Rotator Cuff Integrity In Reverse Shoulder Arthroplasty: Finite Element Analysis to Maximize Function and Stability, While Minimizing Acromial Fracture Risk

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INTRODUCTION: Controversy exists regarding the optimal reverse shoulder arthroplasty (RSA) implant configuration(s) to maximize impingement-free range of motion and prosthetic stability while minimizing risk of subsequent acromial or scapular spine fracture. Understanding of the biomechanical trade-offs between joint tensioning and acromial fracture risk continues to evolve. The purpose of this study was to use an RSA finite element analysis (FEA) to evaluate changes in joint compressive forces as well as acromial fracture risk with variations in glenoid component lateralization, humeral distalization, and rotator cuff integrity.

METHODS:

FEA was conducted to simulate scenarios of variable rotator cuff tear arthropathy (CTA) severity by varying rotator cuff integrity. The FEA incorporated the deltoid, subscapularis, infraspinatus, and teres minor tendon and muscle geometries, combined with a commercially available RSA system with an inlay humeral stem and 36 mm glenosphere. Simulations were performed with 0, 3, and 6 mm of glenoid component lateralization (Figure 1). Humeral-sided tensioning was also performed to include inlay and onlay geometries. The acromion was assigned representative scapula-specific bone properties. The influence of joint tensioning was evaluated by comparing joint contact force after virtual implantation of the RSA components and subsequent simulation of external rotation from neutral to 50°. Joint tensions were evaluated first for a baseline RSA configuration (0 mm glenoid lateralization, inlay humeral stem) with intact cuff and deltoid musculature, and then after progressive removal of cuff tendons to simulate different severities of CTA. For each rotator cuff configuration, acromial fracture risk was evaluated by quantifying the percentage of the total cortical bone region experiencing stresses above yield strength throughout rotation. To evaluate mechanical trade-offs with joint tensioning, glenohumeral contact force and acromial fracture risk for each rotator cuff configuration and through varying levels of glenoid lateralization and humeral distalization were compared to the intact cuff baseline RSA configuration.

RESULTS: For the baseline RSA configuration (0 mm lateralization), joint tension decreased with progressive removal of rotator cuff compared to the intact rotator cuff state, with absent: infraspinatus (4% decrease), subscapularis (58% decrease), infraspinatus and subscapularis (57% decrease), and all rotator cuff musculature absent (54% decrease) (Figure 2). Absent subscapularis resulted in the greatest decrease in joint tension compared to other rotator cuff deficient states. Glenohumeral contact force increased with progressive levels of glenoid lateralization. With 3 mm and 6 mm of glenoid lateralization, joint tension increased (41% and 71%), respectively, for all rotator cuff configurations compared to baseline configuration. In the setting of subscapularis deficiency, 6 mm of glenoid lateralization was able to restore joint tension to similar levels achieved with the subscapularis intact baseline RSA configuration (Figure 2). Acromial fracture risk was relatively similar across rotator cuff configurations (13.8% to 15.4%) with baseline glenoid lateralization (Figure 3). Increased joint tension with 3 mm glenoid lateralization did not influence acromion fracture risk, while additional tension of the deltoid with 6 mm of glenoid lateralization resulted in a marginal increase (0.2% to 1.8%) in the bone region at risk of fracture. With subscapularis deficiency, the onlay configuration with baseline glenoid lateralization achieved similar joint tension to the intact cuff baseline, but with the trade-off of considerably larger acromial regions experiencing stresses above yield strength.

DISCUSSION AND CONCLUSION:

The rotator cuff provides a compressive glenohumeral contact force that stabilizes the joint during motion. In patients with a deficient rotator cuff undergoing RSA, increased glenoid component lateralization and humeral distalization improves joint stability, but it may also increase acromial fracture risk. Conversely, lack of appropriate tension can lead to dislocation of the reconstructed glenohumeral joint. This FEA parametrically evaluated joint tension changes with implant lateralization and the corresponding changes in acromial stresses. These data demonstrate objective quantifiable evidence of the importance of rotator cuff integrity in joint stability and compressive forces in RSA with varying severity of CTA. In the setting of rotator cuff compromise, joint compression can be recovered to some extent with glenoid lateralization and humeral distalization. Acromial stress is increased more with humeral distalization as compared to glenoid lateralization. Data from this computational may help surgeons select the appropriate implant configuration based on patient clinical presentation to optimize joint tension and stability while limiting risk of acromial stress fracture.

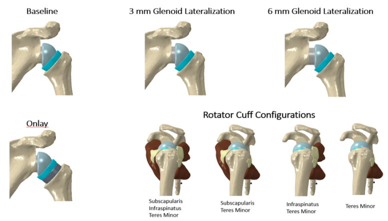
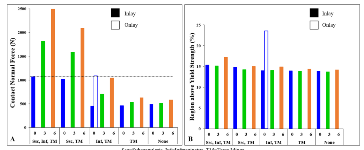


Figure 1. FEA model with baseline, 3mm and 6mm of glenoid lateralization, and inlay and onlay humeral configurations. Variable rotator cuff configurations illustrated.



Ssc=Subscapularis. Inf=Infraspinatus. TM=Teres Minor.

Figure 2. Joint Contact Force and Acromial Stress with 0mm, 3mm and 6mm glenoid lateralization.
Figure 2A: RSA joint contact forces varied by glenoid lateralization, rotator cuff integrity, and humeral inlay and onlay configurations.
Figure 2B: Acromial Stress varied by glenoid lateralization, rotator cuff integrity, and humeral inlay and onlay configurations.

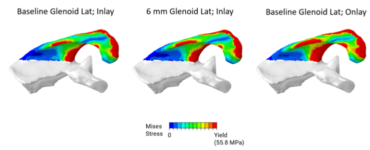


Figure 3. Acromial stress with Infraspinatus and Teres Minor intact with baseline and 6 mm glenoid lateralization, and inlay versus onlay humeral configuration.