The Effect Of Image Analysis Technique On Modelled Deltoid Action

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Abstract— **The accurate use of Magnetic Resonance Imaging (MRI) based techniques to calculate muscle moment arms has been widely demonstrated. However, initial efforts to apply these techniques to the deltoid muscle have yielded differences between results from MRI based methods and results from tendon excursion methods. Although the relative merits of the two have been demonstrated, the discrepancy is such that it requires further investigation, due to the functional importance of the deltoid in upper limb mobility. This study aims to explain the reasons for the differences and suggests a revised analysis of the images. The principle revision to previous studies is the application of the information obtained about the line of action of the muscle from the Anatomical Cross Sectional Area method.**

Keywords-moment arm; MRI; centroid; deltoid

I. INTRODUCTION

The large and complex shape of the deltoid muscle presents a challenge for the biomechanical modeller. In current models it is normally represented by three strings wrapping directly around the bony skeleton. This has the advantage of simplicity in calculating wrapping paths and moment arms, but is not a truly anatomical representation of the muscle. In this paper, we have explored the possibility of using data from the calculated centroid of the muscle portion to define the line of action. The first consequence of this is that the line of action is displaced from the centre of rotation of the glenoid, with a likely increase in moment arm. The second consequence is that the line of action is no longer straight, and its shape is dependent upon the position of the shoulder. Practically, it is possible only to determine the centroids with the limb in a single fixed position. Therefore, if the moment arm is to be predicted for a range of shoulder positions, it is necessary to propose some approach to muscle wrapping.

In current models, most of the physical parameters have been derived from cadavers [1, 2, 3, 4, 5, 6]. However such data are probably not representative of the general population, since the source cadavers are unlikely to form a cross-sectional sample of the human population. Most are elderly and likely to have muscle wasting, and the embalming process removes all tissue fluid so that sizes of muscles, for example, may be further reduced. With the advancement of imaging techniques, it is possible to extract modelling parameters from a sample of the normal population.

In this study, magnetic resonance imaging (MRI) has been used to create three-dimensional images of the shoulder. These images have subsequently been analysed to compute the lines of action of the three regions of the deltoid, and so to calculate the moment arms at the glenohumeral joint.

II. METHOD

MR images at 3mm slice intervals of the shoulder and upper arm were studied for the left and right shoulders of 6 normal healthy subjects [11]. For each slice, coordinate data for the centre of the humerus and up to 140 points along the deltoid cross section outline (Fig. 1) were produced using Matlab (image processing toolbox). For each shoulder, a dataset was produced by combining the coordinate data from all slices along the image set.

Figure 1. Digitisation of an MRI of a deltoid cross section.

Due to the difficulty of distinguishing between the three bellies from the grayscale images, the data corresponding to the section of the total muscle was subdivided in to three segments, centred on the centre line of the humerus, using custom written software in MathCAD (Fig. 2).

Further image analysis provided input coordinates for a Gauss-Newton algorithm to find an estimate of centre and radius of a best fit sphere around the humeral head. The centre of this sphere was taken as the centre of rotation of the humerus.

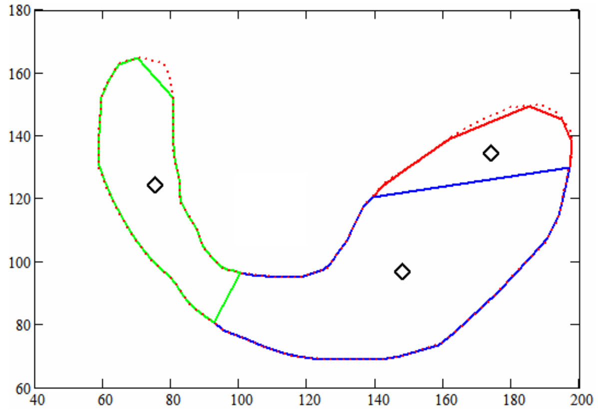

Figure 2. MathCAD output of the deltoid cross section in Fig. 1. The area is divided into the three defined sections according to a defined ratio. The diamonds represent the centroid of each section.

For this study it was assumed that the line of action lies within the path of the muscle fibres, according to the load produced across the section. The simplest interpretation of this is to assume a constant tensile stress, so that the line of action follows a centroid of the muscle cross section, constrained to lie within the muscle.

By representing the centroid path of the muscle cross section as a polynomial fit curve, the following relation between any point on the curve and the centre of rotation holds:

r = **r**(s) can represent the polynomial fit curve calculated by from the path of each centroid in three-dimensional space, where s represents the arc length measured along the curve from a fixed point A to the point P(r) (Fig. 3). If P’ is a point on the curve near P(r), with parameter $s + \Delta s$, then the vector

$$\mathbf{t} = \lim_{\Delta s \to 0} \frac{PP'}{\Delta s}$$

is the unit tangent vector at P in the direction of s increasing. Since **t** is a unit vector,

$$\frac{d}{ds}(\mathbf{t}.\mathbf{t}) = \mathbf{0} = 2\mathbf{t}.\frac{d\mathbf{t}}{ds}$$

which shows that *d***t**/*ds* is perpendicular to **t**.

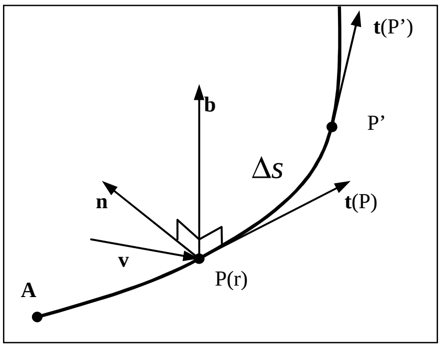

Figure 3. Vector representation of a polynomial fit of a centroid curve.

The moment imparted at any increment *ds* around the centre of rotation of the line is the vector product of the position vector **v,** relative to the centre of rotation on the instantaneous line of action (in this case the tangent vector **t**).

In practice, by splitting the centroid path into suitable increments, this representation can be simplified (Fig 4.). The moment arm of any increment could be interpreted as the perpendicular distance between the centre of rotation and the line between incremental adjacent points along the centroid path.

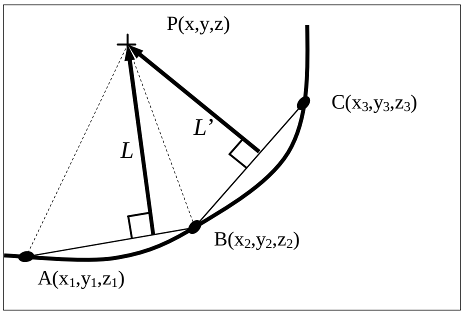

Figure 4. Calculation of moment arm.

The length of the perpendicular between the centre of rotation and incremental lines AB and BC can be calculated as:

$$L = \frac{|AB \times AP|}{|AB|} \qquad L' = \frac{|BC \times BP|}{|BC|}$$

with the arithmetic mean of length L taken as the moment arm magnitude.

The image scope was such that the epicondylar points required to produce an ISB standardised humerus reference frame [13] were not available However the coordinates of the remaining relevant bony landmarks were obtained to produce reference angles, about which the image based coordinate axis could be rotated. (Fig. 5.)

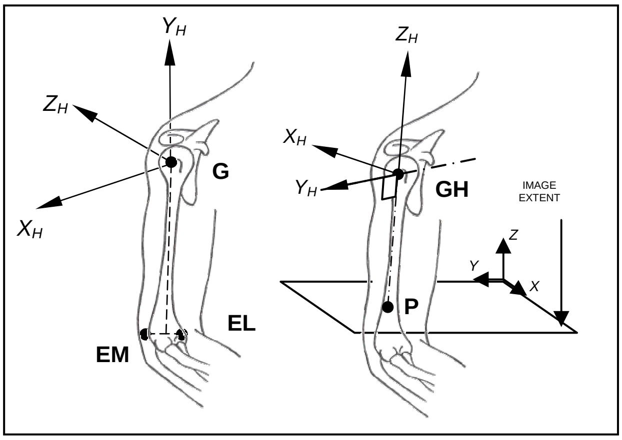

Figure 5. LH image – ISB humerus coordinate system. EM and EL were outside the image envelope, so the adapted humerus coordinate system (RH image) was developed.

The resultant moment arm calculations were compared to results obtained by tendon excursion techniques where a corresponding anatomical position has been used. The results were also compared to other published data from previous image based and computer model simulation deltoid moment arm calculations.

III. RESULTS

MR images were collected from 18 shoulders of 9 healthy subjects (5M/4F, average age = 31.8 years). The average height and mass were 1.82m, 84.2kg (male) and 1.69m, 74.0kg (female). Subsequent study of the images showed that only 12 image sets were suitable for analysis (8M/4F). The average muscle volume was 0.4 m^3 (M), 0.19 m^3 (F) and the average Physiological Cross Section Area (PCSA) was 29.0cm^2 (M), 19.1 cm^2 (F).

TABLE I. RESULTS COMPARISON

Moment Arm Results			
	Deltoid Portion		
	Anterior	Middle	Posterior
Karlsson [7]	21.0	36.0	43.0
Holzbaur et al [8]	51.0	59.0	58.0
J Liu [9]	2.0	12.0	30.0
Lewis-Morris, Johnson [10]	70.0	75.0	71.0
Johnson [11]	19.0	54.0	27.0
Poppen and Walker [12]	26.4	39.2	34.4
Curved Line of action (present study)	41.5	50.1	61.3

Table 1. Comparison of moment arm calculations based on centroid method (present study and Lewis-Morris Johnson), computer simulation model (Holzbaur et al), PCSA method (Johnson), 3D biomechanical model (Karlsson) and tendon excursion methods (Poppen and Walker, Liu).

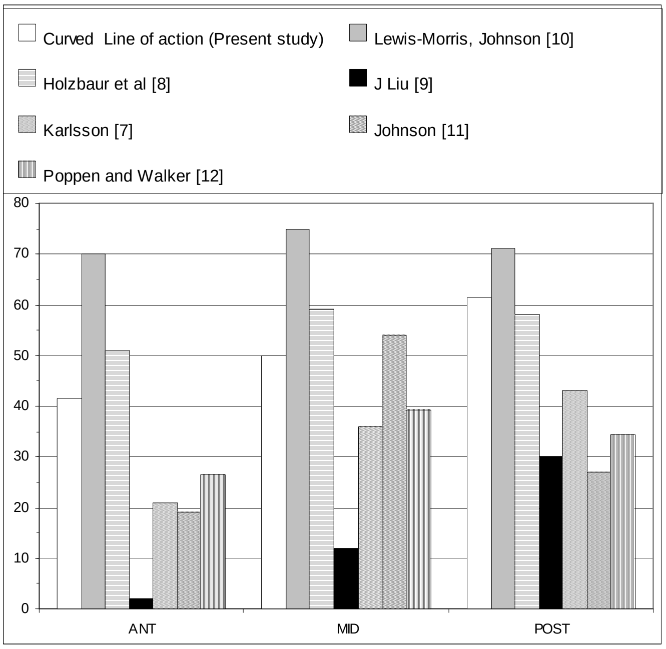

Figure 6. Comparison of moment arm calculations based on centroid method (present study and Lewis-Morris Johnson), computer simulation model (Holzbaur et al), PCSA method (Johnson), 3D biomechanical model (Karlsson) and tendon excursion methods (Poppen and Walker, Liu).

IV. DISCUSSION

This study assumed that moment arm calculations based on tendon excursion methods are inherently more accurate. Tendon excursion moment arm results are acquired irrespective of the necessary complexities and compromises required when modelling the deltoid. It was therefore considered that underlying assumptions about the line of action of the muscle would in some way be validated if the results reflected those results obtained from tendon excursion methods.

This study aimed to address the effect of approximating the muscle line of action on calculated moment arm. This was to be achieved by calculating the moment arm using a method which did not involve simplifying the action of the muscle to a single line. An assumption was made that the modelled action would lie within the muscle according to the load produced across the section, following the centroid of the muscle cross section.

The study by Lewis-Morris and Johnson [11] used the technique of centroid calculation to determine moment arm magnitudes for the same images. This study used the same method to calculate the centroid path of the muscle; however the studies differed in how this information related to the line of action of the muscle. Lewis-Morris and Johnson [11] assumed a muscle line of action coincident with the first 7 points along the muscle centroid from the point of insertion on the humerus. The results obtained by the Lewis-Morris and Johnson study [11] were consistent with those obtained from tendon excursion experiments, in terms of the relative ratios of anterior, middle and posterior relative ratios. However, the magnitude of each of the three moment arms was up to a factor of 2 greater than those obtained from tendon excursion studies [9,12]. In this study, the differences between the Lewis-Morris and Johnson study and experimental moment arm calculations are assumed to be attributable to the interpretation of the line of action of the muscle, most notably the assumption that the line of action of the muscle linearly approximates to the first 7 points along the muscle centroid.

With respect to addressing the effect of this idealisation on the calculated moment arm, the method used by this study is inadequate. The results from this study vary from the study by Lewis-Morris and Johnson [11], as the moment arm magnitudes are closer to those obtained by tendon excursion methods [9,12], (Fig. 6). However, wide variations remain between the results of this study and those obtained by tendon excursion methods [9,12] in both the magnitude of the moment arms and the relative magnitudes between anterior, middle and posterior muscle sections.

Moment arm calculations from this study are comparable to those obtained by the Holzbaur study [8] both in the magnitude of the moment arms calculated and the relative magnitudes of the posterior, middle and anterior deltoid moment arms.

The similarity between this study and the Holzbaur study, and the differences in the moment arm of these to experimental moment arm magnitudes, suggest that representing the muscle line of action along a single line does not sufficiently model muscle structure.

Subsequent studies that better reflect the results obtained by tendon excursion methods could be deemed more accurate, but accuracy in this context is relative. Any model that produces results that reflect those obtained by tendon excursion methods will never be truly representative of the deltoid complex as there is no sure way of determining the actual moment arm in the deltoid complex.

This study has aimed to address the differences that can arise between model results and experimental results when a simplified interpretation of a muscle line of action is used. The technique used in this study has gone some way to produce a model that better represents what is observed experimentally but accurate muscle parameters are required to model the deltoid more effectively and calculate the moment arm from MR images.

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