Correlation between non-recoverable strain and surface area measurements of the glenohumeral capsule following multiple shoulder dislocations using 3D geometric models from MRI

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INTRODUCTION: As a surgical treatment for recurrent instability of glenohumeral joint, capsular plication has been performed in addition to Bankart repair.[1,2] The amount and location of capsular plication utilized to address permanent deformation of the inferior capsule in the current methods are determined based on the surgeon's experience. Thus, the development of an individualized capsular plication method is needed since permanent deformation patterns vary with injury. Permanent deformation of the capsule can be identified by non-recoverable strain in cadaveric specimens.[3,4,5] However, in the clinical setting, capsular injury should be evaluated by magnetic resonance imaging (MRI). Therefore, the present study aimed to correlate non-recoverable strain with the change in capsular surface area from 3D MRI following multiple dislocations. We hypothesized that increased surface area would positively correlate with the magnitude of non-recoverable strain within each capsular sub-region following dislocation.

METHODS: Four fresh-frozen cadaveric shoulders were dissected free of all soft tissues except the glenohumeral capsule and coracoacromial ligament. A 7 x 11 grid of gadolinium-soaked canola seeds was attached to the inferior capsule to divide it to following eight sub-regions: anterior band of inferior glenohumeral ligament - glenoid side (ABG) and humeral side (ABH); anterior axillary pouch - glenoid side (AAPG) and humeral side (AAPH); posterior axillary pouch - glenoid side (PAPG) and humeral side (PAPH); and posterior band of inferior glenohumeral ligament - glenoid side (PBG) and humeral side (PBH). (Figure 1) A MRI dataset for the intact shoulder was collected while the capsule was inflated by 0.9 psi at 60° of abduction with neutral rotation using a specialized jig. The shoulders were then mounted on a 6 degree-of-freedom robotic testing system and dislocated anteriorly 5 times at 60° of abduction with 60° of external rotation while applying a 200 N of compressive force. The dislocation was defined as anterior translation reaching one-half the maximum anterior-posterior width of the glenoid plus 10 mm. The non-recoverable strain was obtained following 5 dislocations by optical tracking of seeds on the capsule while it was inflated by 0.9 psi. In addition, a post-dislocation MRI dataset was obtained in the same setting as the intact shoulder. Changes in the capsule surface area were obtained by comparing each sub-region between the intact and dislocated states on 3D geometric models created from the MRI datasets (Figure 2). Spearman correlations were used to determine the correlation between non-recoverable strain and change in surface area according to eight sub-regions. Statistical significance was set at $P<.05$.

RESULTS: The range of non-recoverable strain for each region was 5-14%, 4-14%, 5-13%, 5-11%, 5-16%, 5-11%, 7-14%, and 5-14% in ABG, ABH, AAPG, AAPH, PAPG, PAPH, PBG, and PBH, respectively. The range of change in capsular surface area for each sub-region was 7-16%, 0-14%, 4-15%, 4-12%, 4-17%, 4-10%, 11-14%, and 6-13% in ABG, ABH, AAPG, AAPH, PAPG, PAPH, PBG, and PBH, respectively. The change in capsular surface area showed a strong correlation with the magnitude of non-recoverable strain for each sub-region ($r = 0.738$, $P < 0.01$). (Figure 3).

DISCUSSION: This study showed that non-recoverable strain (or capsular injury) could be assessed by measuring the change in capsular surface area on 3D geometric models generated from MRI datasets. The repeatability of the measurement methods for non-recoverable strain (3%) and surface area (7%) introduce variability between the two measurement methods, but a strong correlation was detected in the study. Consistent with previous studies,[3,4] no trend was found in the location of peak strain between specimens, which indicates that the location of high strain should be evaluated individually. An individualized plication based on non-recoverable strain has been shown to restore the kinematics following dislocations.[6] Thus, our study revealed that 3D MRI datasets can be used to guide individualized capsular plication in the clinical setting. In the future, differences in surface area of the glenohumeral capsule will be examined in injured and contralateral shoulders for subjects that have experienced a traumatic dislocation.

SIGNIFICANCE/CLINICAL RELEVANCE: Injuries to regions in the inferior capsule can be identified by measuring the change in capsular surface area based on 3D geometric models derived from MRI datasets.

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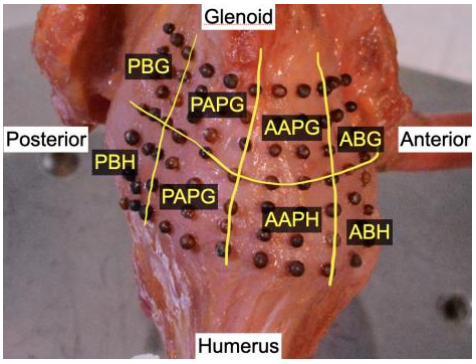

Figure. 1. Inferior glenohumeral capsule divided into eight sub-regions.

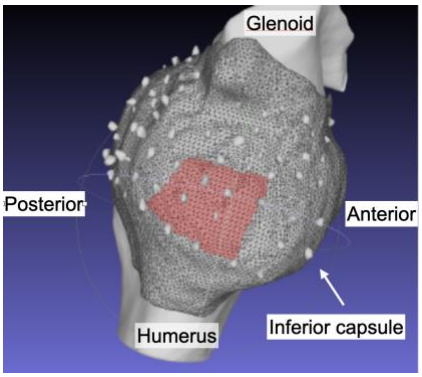

Figure. 2. 3D geometric model of the inferior capsule for a representative shoulder. The pink area shows the surface area of the anterior axillary pouch on the glenoid side.

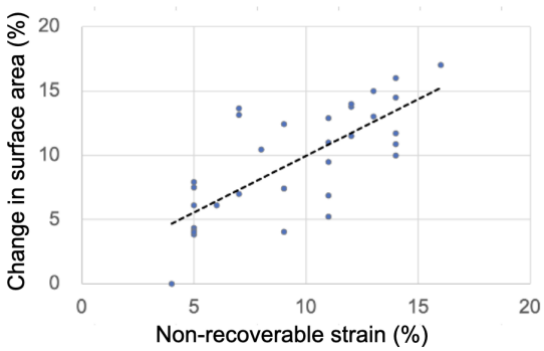

Figure. 3. Relationship between non-recoverable strain and the change in capsular surface area. A significant correlation was found between them ($r = 0.738$, $P < 0.01$).