Eccentric Joint Contact Loading Occurs after Total Shoulder Arthroplasty

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INTRODUCTION

The most common complication after a total shoulder arthroplasty (TSA) is glenoid loosening accounting for about 32% of all complications11. Glenoid implant retrieval studies show consistent wear and deformation in the posterior quadrant5, 7. Non-conforming implants formed new articulating concavities located postero-inferiorly or postero-superiorly from the original center of the glenoid bearing surface5. These wear patterns confirm the “rocking horse” phenomenon in that eccentric forces imparted by migration of the humeral head on the glenoid implant may cause tensile forces on the opposing side and as a result induce loss of glenoid fixation5.

These clinical retrieval studies suggest that glenoid component failure is associated with abnormal joint contact forces (JCF). However, little is known about the joint contact mechanics of the gleno-humeral joint. The objective of this study was to predict the gleno-humeral translations, joint contact force, and muscle activation patterns during abduction (a common activity of daily living) using a six degree of freedom computational shoulder model. To validate the model, the predicted results were compared with retrieval and other clinical findings.

METHODS AND MATERIALS:

To implement the inversely dynamic computational model, a digitized model of the anatomy of a cadaver was created (i.e. muscle origins/insertions, joint center, neutral position). A TSA reconstruction was performed on the cadaver with a non-conforming Biomet modular implant. The humeral head and glenoid implant diameters were 50mm and 76.2mm, respectively, and were modeled as spheres. The 2D projected surface of the normally pear-shaped glenoid was approximated as a rectangle. The eight muscles of interest were the anterior, posterior, and middle deltoids (AD, PD, MD), supraspinatus (SSP), infraspinatus (ISP), superior and inferior subscapularis (SSSC, ISSC), and the teres minor (TM). These muscles were chosen because they are active in abduction in the scapular plane (scaption)6.

The computational model requires inputs of the digitized anatomy, the lines of action of the muscles, and the desired position of the humerus in scaption. The outputs are: the muscle forces required to achieve the desired humeral position; the amount of humeral head translation; and the JCF vector. The model uses an optimization technique to determine the eight physiological muscle forces across the shoulder by minimizing $J$, which is the sum of the stresses, $\sigma$, cubed in the muscles6:

\[ J = \sum \sigma^3 \]

The biomechanics of the reconstructed gleno-humeral joint were analyzed under scaption from 20 to 60° where all the rotator cuff (RTC) muscles are functional.

RESULTS:

Figure 1 shows an anterior view of the glenoid implant with JCF vectors. The results predict superior edge loading of the glenoid implant at all angles of scaption after 20° (Fig. 1).

Figure 2 depicts a lateral view of the glenoid implant showing superior translation of the humeral head after 20° of scaption. Posterior translation occurred for all degrees of scaption (Fig. 2a). The contact location of the humeral head indicated eccentric loading in the superior and posterior quadrants of the glenoid implant (Fig. 2b).

DISCUSSION:

Glenoid retrieval studies found significant wear in the posterior quadrant of the glenoid implant, with wear in the superior and inferior quadrants equally likely5, 7. Radiographic studies measured superior subluxation of the humeral head in reconstructed shoulders even in the presence of all RTC muscles5. Radiolucent lines around the superior and inferior edges of the implant are common and indicative of glenoid loosening11, 12. Roentgenograms taken after a TSA showed significant posterior humeral head translation5.

Our model of a TSA with intact musculature was successful in corroborating these clinical findings. Significant eccentric superior and posterior translation of the humeral head occurs relative to the glenoid implant. This loading pattern supports the rocking horse phenomenon in both the supero-inferior and the antero-posterior directions.

The model predicts that all the included muscles except the TM play an important role in abducting and stabilizing the shoulder. The TM may not have been activated by our model due to its digitized line of action. The model is required to be in static equilibrium at each discrete scaption angle; as a result, as scaption angle increases, the total muscle force required to abduct the arm increases, and thus increases the resulting JCF. The magnitude of the JCF predicted from our model is less than what has been measured in vivo10. This may be due to our physical setup, which resulted in slightly larger moment arms for the deltoids, however our model is still able to predict muscle activation patterns that closely match EMG data5.

Limitations of this study include the use of a single cadaver, the restriction of motion in the scapular plane only, and lack of other soft tissue constraints. Despite these limitations, this model can be developed to understand better how the mechanics of the shoulder are altered post-TSA with RTC injuries and eventually mechanics of the native shoulder.

SIGNIFICANCE:

This study provides insight into the mechanisms of glenoid implant failure in total shoulder surgeries. Ultimately, these results can be applied to better design the glenoid implant.

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REFERENCES: