Lateralization of the Joint Center of Rotation of Reverse Total Shoulder Implants Produces Increased Loading Across the Glenosphere

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Introduction: Reverse total shoulder arthroplasty (RSA) was introduced to restore stability and function in challenging pathologies like rotator cuff (RC) arthropathies. Early designs were fully constrained where the glenoid component had a lateralized center of rotation (CoR). Those designs were prone to failure due to glenoid loosening[3]. Recent designs follow the Grammont concept where the CoR is medialized and located on the glenoid fixation. While these designs have become popular for addressing pathologies with irreparable RC tears they have been associated with scapular notching, limited internal/external range of motion, and poor aesthetic appeal. This has prompted renewed interest in implant designs that lateralize the joint CoR.

To address glenoid loosening concerns on reverse implants with lateralized CoR many studies have focused on the glenoid fixation[4], but have based their loads off the ASTM[1] standard for testing anatomic total shoulder implants. It has been demonstrated that reverse implants experience a different set of loads[7] but the effect of lateralizing the CoR of the implant on those loads has yet to be explored. The goal of this study was to determine the effect of a lateralized joint center of rotation on the contact forces experienced by the glenosphere.

Methods: The Newcastle Shoulder Model[5] was used to simulate motions in abduction, scapular plane elevation, and forward flexion. To match indications for an RSA, a large thickness rotator cuff tear was simulated, with all cuff muscles deactivated save the Teres Minor. The model was adapted to describe the geometry of RSA by using a commercially available reverse prosthesis (DELTA® III, DePuy) with a 36mm glenosphere diameter. Standard surgical guidelines were followed for the glenoid reaming and the fixation of the glenosphere (-5mm position). Four additional configurations were created by lateralizing the glenosphere (and CoR) in 5mm increments (c = 0, +5, +10, +15 positions - Fig 1). The model in its final state can predict muscle and joint contact forces using inverse dynamics and a static optimization method (minimization of squared muscle stresses). The joint contact forces acting on the glenosphere were decomposed into compression, superior/inferior (S/I) shear, and anterior/posterior (A/P) shear.

Results: The contact load magnitudes were sensitive to lateralization in both abduction and scapular plane elevation motions. In abduction, moving from the baseline (-5mm) to most lateralized (+15mm) positions led to a 46% increase in contact load. The compressive, S/I shear, and A/P shear components increased 43%, 38%, and 45%, respectively. For scapular plane abduction, the same lateralization led to a 28% increase in contact load, followed by compressive, S/I, and A/P shear component changes of 28%, 35%, and 48%. Forward flexion was the least sensitive to lateralization. It only resulted in a 2% change of contact force across the range of lateralization, with compressive, S/I, and A/P shear changes of 2%, 5%, and 4%. Moment arms of the Deltoid muscles for humeral elevation consistently decreased with lateralization for all planes of elevation tested. (Fig 3)

Discussion: The increases in joint contact force on the lateralized configurations may be explained by the associated decrease in the deltoids’ abduction moment arms. As the primary abductors in a cuff deficient shoulder, the shortened moment arms require larger deltoid forces to counteract the external torque in the joint. Forward flexion may be less sensitive to this effect partly due to the posterior deltoid, which remained an adductor independent of the center of rotation.

The model demonstrated that lateralization resulted in large increases on the forces crossing the implant in all directions. Additional shear forces generated by lateralization, along with the moment generated due to the lateralized joint center, create additional bending stresses at the bone implant interface that increase the risk of lossening due to the “rocking horse” effect. Future fixation studies on lateralized implants will need to use higher loads than those used on the medialized implants to reflect these increases in force. The effect of these increases will be exacerbated by an external load as demonstrated by Bergmann et al, who showed with an instrumented total shoulder that a 2kg weight at the hand resulted in double the joint contact load relative to unweighted motions[2].

The data has shown non-negligible shear loads in the Anterior/Posterior direction, although few studies investigate fixation performance under these loads. Stroud et al[6] performed a displacement test with a static 357N A/P load in concert with 50 N in compression. The study concluded that simulated osteoporotic bone loaded in this manner led to high strains (180±58 μm) that exceed the 150 μm physiologically acceptable threshold. Given the loads in the current study were...
comparable to these applied loads; we may infer that there is a risk of glenoid loosening in the A/P direction.

**Significance:** As reverse implant designs become more lateralized proper loads must be applied to them to test their fixation to the glenoid. This study has shown that these loads must be larger than those used to test fixation of medialized implants and that loading in the A/P direction must be included to assess the risk of glenoid loosening.

**Acknowledgments:**

**References:**

Figure 1: The resultant glenohumeral force ($F_{gh}$) is analyzed in its compressive ($F_{compressive}$), S/I shear ($F_{shear\_superior}$) and A/P shear (into the page, not shown) components. Both shear components can create a bending stress (‘rocking horse phenomenon’) to the bone-implant interface when the joint center is lateralized ($C>0$).