BI-DIRECTIONAL MECHANICAL PROPERTIES OF THE POSTERIOR REGION OF THE GLENOHUMERAL CAPSULE

Susan M. Moore, Patrick J. McMahon, Richard E. Debski

Musculoskeletal Research Center
Department of Orthopaedic Surgery
University of Pittsburgh
Pittsburgh, PA

INTRODUCTION

The glenohumeral joint is the most frequently dislocated diarthrodial joint in the body. Recurrent instability following a capsular shift procedure for posterior instability has been reported to be as high as 72%. (3) Additionally, capsular shift procedures used to treat anterior instability have resulted in an increase in posterior capsular strain (2.9%-6.6%) as the humerus was elevated. (4) While experimental and analytical models have focused on the uniaxial tensile properties of the glenohumeral capsule, (1, 7) surgical repair techniques shift the capsule in the medial-to-lateral and superior-to-inferior direction. This translates the posterior capsule perpendicular and parallel to the long axis of the posterior band of the inferior glenohumeral ligament (PB-IGHL). Moreover, the posterior capsule has been shown to transmit forces in the direction perpendicular to its longitudinal axis. (2) Therefore, the objective of this study is to determine the mechanical properties of the posterior capsule in the directions perpendicular (transverse) and parallel (longitudinal) to the longitudinal axis of the PB-IGHL.

METHODS

Four cadaver shoulder specimens (average age: 63 ± 7.4 years). Each shoulder was thawed at room temperature and dissected leaving the glenohumeral capsule intact. The PB-IGHL was identified and the posterior capsule was dissected free from the joint. One longitudinal and one transverse dog-bone (midsubstance: 12.5 mm x 2.5 mm) tissue sample was harvested from the posterior capsule of each specimen. Throughout the entire testing protocol, tissue samples were kept moist with physiological 0.9% saline solution. The cross-sectional area of the midsubstance of each sample was determined using a laser micrometer system while the specimens were fixed within customized clamps. A circular punch was used to obtain reflective plastic markers (1.6 mm diameter) for non-contact video strain analysis. Two markers were fixed to the midsubstance of each sample using cyanoacrylate, centered approximately 10 mm apart, and analyzed with a Motion Analysis™ system.

The samples were subsequently mounted in a preheated saline bath (37°C) on a uniaxial material testing machine (Instron Model 4502). The load cell had a range of 0-44.8 N with an accuracy of ±0.07 N. A 0.1 N preload was applied to each sample and the tissue was preconditioned via cyclic elongation (0.0-0.3 mm) for 10 cycles. A load-to-failure test was then performed at a crosshead displacement rate of 10 mm/min. From the stress vs. strain curve, the tangent modulus and the ultimate stress were obtained. A paired t-test was used to compare the parameters from the longitudinal and transverse directions with statistical significance set at $p<0.05$.

RESULTS

The traditional "toe region" followed by a linear region prior to failure was found for four of the eight tissue samples examined (**Figure 1**). Seven tissue samples failed in the midsubstance and one tissue sample failed at the tissue-clamp interface. A significant difference ($p>0.05$) was not detected between the cross-sectional areas of the transverse (3.7±1.3 mm^2) and longitudinal (4.2±1.2 mm^2) tissue samples. No significant differences could be demonstrated for the tangent modulus, stress at failure, strain at failure, and strain energy density of the transverse tissue samples compared to the longitudinal tissue samples (**Table 1**). However, the stress at failure and tangent modulus of the longitudinal tissue samples were both 35% larger than that of the transverse tissue samples. Additionally, the strain energy density exhibited in the longitudinal direction was nearly two times greater than the strain energy density in the transverse direction. A linear correlation between the strain at failure and the tangent modulus was present for both the transverse (R^2=0.90) and the longitudinal (R^2=0.88) tissue samples (**Figure 2)**. No correlation existed between the stress at failure or the strain energy density and the tangent modulus.

DISCUSSION

The mechanical properties of the posterior capsule in the directions perpendicular (transverse) and parallel (longitudinal) to the longitudinal axis of the PB-IGHL were determined and found to be quite variable.

Previous researchers have investigated the mechanical properties of the posterior capsule in the longitudinal direction. (5) The tangent modulus (67.1±22.4 MPa) and stress at failure (21.2±5.7 MPa) were greater than the data for the current study. The differences may be due to different testing methods which include the type of sample tested (bone-posterior capsule-clamp) as well as the technique for strain measurement.

The strain at failure is substantially less than that reported previously for transverse (49±21 %) and longitudinal (42±18 %) samples of the axillary pouch. (6) This finding suggests that the functional role of the axillary pouch may be to accommodate large strains compared to the posterior capsule. Hurschler and coworkers reported as much as a 6.6% increase in strain of the posterior capsule following capsular shift procedures used to treat anterior instability. (4) Based on the data from this study, the strain increase associated with these procedures would shift the posterior capsule into the linear region of its stress-strain curve. Thus, the functional range of the tissue would be reduced. This may explain the high incidence of complications associated with capsular shift procedures used to treat anterior instability.

The linear correlation between the strain at failure and the tangent modulus will aid in mathematical modeling of the tissue and might account for the variations observed in the toe region of the stress-strain curves between tissue samples. In the future, the mechanical properties collected in this study will used as inputs into a finite element model of the entire glenohumeral capsule.

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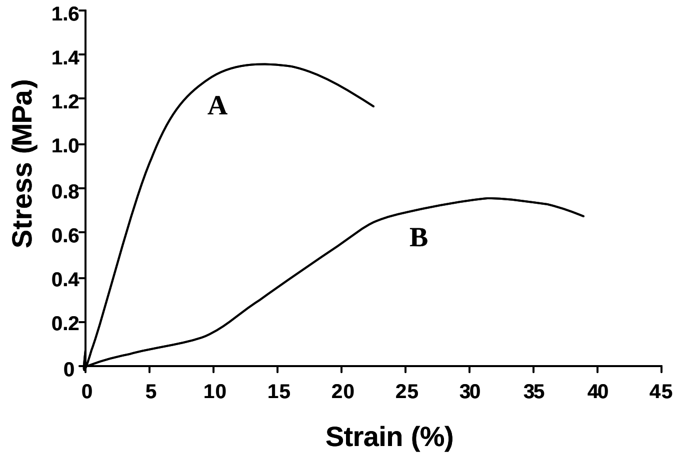

Figure 1. Typical stress-strain curves for the posterior capsule in the: A) transverse and B) longitudinal directions.

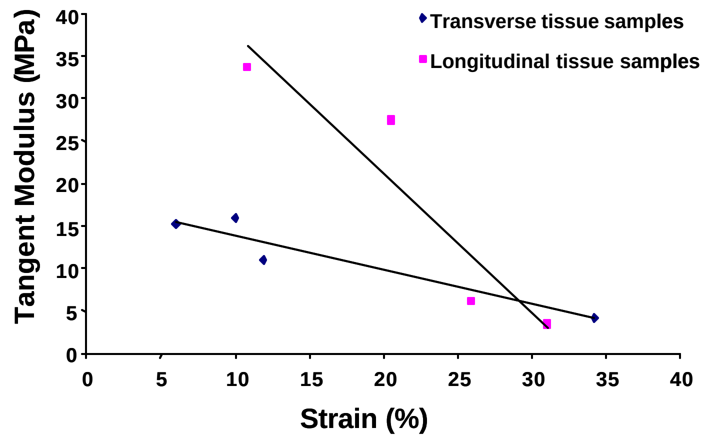

Figure 2. Linear correlations between the strain at failure and the tangent modulus of the transverse and longitudinal tissue samples.

Table 1. Mechanical properties of the transverse (Trans) and longitudinal (Long) tissue samples from the posterior capsule.

	Stress at Failure (MPa)		Strain at Failure (%)		Tangent Modulus (MPa)		Strain Energy Density (MPa)	
	Trans	Long	Trans	Long	Trans	Long	Trans	Long
Range	0.6-1.8	0.8-3.9	6.0-34.2	10.8-31.0	4.2-15.9	3.4-33.7	2.2-14.8	4.3-32.0
Average	1.1±0.5	1.8±1.4	15.5±12.7	22.1±8.6	11.6±5.4	17.7±15.2	9.1±5.2	16.8±11.8

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