Improving the Neer and AO Classifications of Greater Tuberosity Fractures: A Computational Framework

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Introduction

Proximal humerus fractures are painful and debilitating injuries with an incidence rate that is expected to triple over the next thirty years.[1] Greater tuberosity (GT) fractures account for roughly 20% of proximal humerus fractures, and the vast majority of these injuries involve relatively small displacements of the GT bone fragment.[2] Traditionally, Charles Neer and the AO have classified the GT fragment as displaced (i.e. requires surgery) if it translates more than 5 mm from its anatomic position.[3] However, the Neer and AO classification systems do not take into account patient-specific anatomy, nor do they consider fragment orientation within the joint. The purpose of this study was to create a computational model that was capable of predicting subacromial impingement in patient-specific models. We hypothesized that the Neer and AO classification systems would not be able to accurately predict impingement in controlled simulations of GT fractures.

Methods

Eight intact fresh-frozen upper extremity cadaveric specimens were utilized in this preliminary study (3F, 1M; 60-70 y.o). Specimens were scanned in the anatomic pose with a clinical CT scanner using 0.5 mm axial slice thickness. Humeral and scapular geometries were segmented into 3-D renderings. Using a custom Matlab script, virtual bones were aligned to the International Society of Biomechanics shoulder coordinate system.[4] 3-D geometries were then inserted into a validated OpenSim shoulder model, which includes scapular rhythm during dynamic activities.[5] Virtual joints were adjusted to ensure they recapitulated patientspecific anatomy captured with CT scans. Specifically, we ensured that the humeral head was centered in the nadir of concavity of the glenoid and appropriate space was afforded between the proximal most point of the humerus and the inferior surface of the glenoid. Displaced GT fragments were created by slicing the humeri in the sagittal plane, 8mm medial to the lateral-most point of the GT. The GT fragments were systematically moved relative to the humerus with 4 different displacements (2.5, 5.0, 7.5, 10.0 mm) at 8 angles (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) (Fig 1A). Once models were assembled, passive ROM tests were performed. Specifically, the models sequentially performed abduction from 0°-180° at 22 different elevation planes (-90° – 120°) (Fig 1B). For each motion, a binary determination of contact between the GT fragment and the acromion was determined with the onboard elastic foundation subroutine within OpenSim.[6] The probability of impingement for each ROM test was calculated by dividing the number of positive impingement motions by the total number of motions in a ROM test (22).

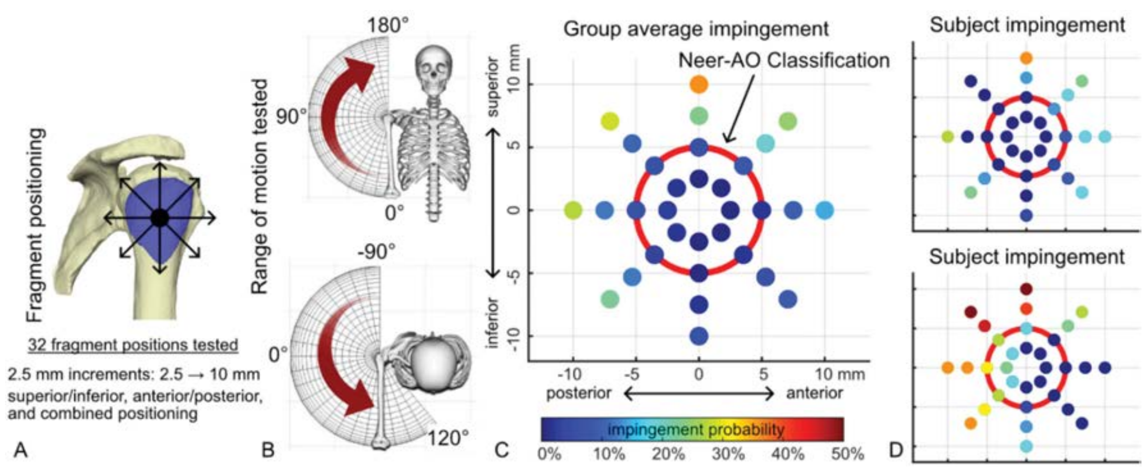

Figure 1. (A) The greater tuberosity fragment was iteratively positioned in 2.5 mm increments **(B)** and contact was simulated by creating abduction motions (top) in 22 different planes (-90° - 120°, bottom). **(C)** On average, fragment positioning of 5 mm or less from the anatomical position did not increase impingement probability. (D) While some individual specimens (top) had similar impingement profiles as the group average, other specimens bottom) experienced impingement with changes in fragment position as small as 2.5 mm.

Results

When averaging results from all 8 specimens, the average probability of impingement was 0.9%, 4.2%, 11.6%, and 21.1% for GT fragment displacements of 2.5, 5.0, 7.5 and 10.0 mm, respectively (Fig 1C). The majority of subacromial contact events occurred when arms were abducting in the 20°- 50° elevation planes. 7 out of 8 specimens did not experience impingement when the GT fragment was displaced 2.5 mm (Fig 1D, top). 2 out of 8 avoided impingement with 5.0 mm of GT fragment displacement. One specimen experienced impingement at all GT fragment displacement levels, but no impingements were detected when the fragment moved anteriorly, or antero-inferiorly (Fig 1D, bottom).

Discussion

The low values of 0.9% and 4.2% for average probability of impingement for the 2.5 and 5.0 mm displacements suggest that the Neer and AO classification systems may provide reasonable clinical guidelines for assessing displaced GT fractures.This finding somewhat nullifies our initial hypothesis, but it should be noted that several specimens in this small cohort of specimens clearly violated these guidelines. In this preliminary study there were large variabilities associated with measurements between specimens, which is to be expected with a human population. Further work is being done to incorporate a larger sample size.This model does not account for internal/external rotation of the humerus, muscle forces, or translation of the glenohumeral joint.All of these issues will be addressed in future iterations of the study.

Significant/Clinical Relevance

Subacromial impingent is difficult to predict with current standards of care, which include planar radiographs and rules-of-thumb that utilize gross displacement of the GT fragment. Precision medicine approaches, which may include 3-D imaging and computational modeling within the clinic, may allow for the accurate prediction of shoulder function following GT avulsions.

References

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