraspinatus, infraspinatus and subscapularis act relatively close to the centroid of the humeral head, resulting in a moment arm comparable to the radius of curvature of the humeral head. Teres minor acts at almost twice this distance away from the centre of rotation. Teres minor was previously deemed as the weaker of all the rotator cuff muscles. and, Although the Teres minor muscle power is significantly less compared to the remaining three,⁷ this increase in moment arm will result in a higher torque production than previously expected.

The findings may aid in improved biomechanics of tendon transfers on and around the humeral head and this may extend to rotator cuff repairs.

The technique to acquire the data, using both manual digitization and a surface laser scanner and combining the data sets, was effective in extracting the geometry of the proximal humerus and individual rotator cuff muscle footprints.⁴

The following limitations are acknowledged in the present study: the small number of specimens, as well as the assumption that no humeral translation occur during rotator cuff movement of the shoulder. Some studies denote 1 mm to 5 mm of glenohumeral translation.⁶ During active rotator cuff motion, the rotator

cuff acts as stabilizers reducing any glenohumeral translation. Further investigation is required to confirm this because studies that measure glenohumeral translation start with a fixed scapula.⁸ We theorize that minimal translation in these experiments would be nullified by scapular movement in a live shoulder complex.

Summary

Different methods of estimation of moment arms have been described⁹ but, in our experiment, the actual distance from a perpendicular line of force from each footprint centroid to the centroid of the articular surface of the glenoid was measured.

Teres minor was found to have a moment arm further posterior and distal to the centroid of the articular surface, giving it an increasing mechanical advantage. Teres minor was previously dismissed as being the weaker of the four rotator cuff muscles. Despite the weaker muscle force, teres minor has a larger moment arm that amplifies its role in shoulder external rotation and stabilization.

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Declaration of Conflicting Interests

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Ethical review and patient consent

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