Journal of Anatomy

J. Anat. (2008) **212**, pp863–867 doi: 10.1111/j.1469-7580.2008.00903.x

BRIEF COMMUNICATION

Definition of the capsular insertion plane on the proximal humerus

Hippolite O. Amadi,[1,2] Sanjay M. Sanghavi,[2,3] Srinath Kamineni,[4,5] Roman Skourat,[4] Ulrich N. Hansen[2] and Anthony M. J. Bull[1]

Departments of [1]Bioengineering, [2]Mechanical Engineering, and [3]Musculoskeletal Surgery Imperial College London, UK
[4]Department of Bioengineering, Brunel University, London, UK
[5]Wellington Hospital, London, UK

Summary

The aim of this work was quantitatively to establish the relationship between the plane that hosts the humeral head lateral margin (anatomical neck) and that of the capsular insertion. Eight cadaveric shoulders were used. These were dissected, exposing the humeral head margin and the root of the capsular humeral insertion to extract digitally their outlines using a mechanical 3-d digitizer. The datasets of the digitized outlines were applied and the geometric planes they best fitted mathematically calculated. Vector analysis techniques were finally applied to the two planes to quantify the relationship between them. The humeral head margin is circular (± 2.2% of radius), having each of its outlining points on the same plane (within ± 1.5 mm.) The capsular attachment outlining points also insert on a plane (± 1.4 mm). The two planes are related to one another by an inclination of 14.5 ± 3.6°. The relationship described here would allow for *in vivo* prediction of humeral attachment of capsular structures by using radiological datasets of the anatomical neck. This would be useful in patient-specific modelling to study and understand the glenohumeral ligament kinematics during clinical examinations and to plan surgical reconstructive procedures.

Key words anatomical neck; bicipital groove; humeral head; fovea capitis.

Introduction

Glenohumeral joint (GHJ) instability is a common shoulder pathology amongst the sporting population (Bigliani et al. 1994). This has been linked to pathologies of the GHJ ligaments and treatments include surgical reconstruction, re-attachment and tightening (Gerber & Ganz, 1984; Gagey & Gagey, 2001). GHJ ligaments are described as thickenings of the GHJ capsule structure that strengthen the articulation of the humerus to the glenoid (Williams et al. 1989; Martini et al. 2001). The GHJ ligaments are known to provide rotational restraint to axial rotation of the humerus (Kuhn et al. 2005) and translational restraint to anterior-posterior drawer (Debski et al. 1999). Novotny et al. (2000) noted that successful repairs are often achieved without full restoration of the humeral range of motion. This could be due in part to the fact that the functional kinematics and characteristics of these ligaments are not yet fully understood, even though their mechanical effects have been recently elucidated (Bigliani et al. 1992; Boardman et al. 1996; Debski et al. 1999; Kuhn et al. 2005). This is primarily as a result of the present lack of any technique for the quantification of humeral ligament attachment *in vivo*.

A fundamental variable in the calculation of ligament loading during GHJ kinematics is the location of the humeral insertion points. Obtaining these data *in vivo* is not possible as even magnetic resonance scanning has insufficient resolution to identify these structures. Anatomical work has shown that the capsular ligaments originate from the glenoid rim of the scapula and insert at the humeral anatomical and surgical necks (Steinbeck et al. 1998; Bey et al. 2005). The attachment of the capsule on the superior humerus is just medial to the tubercles and lateral to the humeral head and the anatomical neck of the humerus. The capsular attachments on the more distal aspects of the upper humerus, however, are more lateral and inferior, at the level of the humeral surgical neck (Fig. 1). The humeral capsular attachment follows through the superior aspect of the humeral head to the inferior aspect at the surgical neck. The hypothesis of this study is that:

Correspondence
Dr Anthony M.J. Bull, Department of Bioengineering, Imperial College London South Kensington Campus, London SW7 2AZ, UK.
T: +44 20 75945186; E: a.bull@imperial.ac.uk

Accepted for publication *13 March 2008*

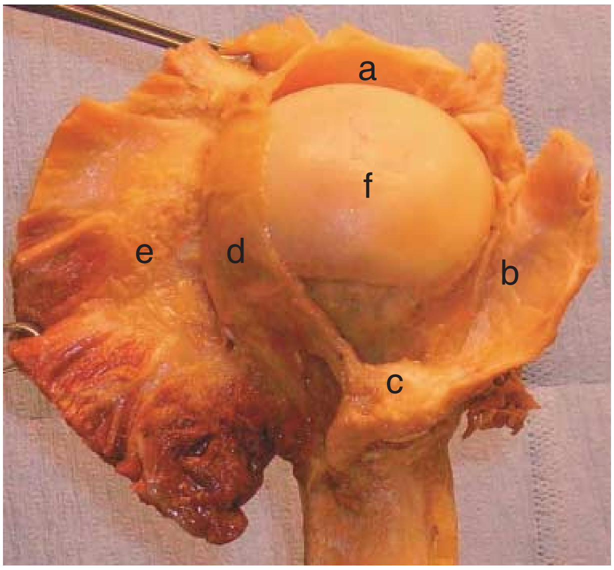

Fig. 1 Insertion on the proximal humerus of the inferior aspect of the glenohumeral capsule (with laterally reflected muscle tendons). a, b, c, d: superior, anterior, inferior and posterior aspects of the capsule. f: cartilage surface. e: rotator cuff tendons, reflected.

(1) the humeral capsular insertion occurs consistently on a mathematically definable plane: the 'humeral capsular insertion plane',
(2) the anatomical neck occurs consistently on a mathematically definable plane: the 'anatomical neck plane' and that
(3) a consistent relationship exists between the two planes
The prediction of the humeral capsular insertion plane from radiological data of any given humerus would allow for the calculation of the insertion points of the glenohumeral ligaments.

It is currently not possible quantitatively to identify the capsule and its humeral insertion on conventional diagnostic medical images because of poor contrast between soft tissues and insufficient resolution of scans. This makes it difficult for the study of GHJ ligament loading *in vivo*. However, bony landmarks such as the anatomical neck are easily identifiable in normal radiology (X-ray tomography or magnetic resonance imaging). By anatomical description, the plane defining the anatomical neck is parallel to the plane defining the lateral margin of the humeral head (cartilage margin). The quantification of a possible relationship between this radiologically identifiable landmark and capsular insertion could be useful for the prediction of their locations from medical images.

The aims of this study were:
(1) to test the hypotheses that the humeral head lateral margin and the humeral capsular insertion both lie on planes that are related to one another by a simple rotation, and
(2) to quantify this relationship.

Materials and methods

Eight embalmed and frozen cadaveric shoulders (all male, average age 79 years, range 66–90) without obvious arthritic changes were dissected and studied. Each specimen was carefully stripped of its muscle without damage to the capsule. The humerus was detached from the joint by excising the capsule from its labral attachment. The capsule was incised longitudinally from the glenoid end to its humeral attachment and reflected laterally to expose the humeral head and the root of the capsule insertion. The humeral head lateral margin, which is the border of the cartilage-covered area of the humeral head, was defined with its anterior, posterior and inferior extents, following the anatomical neck. Typically, the capsule attaches on the humerus in a circular formation between 4 o'clock and 8 o'clock positions through the superior aspects. It links the two positions inferiorly at the surgical neck through a v-shaped formation (O'Brien et al. 1990; Pouliart & Gagey, 2005; Sugalski et al. 2005).

The outlines of eight humeral landmarks were extracted directly from the humerus using a Faro Arm Digitizer (Direct Dimension Inc, Owings Mills, MD) that allows the three-dimensional location of any coordinate to within 0.0125 mm. The landmarks that were digitized were:
(1) over 2000 points over the entire humeral head surface,
(2) over 300 points along the outline of the lateral margin of the humeral head,
(3) the proximal end point of the bicipital groove (fovea capitis),
(4) over 350 points along the outline of the root of capsular attachment and
(5) the three vertices of the inferior v-shaped formation of the capsule insertion.

Software was written to quantify:
(1) the least square (LS) plane fits on the digitized datasets of the humeral head lateral margin (anatomical neck) and the capsule insertion outlines (Fig. 2), and the normal unit vectors to them, respectively;
(2) the radii and centres of LS sphere and circle fits on the humeral head surface and its lateral margin, respectively;

Plane, sphere and circle fitting error analyses were performed on the individual geometric fits to test the hypotheses that these were well-approximated on planes, spheres or circles. The separation angle between planes (a) and (b) of Fig. 2 was quantified by applying the following steps:
(I) The normal unit vectors to planes (a) and (b), defined as $[\mathbf{u}_n]$ and $[\mathbf{u}_c]$, respectively – Fig. 3, were calculated.
(II) The unit vector $[u_p]$ on the anatomical neck plane (a) was quantified. This is orthogonal to the plane-normal $[u_n]$. $[u_p]$ is quantified as a cross-product vector between $[u_n]$ and its mutual orthogonal with the fovea capitis vector $[u_g]$. The angle between the two planes was therefore calculated as the angle between vectors $[u_n]$ and $[u_c]$ (Fig. 3).
(III) The quantified axes ($[u_n]$ and $[u_p]$) from the eight specimens were applied to a common coordinate system and their corresponding $[u_c]$ vectors converted according to this system. These were averaged over the specimens (n = 8) thus:

$$[\mathbf{u}_{ca}] = \frac{1}{n}\sum_{1}^{n}[\mathbf{u}_c].$$

The mean and standard deviation of the plane separation angles (θ_m) were also calculated:

$$\theta_m = \frac{1}{n}\sum_{i=1}^{n}\theta_i.$$

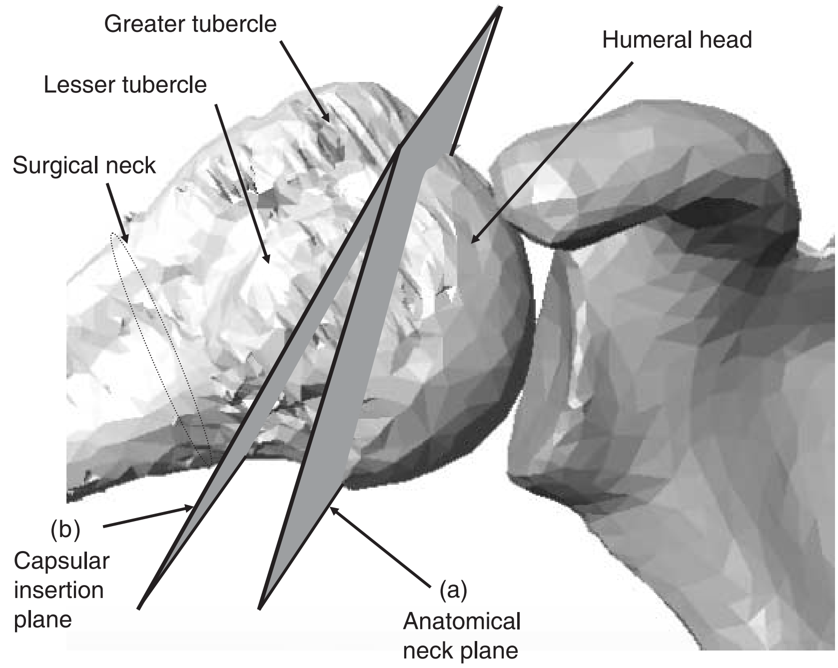

Fig. 2 Relationship between cartilage and capsular planes on the proximal humerus. (a) The hypothesized plane of the proximal humerus upon which the glenohumeral capsule inserts. (b) The hypothesized plane upon which the anatomical neck sits.

Results

The sphere fit of the cartilage-covered humeral head surface produced an average radius of 26.2 mm (SD 1.2, range 24.7–28.4 mm); the radius of the circle fit on the cartilage-covered humeral head lateral margin was 24.5 mm (1.2 mm, 23.0–26.8 mm). The humeral head is a sphere segment to within 1.2% (0.3) of its radius (Table 1). The anatomical neck is a circle to within 2.2% (0.7) of its radius. This lies on a plane with an error of 1.5 mm (0.4). The capsule inserts on a humeral plane to within an error of 1.4 mm (0.3). Table 2 shows the three quantified unit vectors of all the specimens with respect to a common coordinate system. The unit vectors [u_n] (normal) and [u_p] (parallel) to the plane of the anatomical neck coincided and the unit vectors [u_c] normal to the capsular insertion planes produced the differences. The average separation angle between the planes was 14.5° (3.6°). If a Cartesian coordinate system is defined on the humeral head such that its x-axis coincides with a normal to the anatomical neck plane and y axis coincides with a mutual orthogonal approximately pointing towards the fovea capitis, then the normal to a plane fit on the capsular insertion margin points in the direction [0.966, –0.217, –0.022].

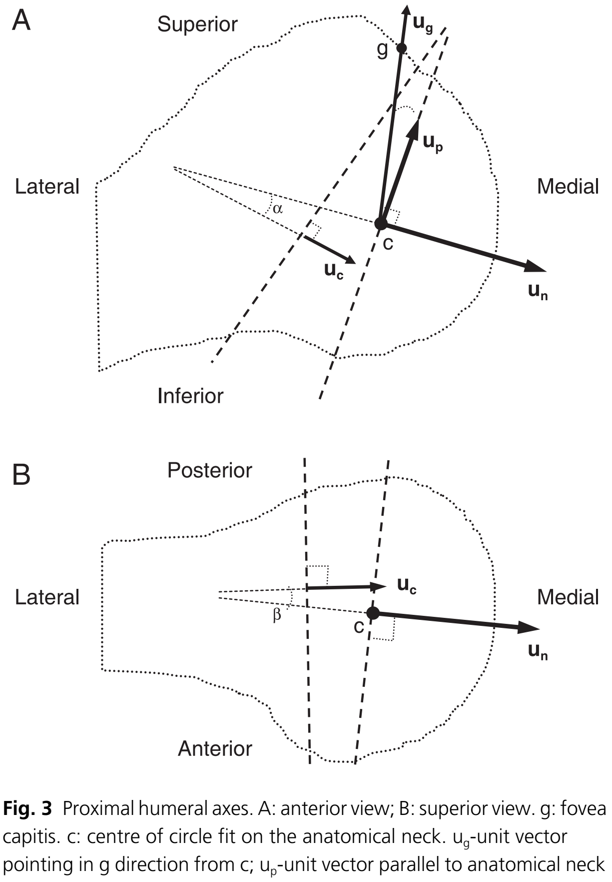

Fig. 3 Proximal humeral axes. A: anterior view; B: superior view. g: fovea capitis. c: centre of circle fit on the anatomical neck. u_g-unit vector pointing in g direction from c; u_p-unit vector parallel to anatomical neck plane; u_n-unit vector normal to anatomical neck plane; u_c-unit vector normal to capsular insertion plane; α-plane separation angle from the coronal view; β-plane separation angle from the axial view.

Discussion

This study aimed to identify, define and relate to each other the anatomical neck and capsular insertion planes on the humerus. The hypothesis that these lie on planes was upheld; errors to the plane of 1.5 mm were measured. We also found that a consistent inclinational relationship

Table 1 The error between a point on the humeral landmark region of interest and the geometric shape fitted to that region

Specimens	Anatomical neck plane fit (mm)	Capsule insertion plane fit (mm)	HH surface sphere fit (% radius)	Anatomical neck circle fit (% radius)
1	1.5	1.5	0.8	1.1
2	2.0	1.2	0.8	1.6
3	1.8	2.1	1.4	2.2
4	1.8	1.6	1.3	3.2
5	1.4	1.3	1.2	2.4
6	1.8	1.3	1.0	3.1
7	1.1	1.5	1.4	1.9
8	0.9	1.0	1.9	2.4
Average	1.5 ± 0.4	1.4 ± 0.3	1.2 ± 0.3	2.2 ± 0.7

Table 2 Vectorial and angular relationships between the two planes based on a common reference frame

Specimens	Capsular insertion plane normal ($\mathbf{u}_c$)			Separation angle (θ°)
1	[0.9542	−0.2892	0.0761]	17.4
2	[0.9833	−0.1773	−0.0409]	10.5
3	[0.9337	−0.2815	−0.2213]	21.0
4	[0.9814	−0.1846	−0.0527]	11.1
5	[0.9852	−0.1477	0.0869]	9.9
6	[0.9673	−0.2305	−0.1063]	14.7
7	[0.9601	−0.2539	−0.1174]	16.2
8	[0.9635	−0.1742	0.2034]	15.5
Average	[0.9661	−0.2174	−0.0215]	14.5 ± 3.6

exists between the two quantified planes. This trigonometric relationship could therefore serve as a transfer function for the prediction of one plane when the other is known.

Previous anatomical studies have suggested that there is a consistent attachment pattern of the origin and insertion of the glenohumeral capsule (Bigliani et al. 1992; Steinbeck et al. 1998; Urayama et al. 2001; Lehtinen et al. 2004; Bey et al. 2005; Sugalski et al. 2005). Bigliani et al. (1992) found that there was a consistent pattern of insertion of the glenohumeral ligaments when mapped onto a 360° coordinate system of a circle based on the lateral margin of the humeral head. The humeral insertion of the inferior aspect of the capsule has been observed to occur in either a collar-like or v-shaped formation (O'Brien et al. 1990; Ticker et al. 1996). In a study of open dissection of 150 cadaveric specimens and arthroscopy of 200 more (*in vitro* and *in vivo*), Pouliart & Gagey (2005) assessed the insertional morphology of the glenohumeral ligaments. They found that the insertion of the inferior capsule fibres was always in the form of a 'v'. This is in contradiction to earlier studies that reported a less than 100% v-shaped insertion (O'Brien et al. 1990; Ticker et al. 1996). Pouliart & Gagey (2005) argued that specimen dissection rather than mere inspection always revealed a v-shape when examining from the outside but connecting synovial bands made this look rounded off when examining from the inside. The earlier authors therefore described synovial lining attachment rather than that of the fibrous capsule. Dissection of specimen as suggested by Pouliart and Gagey was followed in the present study to reveal the capsule insertion for digitization. The v-shaped insertion formation following dissection was also observed in all specimens we dissected. Other studies have quantified various landmarks on the proximal humerus that include the description of the humeral head as a sphere to within 1% of its radius (Soslowsky et al. 1992a; Pearl & Volk, 1995; Boileau & Walch, 1997; Robertson et al. 2000; Sugalski et al. 2005). Although these studies provided data intended to aid prosthetic designs, these could also be applied for the modelling of the glenohumeral joint function. The quantification of the humeral head sphere fit in the present study agrees with the findings of others authors (Soslowsky et al. 1992a; Robertson et al. 2000). This study has, in addition, demonstrated that the anatomical neck and the capsule insertion lie on planes that are related. This information would allow for the application of the parametric quantifications of these earlier studies in patient-specific models of the glenohumeral ligament insertion *in vivo*. Poor imaging contrast and resolution do not allow at present for direct quantification of this insertion.

The results suggest that the anatomical neck plane typically lies at an angle of 14.5° to the capsular insertion plane. By standard anatomical definitions, it is known that the capsular insertion is always lateral to the anatomical neck. In addition to this, we found that a normal to the plane that fits the capsular insertion is always pointing inferiorly relative to that of the humeral head plane.

In conclusion, the planar relationship described here can be applied to predict the humeral insertion of the capsule *in vivo* when the anatomical neck plane is quantified from a medical image dataset. This will allow an estimate of the average topographical positions of the glenohumeral ligament attachments on the humerus. This indirect approach to ligament attachment quantification is novel and will serve as input to ligament modelling for better understanding of their functional kinematics. This will lead to a better understanding of how the ligaments respond during clinical examinations. This planar relationship can also serve as a humeral resurfacing guide during shoulder arthroplasty.

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