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Effect of lateral offset center of rotation in reverse total shoulder arthroplasty: a biomechanical study

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Background: Lateral offset center of rotation (COR) reduces the incidence of scapular notching and potentially increases external rotation range of motion (ROM) after reverse total shoulder arthroplasty (rTSA). The purpose of this study was to determine the biomechanical effects of changing COR on abduction and external rotation ROM, deltoid abduction force, and joint stability.
Materials and methods: A biomechanical shoulder simulator tested cadaveric shoulders before and after rTSA. Spacers shifted the COR laterally from baseline rTSA by 5, 10, and 15 mm. Outcome measures of resting abduction and external rotation ROM, and abduction and dislocation (lateral and anterior) forces were recorded.
Results: Resting abduction increased 20° vs native shoulders and was unaffected by COR lateralization. External rotation decreased after rTSA and was unaffected by COR lateralization. The deltoid force required for abduction significantly decreased 25% from native to baseline rTSA. COR lateralization progressively eliminated this mechanical advantage. Lateral dislocation required significantly less force than anterior dislocation after rTSA, and both dislocation forces increased with lateralization of the COR.
Conclusion: COR lateralization had no influence on ROM (adduction or external rotation) but significantly increased abduction and dislocation forces. This suggests the lower incidence of scapular notching may not be related to the amount of adduction deficit after lateral offset rTSA but may arise from limited impingement of the humeral component on the lateral scapula due to a change in joint geometry. Lateralization provides the benefit of increased joint stability, but at the cost of increasing deltoid abduction forces.
Level of evidence: Basic Science Study, Biomechanical Study.

Keywords: Shoulder simulator; reverse arthroplasty; lateral offset; center of rotation

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Reverse total shoulder arthroplasty (rTSA) reduces pain and improves function in arthritic, rotator cuff-deficient shoulders[2,5,13,30] and predictably improves shoulder forward elevation and external rotation range of motion (ROM), but these improvements are highly variable.[2,5,30] In

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addition, limitation of complications after rTSA, including instability and scapular notching, is a primary goal. Various patient and implant factors have been clinically associated with the variable ROM, notching rates, and rates of instability after rTSA.[2,5,7,10,14,18,25,30]

The Grammont-style rTSA is designed to shift the center of rotation (COR) of the glenohumeral joint inferiorly and medially with respect to the native joint, improving the efficiency of the deltoid.[6,12,18,29] Lateralizing the COR in rTSA has been suggested as a potential method to limit the degree of scapular notching and improve external ROM, and can be achieved by the design of extended or thicker glenosphere components[7,15] or through the use of autograft bone spacers.[5] Although clinical results suggest marked decreases in rates of scapular notching and modest improvements in external rotation ROM,[5-7] no biomechanical data document how lateral offset COR simultaneously influences ROM, abduction forces, and joint stability.

The purpose of the present study was to determine the effect of lateralizing the glenohumeral COR after rTSA on (1) glenohumeral abduction ROM in the scapular plane, (2) external rotation ROM of a flexed arm, (3) force required to abduct the arm, and (4) force required to dislocate the implant in the lateral and anterior directions. To evaluate these outcome measures, a biomechanical shoulder simulator, which was previously used to determine the effect of tension and version after rTSA,[18] was used to test human cadaveric shoulders before and after rTSA with a variable lateral offset glenohumeral COR.

Materials and methods

Specimen preparation

Six fresh frozen, unpaired upper extremities (3 men, 3 women; 3 right, 3 left) were obtained from donors who were a mean $\pm$ SD age of 60 $\pm$ 10 years and had a body weight (BW) of 70.3 $\pm$ 9.5 kg. Specimens were prepared as described previously[18] by embedding the scapula in a 2-part catalyzed polymer resin (3M, St. Paul, MN, USA). Image data from computed tomography (CT) scans were reconstructed using MIMICS (Materialise, Leuven, Belgium) to verify the orientation of the scapula within the embedding block. Bicortical pins were placed in the ulna and distal humerus to fix the elbow. Three lightweight, stretch-resistant, braided cords (300-pound [136-kg] test Spectra Fiber 2000, WSK, Pittsburgh, PA, USA) were affixed to the deltoid tuberosity to simulate the anterior, middle, and posterior heads of the deltoid. Similarly, Spectra cords were sutured to the insertions of the subscapularis (SSc), supraspinatus (SS), and infraspinatus/teres-minor (IS/TM) using No. 2 FiberWire (Arthrex, Naples, FL, USA).

Shoulder simulator

Specimens were tested on a biomechanical shoulder simulator described previously.[18] The embedding blocks were mounted in the machine so that the neutral plane of the glenoid was tilted 10° superiorly,[4,9] the scapula was tilted 10° anteriorly,[20,32] and the plane of the scapula was parallel to the applied deltoid loads. The pins in the humerus and ulna were used to externally fix the elbow to test the influence of straight and flexed (90°) arms. The wrist was splinted and wrapped in Coban (3M Corporation, St. Paul, MN, USA) to stabilize the forearm.

Deltoid lines were routed through custom pulleys that allowed degrees of freedom to prevent binding and dislocation of the dynamically changing lines of action.[18] Pulleys were suspended from the machine frame and positioned with reference to the coracoid, acromion, and scapular spine for the anterior, middle, and posterior deltoid, respectively. Anatomic landmarks were located by palpation. Rotator cuff lines were routed along the midline of the respective muscle bellies[20,32] and maintained by pulleys fixed to the embedding block.

The arm was manipulated by applying excursion forces to the deltoid lines via pneumatic cylinders (Bimba, Monee, IL, USA). Electromechanical encoders (Celesco, Chatsworth, CA, USA) monitored the position of the cylinders while in-line load cells (Omega Technologies, Stamford, CT, USA) recorded the applied force. The spatial position of the arm was quantified with optical tracking diode arrays mounted to the arm, and data were collected using a motion capture system (OptoTRAK 3020, Northern Digital, Waterloo, ON, Canada). The system was controlled by a custom application (LabVIEW 8.0, National Instruments Corp, Austin, TX, USA).

Experimental protocol

The experimental protocol was similar to our previous report.[18] A static 2% BW load (11.6 to 16.1 N) was applied to the actuators and each rotator cuff line (SSc, SS, IS/TM).[3,11,20,21,26,34] The arm was manually articulated through a physiologic ROM for calculation of the humeral head COR from spatial data using a least-squares method.[17,18,31] An abduction motion trajectory was recorded and played back for five cycles to obtain force/position data. For the flexed elbow, 16% BW (92.7 to 128.4 N) was applied to the IS/TM to induce external rotation. The SS and SSc remained at 2% BW. The order of testing for straight vs flexed arms was randomized using the random permuted blocks method.[23]

The native arm was tested in both the straight and flexed elbow conditions before implantation with an Aequalis Reverse Shoulder prosthesis (6.5 mm humeral stem, 36 mm glenosphere, Tornier, Edina, MN, USA) following Tornier's recommended surgical technique. The SSc was resected for implantation, but the line of action was retained at the insertion. The SS tendon was resected to simulate a disrupted rotator cuff. The IS/TM was retained to complete the experimental protocol, including external rotation after rTSA. Typically, rTSA is indicated when the SS and IS are both ruptured. The prosthesis was implanted with 10° humeral component retroversion by aligning the humeral insertion guide with the forearm. We used 10° as the baseline condition for direct comparison to a previous study.[18] The polymer insert (for joint tension) was selected subjectively to provide secure reduction of the joint that minimized gap formation (<2 mm) and implant levering throughout the ROM. Via these selection criteria, the 9 mm polymer insert was used for all specimens.

To test the influence of lateral offset COR, the Tornier prosthesis was modified. The glenoid baseplate was machined to add 3 threaded holes (No. 8-32) to secure spacers that shifted the joint COR laterally. These holes did not interfere with the normal bone−plate−screw interface or implantation technique. Three spacers (for 5, 10, and 15 mm lateral offset) were fabricated to mimic the tapered interface between the glenoid baseplate and the glenosphere, as well as the retaining screw securing the glenosphere (Fig. 1). The clearance holes for the No. 8-32 screws were countersunk into the spacers to provide a self-centering mechanism on the glenoid baseplate.

After rTSA, the arm was tested in the ''baseline'' condition (10° humeral retroversion, baseline polymer insert, no lateral offset COR) for the straight or flexed elbow (order randomized). After baseline, a lateral offset spacer was inserted between the glenoid baseplate and the glenosphere (order randomized). The glenosphere was then impacted and secured with the retaining screw before abduction testing. All 3 lateral offset COR spacers were tested before the elbow was reconfigured. Ten cases were examined for each specimen, comprising native straight elbow, native flexed elbow, 4 straight elbow rTSAs, and 4 flexed elbow rTSAs.

After the flexed elbow condition in rTSA cases, the force to dislocate the implant was tested.[18] The 2% BW load was applied to the SSc, the IS/TM, and the deltoid actuators. A Spectra line was fastened around the proximal humerus near the metaphysis of the humeral component. One investigator (H.H.) applied a manual force, through the Spectra line and an in-line load cell, to dislocate the implant. Lateral dislocation was performed with the arm at resting abduction in neutral external rotation. The load cell recorded the laterally applied force until a ∼5-mm gap formed between the glenosphere and the insert. Anterior dislocation was performed with the arm at resting abduction and 90° external rotation. The load cell recorded anteriorly directed forces until the humeral component released around the glenosphere. Eight dislocations were performed for each arm (4 lateral offset COR, lateral dislocation, anterior dislocation).

Data analysis

The outcome measures were humeral COR, resting abduction angle (increase vs native considered adduction deficit), cumulative deltoid force at 60° scapular plane abduction (sum of anterior, middle and posterior deltoid), external rotation at 60° scapular plane abduction (flexed elbow, deviation from neutral), and force to dislocate the implant. The 5 cycles of arm motion were averaged to generate a representative data set for each condition. Coefficients of variance over 5 cycles were 0.5% to 4% for resting abduction, 1% to 7% for external rotation, and 2% to 9% for deltoid force. All statistical comparisons used paired *t* tests at a significance level $P \leq .05$. Holm's step-down correction adjusted for multiple comparisons.[19] The paired *t* tests allowed for multiple comparisons to be made in lieu of analysis of variance and post hoc analysis. The sample size of 6 specimens was determined to provide statistical power of 0.8 based on a priori estimates of the effect sizes for the outcome variables from a previous study.[18] All data are presented as mean ± standard deviation, unless otherwise noted.

Results

Based on the scapular plane, the native COR was 0.4 ± 5.0 mm anterior, 5.7 ± 1.7 mm superior, and 19.9 ± 2.9 mm lateral to the center of the glenoid. The rTSA shifted the baseline COR posterior, inferior, and medial with respect to the native COR (Table I). Medial shifts were significant between lateral offset cases (all $P \leq .001$), but were only significant vs native for the baseline rTSA and +5 mm offsets (both $P \leq .021$). There were no differences in anterior/posterior (all $P \geq .165$) and superior/inferior shifts (all $P \geq .138$), but the inferior shift was significant for all rTSAs vs native COR (all $P \leq .038$).

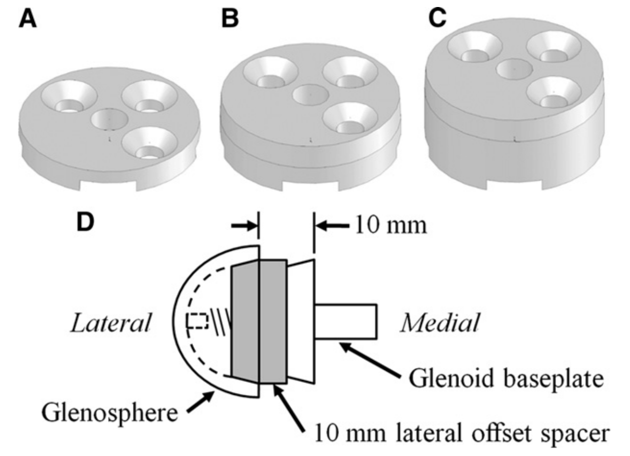

Figure 1 Schematic of custom lateral (**A**) 5-mm, (**B**) 10-mm, and (**C**) 15-mm offset spacers. (**D**) Representation shows assembly with a 10-mm offset spacer in place between the fixed glenoid baseplate and the lateral offset glenosphere.

Resting abduction angles increased approximately 20° for the baseline and all lateral offset COR rTSA cases vs native (all $P \leq .006$, Fig. 2, *A*). No differences in resting abduction were detected between any rTSA cases (all $P \geq .377$). When 16% BW was applied to the IS/TM, native arms externally rotated up to 20° from neutral at 60° scapular plane abduction (Fig. 2, *B*). The rTSA resulted in deficient external rotation compared with the native shoulders (all $P \leq .018$), but no differences were detected among the rTSA cases (all $P \geq .783$).

Cumulative deltoid force to achieve 60° abduction in the scapular plane decreased approximately 25% for baseline rTSA compared with the native shoulder (Fig. 3).[12,18,29] The deltoid force to abduct the arm subsequently increased in a step-wise fashion as lateral offset was added to the COR. This change was significant between all lateral offset cases tested (all $P \leq .018$). However, only the baseline rTSA and +5 mm lateral offset cases significantly decreased compared with the native shoulders (both $P \leq .049$). In native shoulders, the anterior, middle and posterior heads of the deltoid assumed 22.8% ± 6.3%, 58.8% ± 8.1%, and 18.4% ± 4.6% of the cumulative deltoid load, respectively. After rTSA, the load distribution shifted to 22.0% ± 7.9%, 52.1% ± 7.6%, and 25.9% ± 4.4% for the anterior, middle, and posterior deltoid, respectively. Compared with the native shoulder, rTSA caused no change in anterior deltoid load (all $P \geq .071$), but the middle deltoid force decreased (all $P \leq .036$) and the posterior deltoid

Table I Change in joint center of rotation after reverse arthroplasty, with values (mean ± standard deviation) reported with respect to preoperative center of rotation

First author (year)	Implant	X, mm (anterior +)	Y, mm (superior +)	Z, mm (medial +)
Present study	Tornier*			
Baseline		−0.6 ± 1.7	−9.7 ± 3.5†	17.3 ± 1.8†,‡
+5-mm offset				11.6 ± 2.3†,‡
+10-mm offset				6.1 ± 2.2‡
+15-mm offset				0.7 ± 2.8‡
Henninger[18] (2011)	Tornier*	3.0 ± 2.0	−12.3 ± 3.6	17.4 ± 4.3
Ackland[1] (2010)	Zimmer§	—	−9.5 ± 4.1	20.9 ± 3.9
De Wilde[8] (2005)	Delta¶	0 ± 0	−5 ± 1.0	28 ± 1.0
Saltzman[27] (2010)	Delta¶	0.2 ± 1.3	−6.9 ± 3.1	19.3 ± 2.5
Saltzman[27] (2010)	Encore‖	−0.4 ± 1.3	−2.0 ± 3.0	28.0 ± 3.3

* Tornier, Edina, MN, USA.
† Significant with respect to native.
‡ Significant between offset center of rotation.
§ Zimmer, Inc., Warsaw, IN, USA.
¶ DePuy International Ltd, Leeds, UK.
‖ Encore Orthopedics, Austin, TX, USA.

force increased (all $P \leq .050$). There were no differences in load sharing between offset COR cases (all $P \geq .105$).

For all rTSA cases, the forces necessary to create lateral dislocation were lower than their anterior counterparts (all $P \leq .035$, Fig. 4). Increasing lateral offset COR resulted in a step-wise trend, with increasing force to create a lateral dislocation. The changes were significant (all $P \leq .033$) for all but 2 cases (baseline COR vs +5 mm, and +10 vs +15 mm, both $P \geq .064$). The force to create anterior dislocation showed a step-wise trend with increasing lateral offset, but only the baseline COR vs +10-mm case was significant ($P = .015$, all other $P \geq .343$).

Discussion

The purpose of this study was to determine how lateralizing the glenosphere (and COR) in rTSA affected ROM (abduction and external rotation), deltoid abduction force, and joint stability. Lateralization of the COR after rTSA had no effect on ROM. Conversely, lateralization required increased deltoid force to abduct the arm and also increased the force required for dislocation both in anterior and lateral directions.

Similar to previous reports, the glenohumeral COR was shifted inferiorly and medially after rTSA (Table I).[8,12,18,27,29] The calculated COR was lateralized incrementally as lateral offset spacers were added, validating that the intended intervention was achieved. Because no anterior/posterior and superior/inferior differences were detected among the lateral offset cases, the effects measured in this study are likely attributed to the lateral offset intervention.

The first major finding was that lateral offset COR did not influence resting abduction (Fig. 2, *A*). The magnitude of adduction deficit created after the baseline rTSA compared with the normal shoulder was in good agreement with our previous study of humeral version and joint tension (∼20°), supporting the repeatability and reliability of the experimental technique.[18] Although version and tension both strongly influenced the adduction deficit,[18] lateral offset COR had a minimal affect (<3°). To reduce the adduction deficit, alternative strategies such as inferior glenosphere tilt/position, steeper humeral neck-shaft angles, or lateralization with alternative implant designs, such as the Encore Reverse Shoulder Prosthesis (RSP; (Encore, Austin, TX, USA), may be used.[14]

Although lateral offset COR reduced the rates of clinical scapular notching,[6,7] the present results suggest a reduction in notching is unlikely to have resulted from increased adduction ROM. Gutierrez et al[16] noted that lateralization resulted in the formation of a gap between the humeral component and the lateral scapula border in an in vitro model, limiting the ability of the humeral component to impinge upon the scapula. The use of computational and in vitro analyses of absolute abduction ROM in a bone surrogate model showed that rTSA resulted in an adduction deficit of at least 25° when no lateral offset COR was added,[14,15] which agrees with data for our baseline rTSA (Fig. 2, *A*). In contrast to our data (Fig. 2, *A*), adduction deficit decreased with lateral offset COR on the bone surrogate.[14,15]

Significant differences in experimental methods may explain the perceived opposing influence of lateral offset COR between our results and Guiterrez et al.[14,15] First, the present study used a soft tissue−constrained cadaveric model in which joint tension influences the adduction deficit.[18] The presence of native deltoid tension may have prevented the increased adduction that was possible after lateral offset COR in the bone surrogate models.[14,15]

Second, the present model was configured with a 10° superior glenoid tilt to mimic the anatomic resting position

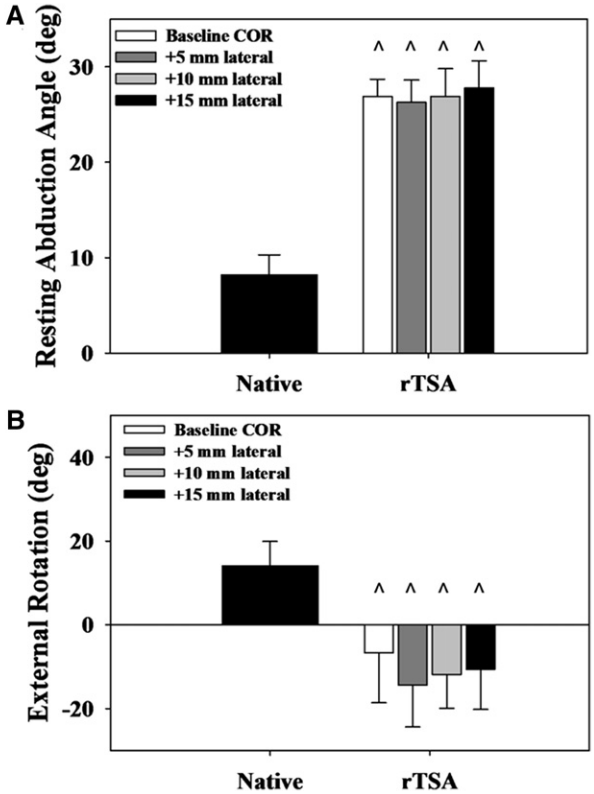

Figure 2 Range of motion in native shoulders and shoulders after reverse total shoulder arthroplasty (*rTSA*). (**A**) The rTSA resulted in significantly increased resting abduction angles vs native arms (^), where applied loads and scapular orientation were otherwise constant. Lateral offset center of rotation (*COR*) had no significant effect on resting abduction. (**B**) External rotation after rTSA (at 60° scapular plane abduction, 16% BW applied to the infraspinatus/teres-minor) resulted in deficient external rotation vs the native arms (^). Lateral offset COR had no significant effect on the degree of external rotation. Mean data are shown with the standard error of the mean (*error bars*).

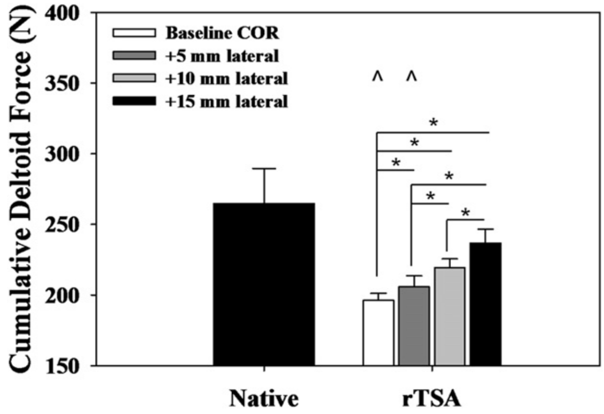

Figure 3 Cumulative deltoid force at 60° scapular plane abduction. Reverse total shoulder arthroplasty (*rTSA*) significantly reduced the force required to abduct the arm for baseline and +5 mm center of rotation (*COR*) offset cases vs the native arms (^). Lateral offset COR resulted in a step-wise increase in abduction force, which was significant for all cases examined (*). Mean data are shown with the standard error of the mean (*error bars*).

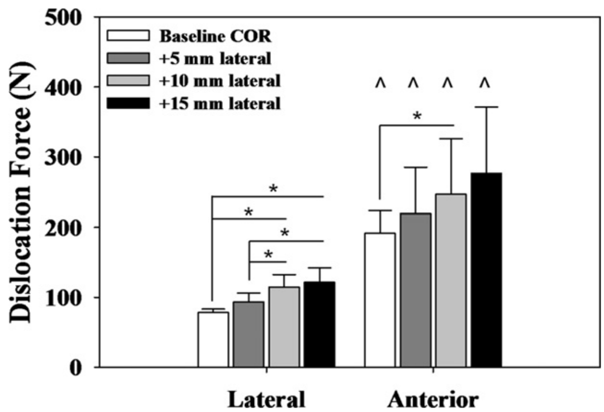

Figure 4 Force required to dislocate the reverse total shoulder arthroplasty laterally (in neutral external rotation) and anteriorly (in 90° external rotation). Lateral dislocation required significantly less force than anterior dislocation for all lateral offset center of rotation (*COR*) cases (^). Lateral dislocation force exhibited a step-wise increase with lateral offset COR, which was significant for most combinations tested (*). Anterior dislocation exhibited a similar trend but showed limited statistical significance (*). Mean data are shown with the standard deviation (*error bars*).

of the scapula, and the glenosphere was mounted flush to the glenoid, with no additional tilt. The previous models oriented the glenoid vertically.[14,15] This difference may have affected the gross magnitude of the adduction by shifting the position of the lateral scapula border with respect to the vertical plane.

Finally, inherent differences in the implant design exist between the Tornier Aequalis and the Encore RSP. The Aequalis uses a hemispherical glenosphere that was offset using a cylindrical spacer, whereas the RSP features a more spherical glenosphere that potentially allows more inferior clearance for the humeral component.

Scapular reorientation after rTSA may also affect the incidence of inferior impingement, and subsequently, scapular notching rates. This effect could not be modeled in the present study because the scapula was held in a constant resting orientation and did not allow for scapulothoracic rotation. Whatever the mechanism, it is unlikely that a change in adduction deficit with lateralization is the cause for the decreased notching rates.

The second finding was that rTSA, independent of lateral offset, led to deficient external rotation ROM with respect to native shoulders (Fig. 2, *B*). We showed previously that humeral version and joint tension have a limited effect on external rotation ROM.[18] Similarly, COR lateralization does not significantly improve external rotation after rTSA. Note that the ''native'' condition in the present model assumed normal cuff force production; thus, differences with respect to native do not account for reduced force production in pathologic rotator cuffs. Our data are contrary to recent clinical series showing an improvement in external rotation with lateral offset COR.[5,7] Bolieau et al[5] determined that external rotation improved by an average of 5° after rTSA for cuff tear arthropathy without lateralization but improved 10° after rTSA with 10 mm of lateral offset. Similarly, Cuff et al[7] found COR lateralization improved external rotation up to 15°. It is possible that the simplified nature of the present model was not able to capture physiologic variables like the in vivo muscle length/tension relationship, which may be important in improving the efficacy of the IS/TM to induce external rotation.

The third finding was that the deltoid force required for abduction decreased for the baseline rTSA but increased step-wise with lateral offset COR (Fig. 3). The baseline rTSA was in good agreement with our previous report (~25% increase in deltoid efficiency vs native), supporting the reliability and repeatability of the experimental technique.[18] Whereas changing humeral version and joint tension did not significantly alter abduction forces,[18] COR lateralization clearly required additional force to elevate the arm. This suggests the mechanical advantage for abduction in rTSA is compromised as lateral offset is added to the COR, as modeled in this study. The loss of mechanical advantage may also be seen in the percentage of load shared between the anterior, middle, and posterior deltoid. Our results indicate that middle deltoid load slightly decreased, but load sharing for the posterior deltoid, not normally considered an active elevator muscle, increased nearly 8%. Anterior deltoid load sharing was unaffected. Because the simulated deltoid lines were unchanged between tests, this change in load sharing, coupled with higher abduction forces, points towards the lateral offset COR as the primary source of the change.

Increased deltoid force may have clinical implications after rTSA. Increased forces could lengthen the time to recover normal abduction after surgery or increase the risk of acromial stress fractures. Also, increased deltoid forces over a long period may lead to deltoid-related pain and accelerate the decline in function that has been reported to occur approximately 6 years after implantation.[13] In addition, lateral offset COR could accelerate the progression of glenoid component loosening due to larger moment arms and higher forces applied to the bone/plate/screw interface at the glenoid. More research is required to clarify these relationships in vitro and in clinical populations.

The final finding of this study was that the forces required to dislocate the shoulder increased with a lateral offset COR (Fig. 4). Similar to our previous study, lateral dislocation forces were significantly lower than the anterior dislocation forces when tested under the same conditions.[18] This again supports that a lateral dislocation mechanism may be a primary source of joint instability, aggravated by inferior impingement, and surgeons should assess lateral stability during rTSA procedures. In contrast to the previous study, where changes in humeral version and joint tension had relatively little influence on stability, lateral offset COR resulted in a step-wise increase in forces necessary to initiate dislocation. Because lateral offset COR did not significantly affect the adduction deficit in the present model, it may indicate that lateralizing the COR is an important factor in improving joint stability without negatively affecting ROM.

The use of a biomechanical simulator has recognized limitations.[4,18,21,24,31] The in vitro model is unable to capture active muscle contraction, changes in muscle length/tension relationships, or proprioceptive control and dynamically changing muscle lines of action. Because scapulothoracic motion was not modeled, all measures of force and external rotation were taken at 60° scapular plane elevation to simulate 90° abduction, assuming a 2:1 scapulohumeral rhythm.[22,28] Also, static rotator cuff loads were estimated from physiologic models,[33] but these data may not be applicable to patients with rotator cuff arthropathy because they present with compromised rotator cuff tissue. The fully loaded IS/TM was retained throughout the experiment, which may overestimate external rotation ROM. Because external rotation was significantly deficient in the implanted compared with native shoulders, this further emphasizes the need to optimize rTSA design to improve external rotation ROM.

The outcome measures presented might be significantly different if COR were altered in the presence of alternative polymer inserts and humeral versions. Because the study was designed to focus on the influence of lateral offset COR, restricting other variables provided estimates of the effect sizes due to lateral offset COR alone. Additional work is needed to fully characterize the outcomes of all possible combinations of intra-operative variables.

Finally, the present results are only relevant to the modified Tornier Aequalis Reverse shoulder prosthesis or similar prostheses. The Encore RSP has the option to significantly increase lateralization by changing the glenosphere as well as the humeral components. The significantly different geometry of the RSP means the conclusions we present may not be applicable.

Because these limitations restrict our ability to directly apply the findings to clinical populations, the study was designed with internal controls to test how lateral offset COR affected ROM and forces in the rTSA shoulder. The absolute magnitudes of the data should be interpreted with caution, but the relative effects of the lateral offset on abduction and dislocation forces, as well as ROM, are considered reliable given that boundary conditions were held constant between test cases.

Conclusions

Lateral offset COR after rTSA had no effect on adduction deficit or the ability to externally rotate the arm; therefore, perceived gains in clinical ROM (adduction or external rotation) may not be solely attributable to the presence of the lateral offset. In contrast, adding lateral offset to the COR increased forces necessary for abduction. Although lateral offset COR may limit the clinical incidence of scapular notching, the increase in required deltoid abduction force and the moment arm about the glenoid may have unintended consequences, including potential lengthening of recovery time and increased risk for deltoid related pain, acromial stress fractures, and glenoid component loosening. Finally, improved joint stability (increased dislocation force) was observed with a lateral offset COR and did not sacrifice ROM. Consequently, lateral offset COR may be an important tool to reduce the incidence of instability after rTSA, but with knowledge that increased stability may come at the cost of higher forces placed on the glenoid baseplate and increased deltoid abduction forces.

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