EFFECT OF PRESSURE ON DETERMINING THE NOMINAL STRAIN STATE OF THE INFERIOR GLENOHUMERAL LIGAMENT COMPLEX

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INTRODUCTION

Eighty percent of glenohumeral joint dislocations occur in the anterior direction and frequently cause injury to the inferior glenohumeral ligament (IGHL). [1] Surgical repair that plicates and shifts the tissue is often necessary; however, post-operatively up to 24% of patients suffer subsequent dislocations. [2] Experimental and analytical models have primarily modeled the shoulder capsule to provide stability as a collection of uniaxial elements [3,4,5], but recent research has demonstrated that the capsule should be modeled as a continuous structure [6,7]. Malicky and coworkers previously determined the nominal strain state for the antero-inferior portion of the capsule [6]; however we hypothesize that the anterior and posterior portions of the capsule may need different definitions of a nominal strain state because these capsular regions function at different joint positions. Since the nominal strain state serves as the reference state for strain calculations, or configuration with no wrinkles and minimal strain, it is crucial to accurately define this state to prevent under/over-estimation of strains during joint motion. Therefore, the objective of this study was to determine the effect of the pressure on the parameters used to define the nominal strain state in the anterior and posterior regions of the IGHL complex and to determine the repeatability of our methodology. Ultimately, being able to determine the direction and magnitude of strains in the capsule will provide a better understanding of its function in clinically relevant joint positions.

METHODS

One cadaveric shoulder specimen was thawed at room temperature and the skin and musculature was dissected, leaving the glenohumeral capsule intact. The shoulder was continuously soaked with saline to prevent drying of the tissue. The boundaries of the anterior and posterior bands of the IGHL complex were identified and a grid of 45 lead markers (diameter: 2 mm, 9 columns, 5 rows) were attached to the surface of the capsule using cyanoacrylate. Two columns of markers were attached on each band of the IGHL complex and 5 columns of markers were attached on the axillary pouch, for a total of 9 columns spaced 10 mm apart.

The humerus and scapula were potted in epoxy putty and mounted within a custom jig, which allowed for 6 degrees of freedom (DOF) motion. (Figure 1) The shoulder was fixed at 60° of glenohumeral abduction, neutral flexion/extension, and neutral rotation with a manual compressive force applied to center the joint. Neutral rotation was defined by aligning the anterior border of the acromion with the bicipital groove. Once the joint was in neutral rotation, a slight distraction was applied to the joint as indicated by Malicky and coworkers. [6] Seven different joint positions (15° external rotation (ER), 10° ER, 5° ER, 0° ER, 5° internal rotation (IR), 10° IR, 15° IR) were then randomly chosen. At each joint position, the capsule was inflated to three separate pressures (2.1 kPa, 3.4 kPa, and 6.2 kPa) via the rotator interval, and the position of the markers on the IGHL was determined using a custom built 3D motion tracking

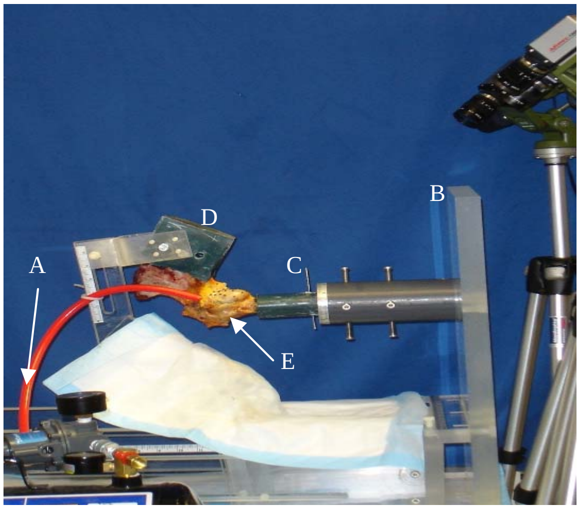

Figure 1. Experimental setup including: A) Air supply B) custom shoulder jig C) humerus D) scapula and E) capsule.

camera system (Adimec 1000M, Adimec, MA) combined with motion tracking software (DMAS6, Spicatek, HI). This motion tracking system was determined to be accurate to within ± 0.08 mm. The joint position at which marker movement between the pressures is minimal indicates the position at which the nominal strain state should be defined. [6] The position of each marker was found, which allowed for comparison of total marker motion between pressures and rotation angles. (Figure 2)

For repeatability, a random joint position (5° ER) was chosen. The capsule was inflated to 0.7 kPa as described by Malicky and coworkers [6] and the position of the markers was determined. A total of 3 trials were performed. The mean and standard deviation of the X, Y, and Z coordinates of each marker between the trials were determined, and the radius of the sphere that contained the markers within a 95% confidence interval, was used to define the repeatability of the method for both the anterior and posterior regions of the IGHL complex.

An un-paired student's t-test was performed to compare marker motions between anterior and posterior regions of the IGHL complex with a significance value set at $p<0.05$.

RESULTS

As pressure was increased in the capsule, marker movement increased steadily. As expected, marker motion was different when comparing the anterior and posterior portions of the IGHL complex at several joint positions. Individual marker motions as large as 5 mm and as small as 0.01 mm were noted. The magnitude of the anterior and posterior marker motions were significantly ($p<0.05$) different at 10° ER when comparing pressures of 2.1 kPa to 3.4 kPa, (Ant: 0.84±1.31 mm, Post: 0.08±0.08 mm) and 2.1 kPa to 6.2 kPa (Ant: 0.46±0.43 mm, Post: 0.21 ± 0.16 mm). There were also significant differences between the magnitude of marker motions at 5° IR when comparing 2.1 kPa to 6.2 kPa (Ant: 0.35±0.14 mm, Post: 0.35±0.14 mm) and at 15° ER when comparing 2.1 kPa to 3.4 kPa (Ant: 0.16±0.13 mm, Post: 0.10±0.07 mm). (Table 1)

Table 1. Magnitude (mm) of anterior and posterior marker motions between 2.1 kPa to 6.2 kPa and 2.1 kPa to 3.4 kPa. (*p<0.05)

	2.1 kPa - 6.2 kPa		2.1 kPa - 3.4 kPa	
	Anterior(mm)	Posterior(mm)	Anterior(mm)	Posterior(mm)
Neutral	0.35 ± 0.26	0.40 ± 0.19	0.18 ± 0.06	0.39 ± 0.12
5° ER	0.34 ± 0.16	0.34 ± 0.19	0.23 ± 0.08	0.23 ± 0.16
10° ER	0.46 ± 0.43*	0.21 ± 0.16*	0.84 ± 1.31*	0.08 ± 0.08*
15° ER	0.49 ± 0.76	0.21 ± 0.14	0.16 ± 0.13*	0.10 ± 0.07*
5° IR	0.35 ± 0.14*	0.51 ± 0.23*	0.15 ± 0.07	0.20 ± 0.11
10° IR	0.39 ± 0.16	0.50 ± 0.29	0.22 ± 0.13	0.28 ± 0.22
15° IR	0.44 ± 0.21	0.50 ± 0.25	0.24 ± 0.11	0.23 ± 0.11

The method used to determine the nominal strain state was found to be repeatable within 0.27 mm overall at 0.7 kPa and 5° ER. At this same joint position and pressure, anterior repeatability was found to be 0.27 mm and posterior repeatability was found to be 0.26 mm.

DISCUSSION

A method for determining the nominal strain state of the anterior and posterior portions of the IGHL complex was evaluated. Pressure was shown to have an effect on the data used for the definition of a nominal strain state, with larger marker motions at higher pressures. It was also shown that it may be required to use two different positions to define the nominal strain state for the anterior and posterior portions of the IGHL complex since the function of these regions is dependent upon joint position. Finally, the method used to obtain the nominal strain state in this study was also shown to be repeatable.

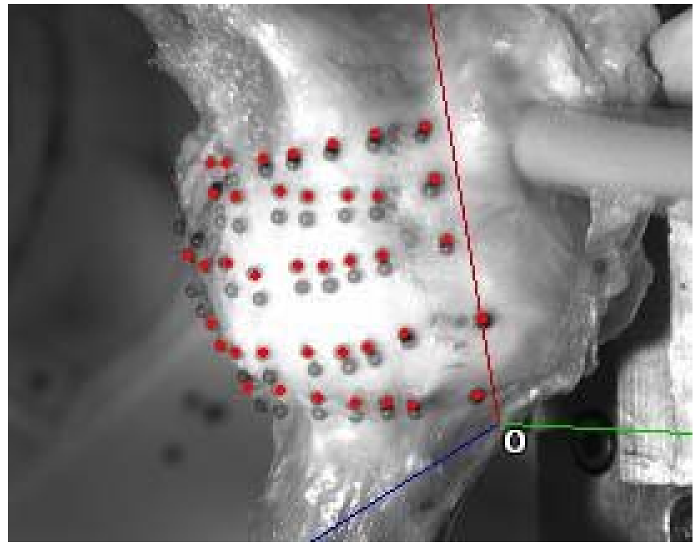

Figure 2. Inferior view of capsule at 15° ER, showing marker motion between 2.1 kPa (light gray) and 6.2 kPa (black).

The data presented in this study compares well with a previous data [6] that used two pressures (0.7 kPa and 4.8 kPa) to define the nominal strain state. Based on figures presented by Malicky [8] depicting marker motions between 0.7 kPa and 4.8 kPa, we estimated that marker motions ranged between 0.1 to 0.5, which was the same range of marker motion presented in this study. These estimations can only be compared to the anterior region of the IGHL complex since they focused on the antero-inferior region of the capsule.

Our results have provided guidelines for future studies to accurately determine the strain field in the anterior and posterior regions of the IGHL complex. However, additional studies are still needed to assess the effect of compatibility on the meshes for each region and variability in the population. Therefore, additional angles of rotation will be analyzed and multiple specimens will be assessed.

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