Predicting Shoulder Stiffness and Joint Stability Following Capsular Plication Using a Patient-Specific Computer Model
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Disclosures:

Introduction: In glenohumeral dislocation, the humeral head translates over the edge of the glenoid, permanently stretching and/or tearing the capsular ligaments, resulting in excessive joint laxity [1]. Several surgical techniques involving capsular plication are currently used to reduce the rate of recurrent dislocations. However, either joint stiffness from over-tightening or continued laxity from under-tightening are common sequelae from these procedures because no optimal amount of tightening nor direction of plication have been established. Current techniques are based on clinical experience and biomechanical cadaveric studies. A significant limitation of cadaveric studies is the inability to accurately simulate injury to properly model and study this pathologic condition [2]. As a result, we have developed patient-specific computer models from patients with shoulder instability to accurately replicate this pathology. The purpose of this study was to simulate capsular plication of the glenohumeral ligaments and to evaluate the effect of plication on glenohumeral joint laxity and rotation.

Methods: A patient (39 y/o male) diagnosed with glenohumeral instability and scheduled for anterior capsular plication was prospectively evaluated. Three-dimensional surface meshes of the patient’s scapula, humerus, and capsule were extracted from the MR arthrogram (Mimics, Materialize, Ann Harbor, MI). The surface mesh of the capsule was imported into remodeling software that extracted a set of profile curves (Rhinoceros, Robert McNeel & Associates, Seattle, WA). These profile curves were then shortened to generate a new surface geometry that simulated surgical capsular plication of the anterior band of the inferior glenohumeral ligament (AB-IGHL). Three amounts of capsular plication were modeled: 0 mm, representing the native injured capsule state, 5 mm, and 15 mm (Figure 1) [3]. The capsule was meshed as linearly elastic quadrilateral shell elements. Two outcome metrics were evaluated for each repair scenario. Stability was evaluated via the clinical load and shift test by measuring the force required to translate the humeral head 23 mm to the glenoid edge. External rotation was measured as the rotation resulting from applying a 2 N•m torque to the humerus. These metrics were repeated for each surgical repair scenario at 0°, 30°, 60° of glenohumeral joint abduction (Abaqus/Explicit, SIMULIA, Providence, RI).

Results: The load and shift test showed that the force required to translate the humeral head to the glenoid edge increased with both increasing plication amounts and shoulder abduction angles. The maximum external rotation obtained when applying an external torque decreased with increased plication amounts but increased with larger shoulder abduction angles (Figure 2).

Discussion: The effect that different amounts of capsular plication has on tightening and stabilizing the glenohumeral joint was quantified in this study for various shoulder positions. For any given shoulder abduction angle, more plication increased the stability of the joint but also reduced the maximum achievable external rotation by increasing shoulder stiffness. The goal of this research is to develop a patient-specific computer model of shoulder instability that will accurately replicate the pathology when subjected to physiologic conditions. This study demonstrated the capability of this model to simulate different capsular plication amounts and the effect on laxity and rotation of the glenohumeral joint. Future work will incorporate non-linear anisotropic material properties and experimental validation.

Significance: This study used a patient-specific computer model developed from a patient with pathologic glenohumeral ligaments. As a result, the biomechanical response of the injured joint and the subsequent simulated repairs were more physiologically relevant than prior cadaveric studies. This modeling approach will provide insight for the practicing shoulder surgeon in their pre-operative surgical planning in their choice of technique and amount of plication for a patient with shoulder instability.

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Figure 1. Simulated capsular plication. (A) Lateral view of the glenohumeral joint with the humerus removed; gray is the scapula, yellow is the native capsule. (B) Zoomed in view of the profile curves that define the IGHL. The AB-IGHL that will be plicated is highlighted. (C) The shortened profile curve simulating capsular plication. (D) Surface geometry of the plicated glenohumeral capsule created from modifying the profile curves.

Figure 2. Stability-stiffness curves of the glenohumeral joint following glenohumeral plication of the AB-IGHL. X-axis is the force required to translate the humeral head to the glenoid edge during the load and shift test. Y-axis is the maximum external rotation obtained after applying a 2 N•m moment to the humerus. Colors represent capsular plication scenarios. Symbols represent tests performed at different shoulder abduction angles.

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