Parameterization of Proximal Humerus Locking Plate Impingement with In Vitro, In Silico, and In Vivo Techniques

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Introduction

Locked plating of displaced proximal humerus fractures is common, but rates of complications remain high.[1] Subacromial impingement of the plate is a frequent complication that can compromise range of motion, cause pain, and lead to revision surgery. Computational assessments of implant impingement have proven to be effective in arthroplasty procedures, but this space has yet to be sufficiently explored in proximal humerus fixation. The goal of this study was to utilize a multidisciplinary approach to elucidate the relationships between common surgical parameters, anatomical variability, and the likelihood of plate impingement.

Methods

Phase 1 - Cadaveric Experimentation

A controlled *in vitro* experiment was conducted to simulate impingement (Figure 1). Four cadaveric upper extremities (2M, 2F, mean age: 66.75 years) were used in this experiment. Shoulder joints were isolated and LCP Periarticular Proximal Humerus Plates (DePuy Synthes) were implanted per manufacturer protocols. Specimens were imaged with fluoroscopy and measurements were made for humeral head diameter, acromial tilt, and acromial slope. Motion capture retroreflective marker clusters were rigidly attached to the implant and scapula to track anatomic motion. A thin-film pressure sensor (i6900, Tekscan) was used to detect subacromial impingement. A custom-built jig was used to create simulated arm abduction, controlled by a universal testing frame (ElectroForce 3550, TA Instruments). A simple two body OpenSim model was created to calculate scapulohumeral joint angles using the inverse kinematics algorithm. Timed data from the pressure sensor measurements were synchronized with inverse kinematics output to identify shoulder joint angles during impingement.

Figure 1. Graphical depictions of the three phases of the experiment.

Phase 2 - Computational Simulations

A dynamic *in silico* musculoskeletal model was developed to simulate changes to implant geometry, surgical techniques, and acromial anatomy that may cause impingement. The locking plate was altered from a neutral position (−10 to +10 mm), and plate thickness was also changed (native bone to +5.0 mm thickness). Acromial tilt and acromial slope were changed between 20-35°.The model used a fixed ball joint to represent the shoulder.To simulate translation of the humeral head during motions, the center of rotation was moved to several discrete locations (neutral to +5.0 mm proximal). The 720 unique models simulated thoracohumeral abductions from 0-180°. The abductions were performed at 23 cross-body adduction angles, ranging from −90° to 130° in 10° increments. Incidence of simulated contact between the plate and acromion was detected with the on-board elastic foundation contact algorithm.

Phase 3 - In vivo measurements

With institutional review board approval and written informed consent, eight healthy subjects (4M, 4F, mean age 21.5 years) performed 9 activities of daily living. Upper extremity kinematics were recorded using a 12-camera motion capture system and reflective markers. Using a boot-strapping technique, 95% confidence intervals for cross-body adduction angle, abduction, and internal rotation were calculated for each ADL. Results were superimposed on Phase 2 results.

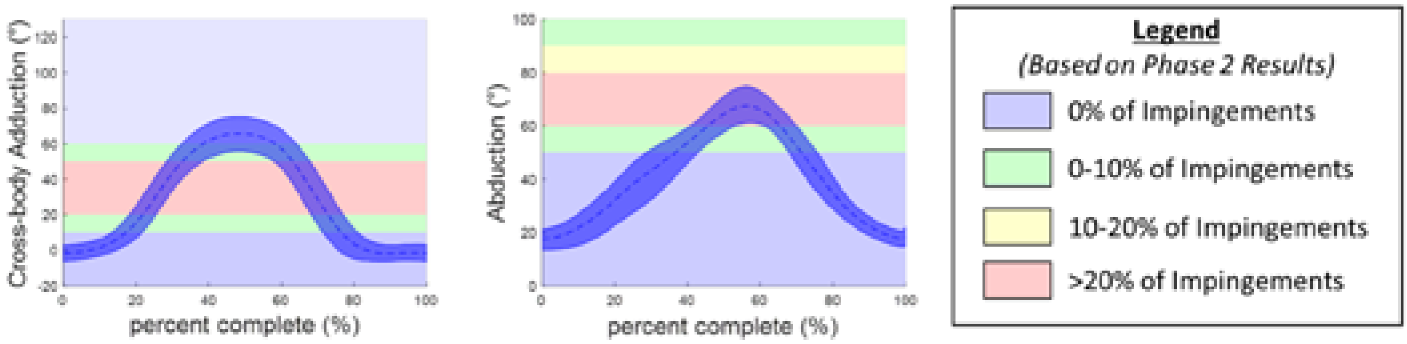

Figure 2. Plots of joint angles during a hair combing activity. The blue clouds represent 95% confidence intervals, based on in vivo data collection, and the colored bands in the background represent the likelihood of impingement in the in silico model.

Results

Impingement was measured at 73.3±14.5° abduction in the cadaveric model and 92.0±34.0° with computational simulations. Overhead activities involving 20-50° of cross-body adduction paired with 60°−80° abduction, similar to combing one's hair, were most likely to cause impingement (Figure 2). Simulation outputs demonstrated that superior implant placement, increases in plate thickness, superior translation of the humeral center of rotation, and increases in acromial tilt all increased the likelihood of impingement.

Discussion

The *in vitro* and *in silico* models used in this study produced results that very closely matched those from previous studies.[2-4] Differences can be attributed to the use of scapulohumeral angles in the cadaveric model, while thoracohumeral angles were used in the *in silico* and *in vivo* models. It is tempting to believe that the higher abduction angles observed in the computational model indicate a later onset of impingement. Interestingly, the opposite is true. When the scapular rhythm is accounted for, impingement occurs when the arm is positioned at approximately 118° of thoracohumeral abduction. This over-approximation in the cadaveric model is likely due to a lax capsule, which may have caused the humeral head to move posteriorly relative to the glenoid. This study has several limitations, as changes to the model's bone geometry may alter simulation results and ADLs measured in a young healthy population may not fully characterize post-operative ranges of motion.

Clinical Relevance

This study improves the biomechanical understanding of locking plate-subacromial impingement with a combination of *in vitro*, *in vivo*, and *in silico* models. It also provides valuable information to allow clinicians and rehabilitation specialists to better predict patient outcomes and better guide rehabilitation.

References

1. Clavert P, Adam P, Bevort A, *et al.* Pitfalls and complications with locking plate for proximal humerus fracture. *J Shoulder Elbow Surg.* 2010 Jun; 19(4):489-94.

2. Graichen H, Bonél H, Stammberger T, *et al.* Sex-specific differences of subacromial space width during abduction, with and without muscular activity, and correlation with anthropometric variables. *J Shoulder Elbow Surg.* 2001 Mar-Apr; 10(2):129-35.

3. Hughes PC, Green RA, Taylor NF. Measurement of subacromial impingement of the rotator cuff. *J Sci Med Sport.* 2012 Jan; 15(1):2-7.

4. Tasaki A, Nimura A, Nozaki T, *et al.* Quantitative and qualitative analyses of subacromial impingement by kinematic open MRI. *Knee Surg Sports Traumatol Arthrosc.* 2015 May; 23(5):1489-97.