The Anterior Stability Provided by the Glenohumeral Capsule May be Similar Among Patients During Abduction and Mid-Range External Rotation: Finite Element Analysis

INTRODUCTION:
The majority of glenohumeral joint dislocations occur in the anterior direction, in joint positions where anterior stability is provided by the glenohumeral capsule. However, physical examinations for anterior instability following dislocation are not standardized for joint position. Since the stability provided by the capsule varies with joint position and among patients, the lack of standardized positions may lead to misdiagnosis of the type, location and extent of capsule pathology. Surgical repair procedures are guided by the diagnoses, and misdiagnosis from the physical examinations may be responsible for over 50% of re-dislocations following surgery. The objective of this study was to use capsule strain distributions in validated, subject-specific finite element models of the glenohumeral joint to suggest joint positions for use in standardized physical examinations where the anterior stability provided by the capsule is similar among patients.

MATERIALS AND METHODS:
Subject-specific finite element (FE) models of the glenohumeral joint were developed and validated by comparing computational and cadaveric capsule strains during equivalent joint motions. FE Models 1 and 2 represented the left shoulder of a 45 year old male and the right shoulder of a 66 year old male, respectively, containing subject-specific surface geometry, material properties, reference positions, and kinematics of motion. Once validated, the two models were used to simulate clinically relevant joint motions involving application of a 25 N anterior load at 60° of glenohumeral abduction and 0° – 50° of external rotation in 10° increments. Maximum principal Green-Lagrange strain in the anterior-inferior capsule was then evaluated in each model, due to this region’s contribution to anterior stability in these joint positions. Strains were calculated at the nodes in 6 sub-regions of the anterior-inferior capsule, corresponding to the glenoid and humeral sides of the anterior band of the inferior glenohumeral ligament (AB-IGHL:G and AB-IGHL:H, respectively), the axillary pouch (AP:G and AP:H, respectively), and the posterior band of the inferior glenohumeral ligament (PB-IGHL:G and PB-IGHL:H, respectively). The values of strain in the six sub-regions were compared at each joint position in each model using a Kruskal-Wallis test (p<0.05) with Bonferroni-corrected Mann-Whitney tests for post-hoc analysis. Differences in strain among the sub-regions were defined to be significant (*) only if they were statistically significant and with an average difference greater than the experimental strain repeatability of ±3.5% strain. Joint positions were then selected where strain in one sub-region was significantly higher than strain in the remaining sub-regions for both FE Model 1 and FE Model 2, in order to identify joint positions where the anterior stability provided by the capsule is similar among patients and localized within the capsule.

RESULTS:
At the clinically relevant joint positions with 20° – 40° of external rotation, strain in the AB-IGHL:G was significantly higher than strains in the remaining five sub-regions for both FE Model 1 and FE Model 2 (Figure 1). With 20° of external rotation, strain in the AB-IGHL:G was 14.5% and 15.5% strain in FE Model 1 and FE Model 2, respectively, which was at least 5.3% and 6.4% strain higher than the remaining sub-regions, respectively. With 30° of external rotation, strain in the AB-IGHL:G was 23.1% and 15.9% strain in FE Model 1 and FE Model 2, respectively, which was at least 12.5% and 6.6% strain higher than the remaining sub-regions, respectively (Figure 1). With 40° of external rotation, strain in the AB-IGHL:G was 29.4% and 21.2% strain in FE Model 1 and FE Model 2, respectively, which was at least 19.6% and 4.4% strain higher than the remaining sub-regions, respectively. At the clinically relevant joint positions with 0°, 10°, and 50° of external rotation, there was not a sub-region with strain that was significantly higher than strains in the remaining five sub-regions for both FE Model 1 and FE Model 2.

DISCUSSION:
Joint positions with 20° – 40° of external rotation resulted in strains that were highest in the glenoid side of the anterior band of the inferior glenohumeral ligament for both models, a region of the capsule that is often injured following anterior dislocation. This implies that physical examinations for anterior instability may be effective at localizing pathology when performed with abduction and a mid-range of external rotation. This is in contrast to current examination procedures where clinicians place the shoulder at or near maximum external rotation to diagnose anterior instability, and may lower the risk of patient pain or apprehension during physical examinations. The strains reported in the current work compare well with previously reported cadaveric capsule strains in similar joint positions. Future work will involve development, validation, and analysis of additional subject-specific finite element models of the glenohumeral joint that contain wider demographic variability, in order to firmly establish joint positions where the anterior stability provided by the capsule is similar among patients for use in more effective physical examinations. The subject-specific finite element models will also be used to identify joint positions where stability is provided by additional sub-regions of the capsule, in order to help clinicians diagnose the type, location, and extent of pathology in the capsule.

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