Quantifying Capsular Injury and Repair to Guide Individualized Capsular Plication After Anterior Glenohumeral Dislocation

Gillian M. Ahrendt[2], Zachary J. Herman[2], Benjamin W. Newell[1], Jumpei Ionue[1], Ehab M. Nazzal[2], Keishi Takaba[1], Luke T. Mattar[2], Volker Musahl[2,1], Albert Lin[2], Richard E. Debski[1,2]
[1]Department of Bioengineering and [2]Department of Orthopaedic Surgery, University of Pittsburgh, Pittsburgh, PA
ahrendtgm2@upmc.edu

Disclosures: Ahrendt (N), Herman (N), Newell (N), Inoue (N), Nazzal (N), Takaba (N), Mattar (N), Musahl (NIH, DOD, Newclip, Smith & Nephew, Ostesys), Lin (N), Debski (N)

INTRODUCTION: Capsuloligamentous injury following anterior glenohumeral dislocation can result in anterior instability due to permanent deformation of the inferior glenohumeral ligament (IGHL).[1] Surgical management for anterior instability includes capsular plication to reduce capsular redundancy.[2,3] However, the location, direction, and magnitude of injury to the IGHL was found to vary between individuals following multiple anterior dislocations using a cadaveric model.[4] This underscores the complexity of capsular redundancy and highlights the challenges with current subjective plication techniques, which result in suboptimal outcomes.[5,6] Individualized capsular repair based on an objective method of quantifying capsular injury may restore native anatomy and glenohumeral joint stability. Prior studies demonstrated an increase in capsular volume following glenohumeral dislocation compared to uninjured controls.[7] Capsular surface area would therefore also theoretically increase and could provide a surrogate measurement for capsular volume, which may be applied clinically to MR arthrograms of patients. Thus, the objective of this study was to quantify capsular surface area using 3D geometric models derived from MR arthrograms of injured, contralateral (control), and repaired shoulders of patients with anterior shoulder instability undergoing plication. It was hypothesized that capsular surface area will increase after dislocation and decrease after plication, with current plication techniques resulting in a non-anatomic surface area compared to controls.

METHODS: Four patients (age 20.5 years ± 1.0; BMI 23.69 kg/m^2 ± 0.76) were recruited for this prospective study and provided IRB approved informed consent prior to any research procedure. All patients were male, had a history of at least one anterior shoulder dislocation, and all dislocations were sport related. All patients underwent standard pre-operative MR arthrogram, which demonstrated no associated glenoid rim boney defect or ipsilateral rotator cuff tear. Arthroscopic anterior labral repair with capsulorrhaphy was performed by a fellowship trained shoulder orthopaedic surgeon. Post-operatively (4.4 weeks ± 0.75), patients returned for bilateral MR arthrograms (3T scanner (Siemens, Prisma), MPRAGE sequence, resolution of 0.98mm x 0.98mm x 0.60mm). Imaging data from injured, repaired, and control MR arthrograms was obtained and segmented in Materialize MIMICs (version 23.0) to produce 3D geometric models of the glenoid, humerus, and IGHL for each state. Surface area of the IGHL in each 3D geometric model was calculated using MESHLab (version 2020.07). The ability to repeatably identify the IGHL was assessed, and surface area measurements were within 7%. Change in surface area was quantified for repaired versus injured and repaired versus control states. To account for individual differences in capsular size and morphology, injured and repaired capsule surface areas were normalized to the control capsule for each patient. Repeated measures one-way ANOVA compared means of normalized injured and repaired surface areas. A Bonferroni post-hoc analysis was performed to test significance. Significance was set at $p<0.05$.

RESULTS: The 3D geometric models demonstrate qualitative changes in capsular morphology across the injured, repaired, and control states (Figure 1). The injured capsule appears enlarged and deformed compared to the control. Additionally, a qualitative decrease in size between the injured and repaired states was observed. Surface area ranged from 1985-2540 mm^2 for injured; 1858-2388 mm^2 for control; and 1785-1944 mm^2 for repaired states (Table 1). All injured capsules had a greater surface area compared to respective controls. Capsular surface area decreased after repair for all subjects. For three subjects, repaired capsules were smaller than the control, while for one subject the repaired capsule remained larger. After normalization to control surface area, injured capsules demonstrated 10% ± 5% increase in surface area ($p = 0.046$). No significant difference in percent change in surface area was found between repaired and control states or injured and repaired states.

DISCUSSION: The current study demonstrated a novel method for quantifying capsuloligamentous injury measured as change in surface area after anterior shoulder dislocation using 3D geometric models of MR arthrograms. Comparison of injured to uninjured capsules demonstrated an increase in surface area following dislocation. A decrease in capsular surface area was found post-operatively; however, this did not achieve statistical significance. In a cadaveric study, increasing the magnitude of capsular plication was found to significantly decrease glenohumeral translation in a cadaveric model.[8] However, a quantitative method to determine how much tissue to plicate is still needed. Based on our limited data set, capsular surface area can be measured and may change after dislocation and plication. This study aims to enroll more patients to continue investigating changes in capsular surface area following injury and repair. Future studies identifying region-specific changes in surface area of the glenohumeral capsule will further guide plication location and may improve surgical outcomes.

SIGNIFICANCE: Recurrent anterior shoulder instability is a prevalent clinical pathology following anterior shoulder stabilization procedures. More targeted, individualized capsular plication guided by change in capsular surface area may reduce rates of recurrent instability.

REFERENCES: [1] O'Brien, S.J., JSES. 1995; [2] Mazzocca, A.D., AJSM. 2005; [3] Sodl, J.F., KSSTA. 2016; [4] Yoshida, M., JOR. 2020; [5] Bonnevialle, N., JSES. 2009; [6] Westerheide, K.J., Arthroscopy. 2006; [7] Hawk, J., ORS. 2020; [8] Mayer, S. CORR. 2018.

ACKNOWLEDGEMENTS: The support from the NIH Grant #1R21AR078418-01 is gratefully acknowledged. The authors sincerely appreciate the assistance of Andrew Cordle MD and Chan Moon PhD of the Department of Radiology, University of Pittsburgh, Pittsburgh, PA.

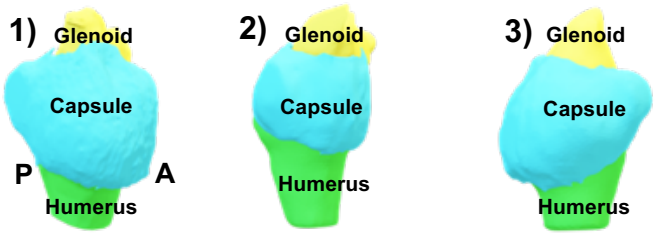

Figure 1. 3D Geometric Models of the Glenohumeral Joint. Injured (1), repaired (2), and control (3) models for a representative subject from an inferior view. All models are depicted in the same anterior-posterior orientation (A, P) as labeled on the Injured (1) model.

	Subject 1	Subject 2	Subject 3	Subject 4
Surface Area				
Injured (mm^2)	2447	2540	2061	1985
Repaired (mm^2)	1944	1785	1792	1913
Control (mm^2)	2102	2388	1876	1858
Percent Change				
Injured	20%	10%	10%	10%
Repaired	-10%	-30%	0%	0%

Table 1. Capsule surface area measurements of injured, repaired, and control shoulders. Percent change in surface area of injured and control states relative to control. Negative values indicate a decrease in surface area.