TOTAL AND NON-RECOVERABLE STRAIN FIELDS OF THE GLENOHUMERAL JOINT CAPSULE UNDER SHOULDER SUBLUXATION

*Malicky, D.M., +Soslowsky, L.J., Mouro, C.M., Frisancho, J.C., Lindholm, S.R., Kuhn, J.E. *Orthopaedic Research Laboratories, University of Michigan, Ann Arbor, MI. +Orthopaedic Research Laboratory, University of Pennsylvania, 424 Stemmler Hall, 36th and Hamilton Walk, Philadelphia, PA, 19104-6081: (215)898-8653, FAX (215)573-2133, soslowsk@mail.med.upenn.edu

Introduction: Instability of the shoulder is believed to be related to deformations of the ligaments and capsule, though the nature of this relationship is largely unknown. In the critical instability position of 90° arm abduction and external humeral rotation, the inferior glenohumeral ligament (IGHL), located throughout the anteroinferior capsule (AIC), has been shown to be an important stabilizer [1,2]. The presence of non-recoverable strain in the AIC, while controversial, is generally believed to exist and result in increased potential for glenohumeral instability. In fact, current surgical procedures for instability [e.g., 3] are aimed at reducing the capsular length due to presumed permanent capsular stretching. Recently, non-recoverable uniaxial strain has been demonstrated in the IGHL due to cyclic tensile testing [4], and total strain fields have been measured in the AIC under glenohumeral subluxation [5]. However, no study has quantitatively assessed non-recoverable strain fields due to subluxation. Quantifying the AIC strain field will aid in understanding one potential mechanism of glenohumeral instability, and help guide surgical reconstructive techniques. The objective of the current study was to measure the total and non-recoverable strain fields in the AIC in an anteroinferiorly subluxed shoulder. We hypothesized that glenoid side strains would be greater than humeral side strains, and that non-recoverable strain would exist with increasing subluxation.

Methods: Seven shoulders (ave. age: 55.4 yrs.) were dissected retaining only the scapula, humerus, capsular and coracohumeral ligaments, and rotator cuff tendons. The extra-articular AIC surface was carefully dissected to expose the superficial layer. Lead object markers of 500µm diameter were attached to this surface in a 5x5mm grid pattern with a small amount of cyano-acrylate. Markers were applied from the most inferior portion of the capsule to the anterosuperior capsule. These markers were used to calculate AIC strains via a stereoradiogrammetric (SRG) procedure.

Specimens were mounted in 60° glenohumeral abduction (90• arm abduction) and external rotation set at 10° less than maximum. Three muscles were modeled: supraspinatus, subscapularis, and infraspinatus and teres minor (combined). Three capsular positions were used for strain field calculations: a nominal state, a subluxed state, and a post-subluxed state. For the nominal state, the capsule was inflated (pressure=1.0kPa (0.15psi)) in neutral rotation and minimal distraction for removal of capsular redundancy. Radiographs were taken at 30°-40° intervals for SRG analysis. For the subluxed state, 53N rotator cuff loads were applied and the humerus was externally rotated and subluxed in an anteroinferior direction. Radiographs were repeated. The post-subluxed state was similar to the nominal, performed within 5 minutes. Post-sublux data was also taken 1 hour after the highest subluxation to investigate the potential for additional viscoelastic tissue recovery.

The three-dimensional coordinates of 14 calibration markers attached to a carbon-fiber-epoxy calibration frame were obtained using a coordinate measuring machine. Radiographs of the shoulder object markers and frame calibration markers were digitized using an optical-mechanical digitizer. Three-dimensional coordinates of object markers were reconstructed with a direct linear transform program [6]. Coordinates of nominal/subluxed and nominal/post-subluxed capsule states were imported to FEM software to calculate total and non-recoverable strain fields, respectively. For hypothesis testing, the glenoid and humeral sides were defined as the tissue between the respective insertion zone and the mid-portion of the ligament. The peak and mean maximum principal strain of each side was computed, and data analyzed with paired t-tests and t-tests. Calibration studies showed positional accuracy of 35µm and strain value repeatability of 2.7% strain, each at 95% confidence.

Results: Strain fields of the AIC, including total (Fig. 1a) and non-recoverable (Fig. 1b) maximum principal strains were obtained in all specimens. No tearing was ever visible at any object marker site.

Total maximum principal strains: At 7mm subluxation, mean strains on the glenoid side of the glenohumeral capsule were greater than on the humeral side ($p=.09$). Peak strains were greater on the glenoid side at all subluxations examined: 7mm ($p=.05$), 12mm ($p=.04$), and 16mm ($p=.09$).

Non-recoverable maximum principal strains: The mean strains on the glenoid side were greater than on the humeral side following subluxations of 12mm ($p=.07$) and 16mm ($p=.06$). Non-recoverable strains were greater than zero at all subluxations ($p<.05$), with average strains of less than 5% following a 16mm subluxation. Overall, the 1 hour delay to allow for viscoelastic recovery had no effect on average strains ($p=.96$).

Discussion: This study reports a general method for measuring planar strains in a three-dimensional membranous structure. Peak strain values were often higher than those found in previous uniaxial ligament tests [7]; the finer grid size and different loading conditions in the current study are two potential explanations for these differences. Generally, strains were not uniaxial, nor were they aligned with the anatomical ligaments.

This is the first study to show the existence of pre-failure, non-recoverable strain due to glenohumeral subluxation. After large subluxations, high non-recoverable strains often existed in isolated regions of the capsule, with remaining regions at low strain (Fig. 1b). At lower subluxations, the distribution was more uniform. The largest total and non-recoverable strains were usually seen on the glenoid side of the AIC, consistent with injuries to this region. Clinically, large subluxations may produce non-recoverable, permanent, strain, which is likely to aggravate joint instability.

Limitations of the study include measuring the surface strain field and testing quasi-statically. Future studies will address strain fields of the glenohumeral capsule and rotator cuff tendons over a range of joint positions.

Acknowledgments: This work was supported by Grace Hospital (Detroit) and NIH (AR-20557). The authors thank M Bey, J Raz, G Ateshian, S Hollister, R Zanecki, D Kayner, and M Stock.

References: 1)Malicky *et al.: J Orthop Res*, 14:282-288, 1996. 2)O'Brien *et al.: J Shoulder Elbow Surg*, 4: 298-308, 1995. 3)Neer and Foster: *J Bone Joint Surg [Am]*, 62:897-908, 1980. 4)Pollock *et al.: Trans ORS*, 23:46, 1998. 5)Malicky *et al.: Trans ORS*, 23:1024, 1998. 6)Ateshian *et al.: J Biomech*, 24:761-776, 1991. 7)Bigliani *et al.: J Orthop Res*, 10:187-97, 1992.

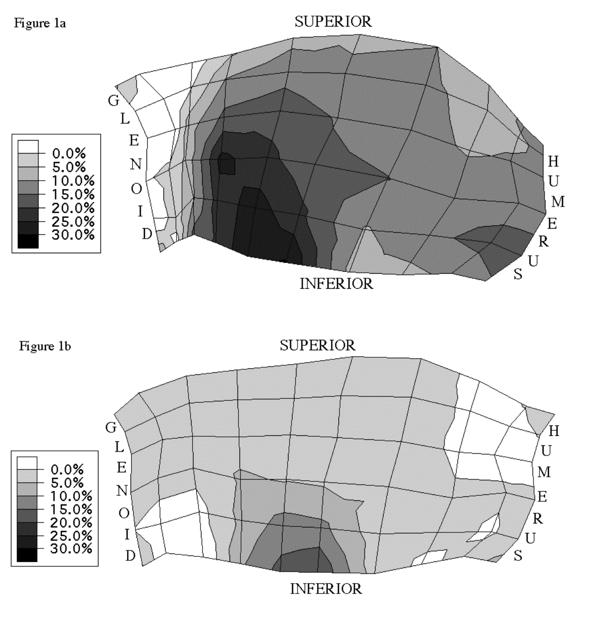

***Fig. 1:** Max principal strains of the AIC in a typical specimen. **1a**: Total strains at 18mm sublux. **1b**: Non-recoverable strains following 18mm sublux.*

☐ One or more of the authors have received something of value from a commercial or other party related directly or indirectly to the subject of my presentation.

☒ The authors have not received anything of value from a commercial or other party related directly or indirectly to the subject of my presentation.