Shoulder Instability Computer Model Replicates Patient Range of Motion When Simulating Capsular Plication

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Introduction: In glenohumeral dislocation, the humeral head translates over the edge of the glenoid, permanently stretching the capsular ligaments, resulting in excessive joint laxity [1]. Various surgical techniques of capsular plication are currently used to treat recurrent dislocations. However, either shoulder stiffness from over-tightening or continued laxity from under-tightening are common shortcomings because optimal magnitude and direction of plication have not been established. Current surgical techniques are based on clinical experience and biomechanical cadaveric studies. A limitation of cadaveric research is the inability to accurately simulate injury to replicate the pathologic condition [2]. As a result, we have developed patient-specific computer models from patients with actual shoulder instability to accurately evaluate the effect of plication magnitude and location on joint range of motion and stability [3]. The purpose of this study was to compare computer simulation against the actual patient pre- and post-operative range of motion and stability measurements.

Methods: Three patients (23 ± 5 y.o.) diagnosed with glenohumeral instability and scheduled for surgical capsular plication were prospectively enrolled. Three-dimensional surface meshes of each patient’s scapula, humerus, labrum, and capsule were extracted from their MR arthrograms (Mimics, Materialize). Profile curves of the capsule mesh were extracted and shortened to simulate plication of the inferior glenohumeral ligament (Rhinoceros, McNeel) (Figure 1). A 3-D finite element model of the glenohumeral joint and surrounding soft tissue was constructed (Abaqus/Explicit, SIMULIA) [3]. The patient operative note was referenced to determine the location and amount of capsular plication to simulate. The clinical load and shift test was simulated to calculate the force required to translate the humeral head to the glenoid edge. Internal and external rotation were calculated with an axial 2 N•m torque applied to the humerus at 0° and 90° shoulder abduction. To validate the results of the computer simulation, the results were compared to the patient operative notes that recorded the pre- and post-operative range of motion and joint stability of the patient under anesthesia.

Results: The computer model calculated that shoulder stability increased and range of motion decreased following capsular plication for all three patients. The changes from the computer simulation were consistent with the operative notes. For joint stability, during the clinical exam, the humeral heads of all patients translated to the glenoid edge and became stable following capsular plication; the computer simulation calculated a 41.9 ± 22.7% increase in the force required to translate the humeral head to the glenoid edge. The average percent difference between the computer simulation and the operative notes for all range of motion measurements was 1.7 ± 15.5% (Figure 2).
Discussion: The goal of this research is to develop patient-specific computer models of shoulder instability that can accurately predict the effect of capsular plication on joint stability and range of motion. This study demonstrated that the magnitudes of the clinical outcome measures calculated by the computer model were consistent with actual patient data both before and following surgery for all shoulder positions. Future work will incorporate non-linear anisotropic material properties in order to further improve the accuracy between the computer model and clinical exam.

Significance: This study compared patient-specific computer models of shoulder instability to the actual patient range of motion pre- and post- surgery. This modeling approach can be used to provide insight to the practicing shoulder surgeon in their choice of surgical plication technique when performing pre-operative surgical planning for patients with shoulder instability.

Figure 1. Computer model of capsular plication. (A) Lateral view of the glenohumeral joint with the humerus removed; gray is the scapula, purple is the native capsule. (B) Zoomed in view of the profile curves that define the capsule. One curve that defines part of the AB-IGHL to be plicated is denoted with points. The patient operative note was referenced to determine the location and amount of capsular plication to simulate. (C) The shortened profile curve simulating capsular plication. (D) Surface geometry of the plicated glenohumeral capsule created from modifying the profile curves.

Figure 2. Shoulder range of motion for one representative patient. External rotation and internal rotation were measured for each patient in the operating room before and after capsular plication. The same procedure and range of motion tests were simulated in the computer model.

ORS 2015 Annual Meeting
Poster No: 1843