The anterior band of the inferior glenohumeral ligament

ASSESSMENT OF ITS PERMANENT DEFORMATION AND THE ANATOMY OF ITS GLENOID ATTACHMENT

P. J. McMahon, J. Dettling, M. D. Sandusky, J. E. Tibone, T. Q. Lee

From the Veterans Affairs Medical Centre, Long Beach, and the University of California, Irvine, USA

Surgical treatment for traumatic, anterior glenohumeral instability requires repair of the anterior band of the inferior glenohumeral ligament, usually at the site of glenoid insertion, often combined with capsuloligamentous plication. In this study, we determined the mechanical properties of this ligament and the precise anatomy of its insertion into the glenoid in fresh-frozen glenohumeral joints of cadavers. Strength was measured by tensile testing of the glenoid-soft-tissue-humerus (G-ST-H) complex. Two other specimens of the complex were frozen in the position of apprehension, serially sectioned perpendicular to the plane containing the anterior and posterior rims of the glenoid, and stained with Toluidine Blue.

On tensile testing, eight G-ST-H complexes failed at the site of the glenoid insertion, representing a Bankart lesion, two at the insertion into the humerus, and two at the midsubstance. For those which failed at the glenoid attachment the mean yield load was 491.0 N and the mean ultimate load, 585.0 N. At the glenoid region, stress at yield was 7.8 ± 1.3 MPa and stress at failure, 9.2 ± 1.5 MPa. The permanent deformation, defined as the difference between yield and ultimate deformation, was only 2.3 ± 0.8 mm. The strain at yield was $13.0 \pm 0.7\%$ and at failure, $15.4 \pm 1.2\%$; therefore permanent strain was only $2.4 \pm 1.1\%$.

Histological examination showed that there were two attachments of the anterior band of the inferior glenohumeral ligament at the site of the glenoid

insertion. In one, poorly organised collagen fibres inserted into the labrum. In the other, dense collagen fibres were attached to the front of the neck of the glenoid.

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A lesion of the anterior and inferior glenohumeral capsule seen after dislocation of the shoulder^{1,2} is termed a Bankart lesion.³ It is known to involve the site of attachment of the anterior band of the inferior glenohumeral ligament (IGHL) to the glenoid. Anatomical studies of patients with anterior glenohumeral instability have identified injury of the ligament at its site of attachment, particularly to the glenoid bone.⁴⁻¹⁰ Matsen, Thomas and Rockwood¹¹ reported that nearly all of their patients with traumatic, unidirectional anterior glenohumeral instability had a Bankart lesion. To determine the cause of the instability, Turkel et al¹² sequentially sectioned the subscapularis muscle and the glenohumeral ligaments, and applied an anteriorly directed force to study the effects on joint translation. The IGHL prevented anterior dislocation of the joint at 90° of abduction. Others have reported that the anterior band of the IGHL is the major static restraint with the shoulder in this position.¹³⁻¹⁵ Its anterior band, located in the inferior, redundant part of the capsule, is a broad structure, and is invariably present. It consists of closely packed collagen bundles¹⁶ which tighten with abduction and external rotation of the glenohumeral joint.

Traditional open methods of Bankart's reconstruction involve incision of the capsule and repair of the capsuloligamentous structures to the glenoid bone. The results of this procedure reveal a low rate of redislocation, generally less than 4%, and preservation of shoulder movement.^{4,17} Most patients are able to return to functional activity. Arthroscopic repair of the Bankart lesion^{18,19} involves repair of the labrum to the glenoid bone, since this is the lesion most visible from within the joint. Unfortunately, this procedure has had much less satisfactory results, with rates of redislocation of at least 8%.¹⁸⁻²⁴ Part of the reason for the discrepancy in the results between the open and arthroscopic methods may be technical, relating to the adequacy of repair. Another explanation may be that a

P. J. McMahon, MD, Assistant Professor
J. Dettling, MD, Orthopaedic Resident
M. D. Sandusky, BS, Biomedical Engineer
T. Q. Lee, PhD, Biomedical Engineer, Associate Clinical Professor
Orthopaedic Biomechanics Laboratory, Long Beach Veterans Affairs Medical Centre and University of California, Irvine, 5901 East 7th Street, Long Beach, California 90822, USA.

J. E. Tibone, Clinical Professor
Kerlan-Jobe Orthopaedic Clinic and University of Southern California, USA.

Correspondence should be sent to Professor T. Q. Lee.

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Fig. 1

Diagram showing the apparatus for tensile testing of the anterior band of the IGHL ligament using the G-ST-H complex.

detachment of the anterior band directly from the glenoid cannot be seen arthroscopically. Recently, 'permanent stretching' of the anterior band of the IGHL, in addition to the Bankart lesion, has been thought to be a meaningful component of the injury.²⁵⁻²⁷ Precise repair of the Bankart lesion and restoration of the normal, preinjury length of the ligament are important in successful surgical treatment.

Unlike any other joint, the attachment of the glenohumeral capsuloligamentous structures includes a fibrocartilaginous labrum which surrounds the periphery of the glenoid. Anatomical studies of the labrum²⁸ and the IGHL provide information on their function.^{13,16,27} The anatomy of the region of their insertion at the glenoid remains ill understood, although repair of the Bankart lesion is a common procedure in the treatment of instability of the joint.^{4,10,17}

Our aim was to determine the permanent deformation of the IGHL and to study the histology of its normal attachment to the bone at the glenoid with the shoulder in abduction and full external rotation (the apprehension position).

Materials and Methods

For the biomechanical experiments we used 12 fresh-frozen glenohumeral joints (7 right, 5 left) from male cadavers with a mean age of 60 years (38 to 79). Gross examination

showed no disease of the rotator cuff, osteoarthritis, or capsular damage. The glenoid-soft-tissue-humerus (G-ST-H) complex was prepared, with careful dissection of all periarticular tissue. The joint capsule was incised, first along the collagen fibres at the anterosuperior margin of the anterior band and then from medial to lateral starting at six o'clock on the glenoid to yield the G-ST-H complex. When viewed from the inside, articular surface, the anterior band was seen to be attached to the labrum. When viewed from the outside the labrum was not visible and the anterior band appeared to be attached to the neck of the glenoid.

In preparation for mounting on the testing apparatus, the G-ST-H complex was positioned and fixed using bolts through aluminium fixtures and further secured with plaster of Paris. During dissection, measurement and mechanical testing, the specimens were moistened with normal saline.

The mechanical tests were carried out using an Instron machine (Instron Corporation, Canton, Massachusetts), a custom shoulder jig, and a video digitising system for measurement of the strain along the length of the ligament (Fig. 1). This custom jig allowed the positioning of the G-ST-H complex with the humerus abducted to 60° and fully externally rotated. This position was chosen because anterior instability is common at 90° of shoulder abduction which corresponds to 60° of glenohumeral and 30° of scapulothoracic abduction.^{29,30} The mount for the humerus allowed three degrees of freedom in rotation and two in

translation. Additional degrees of freedom, three for rotation and one for translation, were provided by the scapular mount. Verhoeff elastin stain markers were placed in five pairs on the anterior surface of the anterior band of the IGHL so that surface strain could be determined using a video digitising system (Fig. 1).³¹

With a load of 1 N applied, the length of the anterior band of the IGHL was measured, midway between the superior and the inferior margins of the anterior band using a digital micrometer. The sites of attachment were defined as the labrum-to-bone junction on the glenoid side and the ligament-to-bone junction on the humeral side. The digital micrometer was also used to measure the width and thickness of soft tissue at three different sites: near the glenoid attachment, near the attachment to the humerus and midway between. A rectangular shape was assumed for the calculation of the cross-sectional area of soft tissue.

To determine the biomechanical properties of the G-ST-H complex, each specimen was conditioned for ten cycles (1 to 2 mm) at an elongation rate of 50 mm/min before the load-to-failure test at the same speed. Structural properties, the ultimate load, yield load, ultimate deformation, yield deformation, and the linear stiffness were determined from the load-deformation curves obtained using a Macintosh based Labview data acquisition system. The permanent deformation of the G-ST-H complex was defined as that which occurs between the yield and ultimate deformation. The material characteristics of the anterior band of the IGHL were calculated as stress at failure, stress at yield, strain at failure, and strain at yield.

To determine the strain at yield and strain at failure for each region of the G-ST-H complex, the video digitising system was used to measure the strain at the humeral attachment, the midsubstance of the anterior band and two distinct parts of the glenoid attachment, including the junction of the anterior band and the labrum, and the attachment of the labrum to the bone (Fig. 1). The resolution and accuracy of the system for these tests were 67 μ m per pixel and greater than 99.5%, respectively.³¹ This accuracy is achieved by the use of multiple pixel outlines and subpixel centroid calculations.

Histological evaluation. Two fresh-frozen cadaver glenohumeral joints were thawed at room temperature and dissected free of all soft tissue except for the musculature of the rotator cuff and the capsuloligamentous structures. The glenohumeral joints were positioned at 60° of abduction and at the limit of external rotation as for the mechanical

tests, before being refrozen. The joints were sectioned in a plane perpendicular to the glenoid through the midportion, creating inferior and superior halves. A second section, in a plane perpendicular to the first through the 12 o'clock and the six o'clock locations in the glenoid, produced four segments. The histological sections were prepared using an accelerated tissue-processing technique described by Ohland et al.³² The anteroinferior and anterosuperior segments were thawed in 70% ethanol, fixed for 14 days, dehydrated, cleared, and embedded in Techovit 7200 resin. After ten days of infiltration, the resin was polymerised by a combination of light and heat. The polymerised blocks were mounted on to an acrylic slide and serially sectioned perpendicular to a plane containing the anterior and posterior rims of the glenoid. Ground sections were then prepared by attaching a plexiglass slide to the face of each block and cutting sections 200 μ m thick, which were then ground down to 30 μ m. Finally, sections were stained with 1% Toluidine Blue zero in 1% sodium tetraborate for light microscopy.

Results

Biomechanical results. The mean length of the anterior band of the G-ST-H complex was 37.3 ± 0.9 mm. The mean widths, thickness and cross-sectional areas of the 12 anterior bands are shown in Table I.

Eight of the 12 complexes failed at the glenoid attachment (Fig. 2a). Of these, the labrum was avulsed from the glenoid bone in five specimens with failure at the labrum-bone junction, and an attachment to the anterior neck of the glenoid bone was avulsed with the ligament. After failure, torn fibres, representing this attachment, were visible medial to the labrum. In three of the complexes, the ligament alone was avulsed, representing failure at the ligament-to-labrum junction; the labrum remained attached to the glenoid. Since the labrum can be seen only from a posterior view, and was hidden from view by the video camera, it was not possible to observe these junctions until failure of the complex had begun. Two complexes failed at the humeral attachment (Fig. 2b) and the remaining two in the midsubstance of the ligament (Fig. 2c).

Figure 3 shows a typical load-deformation curve of the G-ST-H complex and Figure 4 its structural properties. Permanent deformation, the difference between yield and ultimate deformation, of the G-ST-H complex was slight with all three failure modes: 2.3 ± 0.4 , 2.3 ± 2.3 and 2.3 ± 1.8 mm, respectively, for failure at the glenoid attachment, midsubstance, and humeral attachment. This similarity suggests that most of the deformation of the G-ST-H complex is recoverable.

Figure 5 shows the material characteristics for the anterior band of the IGHL for the G-ST-H complex. The strain at yield and the strain at failure were similar regardless of the mode of failure (Fig. 5a). Stress at yield and stress at failure are shown in Figure 5b.

Table I. The mean width, thickness (mm $\pm$ SD) and cross-sectional areas (mm² $\pm$ SD) of the 12 anterior bands of the G-ST-H complex

	Width	Thickness	Cross-sectional area
Glenoid insertion region*	24.8 ± 1.1	2.9 ± 0.2	73.5 ± 7.5
Midsubstance region*	23.3 ± 0.8	2.6 ± 0.2	61.7 ± 6.7
Humeral insertion region*	28.5 ± 0.9	2.6 ± 0.2	74.0 ± 7.0

* glenoid ν midsubstance, $p = 0.0041$; glenoid ν humerus $p = 0.9169$; humerus ν midsubstance, $p = 0.0062$

Fig. 2a

Fig. 2c

Fig. 2b

Photographs showing the three types of failure for the G-ST-H complex: a) at the glenoid attachment, particularly the labrum-bone junction; b) at the insertion into the humerus; and c) at the midsubstance of the anterior band.

Fig. 3

A typical load-deformation curve showing the linear stiffness, yield load and deformation, and ultimate load and deformation of the G-ST-H complex in tension.

Permanent strain, the difference between strain at yield and strain at failure, at the midsubstance of the G-ST-H complex was relatively small being $2.3 \pm 1.1\%$, $3.2 \pm 3.2\%$ and $1.3 \pm 0.8\%$ for specimens that failed at the glenoid attachment, midsubstance, and humeral attachment, respectively. Most of the strain of the G-ST-H complex was

recoverable, regardless of the mode of failure. The properties of the G-ST-H complex are important when failure occurred at the glenoid attachment, simulating the Bankart lesion; eight specimens failed at that site.

Histological findings. The anterior band of the IGHL had two attachments at the glenoid which were seen in both

Fig. 4a

Fig. 4b

Histograms showing the structural properties of the G-ST-H complex for the three types of failure. Figure 4a – The yield load and ultimate load of the G-ST-H complex. Figure 4b – Yield deformation and ultimate deformation of the G-ST-H complex.

Fig. 5a

Fig. 5b

Histograms showing the material characteristics of the G-ST-H complex for the three types of failure. Figure 5a – The strain at yield and strain at failure of the G-ST-H complex. Figure 5b – The stress at yield and stress at failure of the G-ST-H complex.

Fig. 6

The attachment to the glenoid at four o'clock. The anterior band of the IGHL is attached at two sites, one to the glenoid labrum and one to the bone.

specimens (Fig. 6). One was to the anteroinferior labrum and consisted of collagen fibres attached directly to the labrum. Transitional zones of fibrocartilage and mineralised fibrocartilage were present before the attachment to bone. The longest portion of the fibrocartilage zone, about 2 mm, was located at three o'clock on the glenoid. Moving inferiorly on the glenoid each section showed a progressively shorter fibrocartilage zone. It was absent at five o'clock and in this area the collagen fibres near the labrum were very disorganised. The other attachment was to the glenoid bone. Collagen fibres of the anterior band ran principally in a longitudinal direction, and attached at an acute angle along the neck of the glenoid bone. Some fibres were attached directly to bone and some ran parallel to its surface blending with the periosteum. This attachment was thickest and longest at three o'clock, extending for a distance of more than 10 mm on the glenoid, but became thinner and smaller with each section progressing inferiorly. Near five o'clock there was no attachment to the glenoid and the collagen bundles were disorganised in appearance where they were attached to the bony rim.

Discussion

Arthroscopic or radiological techniques have been used to examine lesions found after traumatic anterior instability. Lintner and Speer³³ found a Bankart lesion in 400 of their 472 patients (84.8%) confirming the study by Speer et al²⁶ that the Bankart lesion is not the only factor responsible for anterior instability. In our study, permanent stretching of the anterior band refers to a permanent increase in length of the G-ST-H complex at the time of failure.

When a ligament fails, the change in length has both recoverable and permanent components. This is of interest to surgeons intent on surgical repair since only the permanent increase in length need be corrected. Permanent stretching was measured as the difference between the strain at failure and the strain at yield and was small, never being larger than a mean of 4% regardless of the mode of failure. This was smaller than the total midsubstance strain reported by Bigliani et al,²⁵ Mow et al³⁴ and Ticker et al²⁷; 11%, 9.1% and 10.8%, respectively. Another method measured permanent stretching as the increase in length between the two sites of attachment. In the G-ST-H complexes which failed at the region of the glenoid insertion, this averaged 2.3 ± 0.4 mm or 6.2% of the total length of the anterior band. Bigliani et al²⁵ reported a change in total length of the ligament of the anterior band of the IGHL of 24% at the time of failure (regardless of the mode) and Ticker et al²⁷ measured a change of 30.4% in total length.

The Bankart lesion is not the only lesion responsible for anterior instability. Our study has shown that injuries other than permanent stretching of the capsuloligamentous structures could be responsible. Biomechanical testing in the position of apprehension resulted most commonly in failure at the glenoid attachment, but failure also occurred in other

locations. This has been confirmed in other studies.³⁵⁻³⁸ Bigliani et al²⁵ isolated the anterior band of the IGHL with blocks of bone from the humerus and the glenoid. The most common site of failure in 19 of 48 specimens (40%) was the glenoid attachment, but failure also occurred at the midsubstance of the ligament in 17 (35%) and the humeral attachment in 12 (25%).

Recent clinical studies have identified capsuloligamentous lesions after initial dislocation of the glenohumeral joint in vivo. Detachment of the glenoid labrum (the Bankart lesion) is common,³⁹⁻⁴³ but capsuloligamentous tearing,^{39,40,44} and humeral avulsion of the IGHL⁴⁴ have also been seen. If injury occurred in vivo at the midsubstance or at the humeral attachment it would probably heal quickly, but possibly in a lengthened state. This could occur even with injury at the glenoid attachment. Hara, Ito and Iwasaki⁴⁵ identified the portion of the labrum close to the cartilage of the glenoid as the most common location of failure of attachment. In their study failure also occurred at the junction of the ligament to the labrum. Failure at this junction would also heal quickly, but if anterior instability persisted it would heal in a lengthened state. In this way, the manner of tearing rather than permanent stretching of the capsuloligamentous structures may be responsible for the spectrum of glenohumeral instability which is observed clinically.

In surgical repair of glenohumeral instability surgeons have rightfully dwelt on the importance of the Bankart lesion. The anatomy of the glenoid attachment, however, is more complex than has been previously thought, consisting of two parts. At the 3 o'clock location the labral attachment of the anterior band of the IGHL is similar to some direct insertions of ligament or tendon, such as that of the supraspinatus.^{46,47} The collagen bundles of the midsubstance of the anterior band are primarily orientated in a radial fashion, but near the glenoid they change direction and form the labrum as a circular system. This has been shown in other histological investigations.¹⁶ We found the labrum at the 5 o'clock location to consist mainly of fibrous tissue as have others.^{48,49} In summary, the glenoid labrum which is traditionally thought of as an extension of the articular cavity,⁵⁰ is also the insertion of the capsuloligamentous structures.^{16,48,49}

The glenoid attachment near the three o'clock location was similar to the tibial insertion of the medial collateral ligament as described by Woo et al.⁵¹ Dense collagen fibres approached the bone at an acute angle and attached as an indirect insertion. Superficial fibres ran parallel to the bone surface, blending in with the periosteum with the deep fibres attached straight to the bone.

The significance of the anatomy of the glenoid attachment has been understated in previous studies. Cooper et al²⁸ described the anterior band of the IGHL as being intimately attached to the labrum and the rim of glenoid bone at four o'clock. They implied that the attachment was not consistent, but when there was an attachment to the neck of the glenoid it was well developed, rather than

simply a thickening in the capsule. Gohlke et al¹⁶ also reported that the attachment of fibres at three o'clock was most commonly anchored to the glenoid bone, which agrees with our findings. In their description, these fibres insert at an acute angle, but are part of the middle glenohumeral ligament. Histological cross-sections of the glenohumeral joint, reported by Moseley and Övergaard,⁴⁹ also demonstrate the glenoid attachment. The fibres which we described were from sections through and inferior to three o'clock, where they correspond to the attachment of the anterior band of the IGHL.²⁸

Misunderstanding of this anatomy partly explains the discrepancy in results between the traditional open methods of repair of the Bankart lesion^{4,17} from outside the glenohumeral joint, and arthroscopic repair^{18,19} from the inside. In the open procedure both attachments are repaired whereas arthroscopically the glenoid attachment may or may not be fixed. During surgical procedures for glenohumeral instability, the site of failure should be identified intraoperatively, repaired and the region plicated.

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