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# Lateralization has minimal biomechanical impact on tuberosity fixation with the use of a stem-based repair and a 135° humeral implant in reverse shoulder arthroplasty for 4-part proximal humerus fracture

Michael J. Bercik Jr., MD[a,*], Patrick Denard, MD[b], Michelle H. McGarry, MS[c], Genevieve Fraipont, BA[c], Victor T. Hung, BS[c], Thay Q. Lee, PhD[c], ShARC Group[d]

[a]Lancaster Orthopedic Group, Lancaster, PA, USA
[b]Oregon Shoulder Institute, Medford, OR, USA
[c]Orthopedic Biomechanics Laboratory, Congress Medical Foundation, Pasadena, CA, USA
[d]Naples, FL, USA

A R T I C L E I N F O

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*Level of evidence:* Basic Science Study; Biomechanics

**Background:** Lateralization in reverse shoulder arthroplasty (RSA) has many proven and potential benefits. Concern over the increase in tension on the tuberosities imparted by glenoid lateralization and the subsequent effect on tuberosity healing may limit its use in the setting of RSA performed for fracture. This study evaluated whether glenoid lateralization increased tuberosity fracture gapping in a biomechanical model of a 4-part proximal humerus fracture with a stem-based tuberosity repair. We hypothesized that increased lateralization would increase fracture gapping.
**Methods:** Eight cadaveric shoulders (mean age, 62 +/− 2.4 years; range 52-70 years) were tested with a custom testing system that permits loading of rotator cuff muscles and humerothoracic muscles. A 4-part proximal humerus fracture was simulated and then repaired with a stem-based tuberosity repair. The repaired tuberosities were cycled in internal and external rotation with 1.1-Nm torque at 2 mm and 6 mm of glenoid lateralization. For the 6-mm lateralization RSA, the torque was then increased to reach the range of motion (ROM) values achieved with the 2-mm lateralized RSA and cycled 10 times, followed by doubling the torque values for 10 cycles. ROM, muscle length and fracture gapping were assessed at 2 mm and 6 mm of glenoid lateralization.
**Results:** Internal rotation and total ROM demonstrated a significant decrease in the 6-mm RSA when compared to the 2-mm RSA ($P < .05$). The 6-mm lateralized RSA significantly increased rotator cuff muscle lengths when compared to the 2-mm lateralized RSA condition except for infraspinatus by an average of 2.7 ± 1.9 mm ($P < .05$). There was no significant gapping of the proximal fracture for any condition. There was a significant increase in the gapping of the distal fracture gap in the 6-mm lateralized component condition only after 10 cycles of doubled rotational torque, which measured 1.9 ± 1.5 mm ($P = .031$).
**Discussion:** We hypothesized that lateralization would increase fracture gapping. Fracture gapping did not occur proximally and only occurred at a slight amount distally after 10 cycles of doubled rotational torque. This may have implications on the choice of glenoid components when performing a RSA for fracture.



Reverse shoulder arthroplasty (RSA) designs have been evolving toward increased lateralization and lower neck-shaft angles with the aim of decreasing scapular notching and potentially increasing range of motion (ROM). Recent studies have demonstrated good clinical outcomes with lateralized components and lower rates of scapular notching.[8,11] While improvements in ROM have been less clearly delineated, Werner et al demonstrated an improvement in internal rotation (IR) with lateralized components.[19] Given the potential and defined clinical benefits of lateralization, surgeons continue to use lateralized implants with increasing frequency and with growing amounts of lateralization in their elective shoulder arthroplasty cases.

The indications for RSA have expanded to include 4-part proximal humerus fractures. While many surgeons lateralize

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*Corresponding author: Michael J. Bercik, MD, Lancaster Orthopedic Group, 231 Granite Run Drive, Lancaster, PA 17603, USA.
*E-mail address:* mbercik@lancasterortho.com (M.J. Bercik).

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**Figure 1** Photograph of a left specimen mounted on the custom shoulder testing system.

with their primary arthroplasty patients, they may be less inclined to do so in the setting of fracture repair, given the concerns over tuberosity healing with increased tension on the tuberosity fragments; there has been some concern that glenoid-sided lateralization decreases tuberosity healing.[17] However, tuberosity healing may also be impacted by repair construct. Stem-based repairs and circumferential techniques, for instance, improve biomechanics of tuberosity repair and may thus be able to better withstand lateralization.

The purpose of this study was to evaluate whether glenoid lateralization increased tuberosity fracture gapping in a biomechanical model of a 4-part proximal humerus fracture with a stem-based tuberosity repair. We hypothesized that increased lateralization would lead to an increase in fracture gapping.

## Materials and methods

### *Specimen preparation*

Eight fresh-frozen cadaveric shoulders (mean age, 62 +/− 2.4 years; range 52-70 years) were tested with a custom testing system that permits loading of rotator cuff muscles and humerothoracic muscles. All specimens were screened for rotator cuff tears or trauma. The humerus was transected 2-cm distal to the deltoid tuberosity and all soft tissues were removed leaving the tendinous insertions of the deltoid, supraspinatus, infraspinatus, subscapularis, and teres minor. Suture loops to be used for muscle loading were made using No. 2 FiberWire (Arthrex Inc, Naples, Fl, USA) on the insertions of the tendons. On the scapula, the glenoid labrum and coracoacromial and acromioclavicular ligaments were preserved. The scapula was mounted onto an aluminum bracket, placed in the infraspinatus fossa.

### *Shoulder testing setup*

The scapula was mounted on the custom shoulder testing system in the anatomic position with 20° of anterior tilt (Fig. 1). An aluminum rod was inserted into the medullary canal of the humeral shaft and secured with peripheral screws. This rod was then placed through a hollow digital goniometer (Novotechnik, Southborough, MA, USA) attached to the custom testing system. The humeral rod was attached to an arc and positioned in 20° of glenohumeral abduction. The humeral articular margin was aligned parallel to the glenoid surface to define 0° of humeral rotation.

FiberWire sutures were tied to the suture loops previously placed on each muscle tendon and were passed through custom plates designed to replicate each muscles' origin. The FiberWire cables were loaded using pulleys positioned to align the orientation of the tension force along the orientation of the tendon fibers at the central portion of its respective osseous origin. A balanced muscle loading scheme for all testing condition was used—5 N for each line of pull on (1) anterior and (2) posterior supraspinatus, (3) superior and (4) inferior subscapularis, (5) infraspinatus, (6) teres minor, and (7) anterior, (8) middle, (9) posterior deltoid. This scheme employed a quasi-static design that was previously validated.[18]

### *Biomechanical testing*

Before the creation of a 4-part fracture and implantation of a RSA, the intact specimen was first positioned at 45° of IR and 45° of external rotation (ER) to determine the muscle lengths at this position. For IR, stoppers were then placed on the cables attached to the infraspinatus and the teres minor to prevent further muscle excursion. For ER, stoppers were placed on the 2 lines of pull for the subscapularis. Following placing the stoppers, the amount of torque in IR and ER was measured with a torque wrench using 1.1 Nm. The relatively low muscle loads and IR and ER torques were based on preliminary studies to maximize the quantitative information without compromising the specimen construct. The loading scenario in this study utilizes force couple principles with physiological cross-sectional area ratios. The number of the pulleys was based on the width of each muscle to simulate the direction of the muscle pull. The muscle lengths, the distance from the suture attachment on the tendon to the muscle loading origin plates, were then digitized at neutral rotation using the MicroScribe 3DLX (Revware, Raleigh, NC, USA).

### *Four-part proximal humerus fracture*

A 4-part proximal humerus fracture was simulated. First, the lesser tuberosity was osteotomized with a starting point in the medial bicipital groove. The humeral head was then removed with an anatomical saw cut. The humeral articular margin was defined by the location just medial to the insertion of the cuff. The saw cut was made by a fellowship-trained shoulder surgeon at this location. This is demonstrated in Figure 2. The greater tuberosity was osteotomized with a vertical saw cut just medial to the insertion of the rotator cuff tendons. The 4-part fracture was then completed with a transverse saw cut at the surgical neck. The 4-part proximal humerus fracture simulation was performed by 1 of 2 fellowship-trained Shoulder surgeons (Fig. 2).

### *Surgical procedure for the RSA*

A 135° humeral stem (Univers Revers; Arthrex Inc., Naples, FL, USA) was implanted into the proximal humerus. All specimens were prepared via a press fit and cementation was not required for rotational control. Once the implant was impacted into the

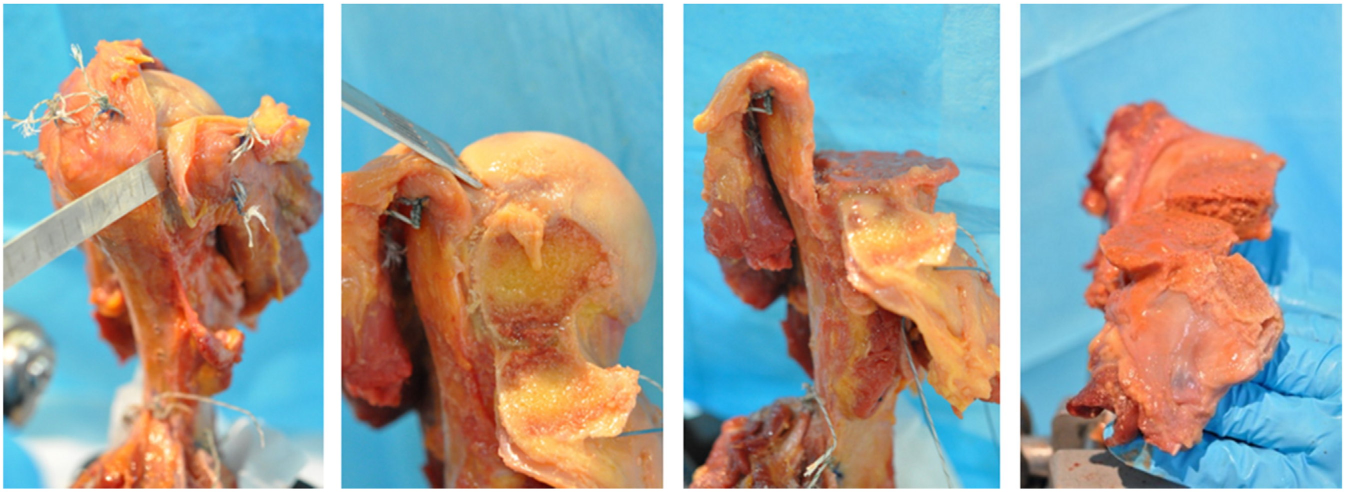

**Figure 2** Photographs showing creation of the 4-part proximal humerus fracture.

appropriate position, the 4-part fracture was repaired to the humeral prosthesis using a stem-based repair (FxBridge; Arthrex Inc., Naples, FL, USA). This repair technique uses the holes within the humeral cup of the RSA component to link the stem to the lesser and greater tuberosities. Two SutureTapes (Arthrex Inc., Naples, FL, USA) are also used through the medullary canal to provide vertical stability (Fig. 3).

In the scapula, a circular baseplate with 2 mm of lateralization (Univers Revers Modular Glenoid System; Arthrex, Inc., Naples, FL, USA) was impacted into the glenoid. This was positioned across all specimens such that the inferior aspect of a 36-mm glenosphere would be in-line with the inferior aspect of the glenoid. Minimal reaming was performed; the glenoid was reamed only to allow the boss of the medial aspect of the baseplate into the bone. The baseplate was then further reinforced with superior and inferior 36-mm locking screws.

Following implantation of the RSA and fracture fixation, 2 conditions were then tested: (1) RSA with neutral glenosphere (2-mm total lateralization) and (2) RSA with a 4-mm lateralized glenosphere (6-mm total lateralization). First, 4 markers were placed approximately 5-mm anterior and posterior to the fracture line, proximally and distally, and digitized with MicroScribe 3DLX. The 4 points for measuring the gapping between the anterior and posterior fragments on the humerus were first digitized to set a baseline for tuberosity fracture position before the application of any rotational torque. The proximal humerus was then rotated in IR and ER to a maximal torque of 1.1 Nm. This amount of torque was adequate to reach a repeatedly consistent endpoint for rotation. The external and IR degrees were determined at this point. The 4 points on the humerus were then redigitized to assess for any fracture gapping of the tuberosities.

The neutral glenosphere was then replaced with a 4-mm lateralized glenosphere to create a total of 6 mm of lateralization. Similarly, the marking points were digitized before applying rotational torque. The proximal humerus was then rotated in IR and ER to a maximal torque of 1.1 Nm and the degrees of rotation were measured. The points on the humerus were then remeasured to assess for any fracture gapping of the tuberosities. The torque was then increased such that the lateralized construct was rotated to the same internal and ERs achieved by the neutral construct. The increased torque required to achieve this was documented and the points on the humerus were redigitized to assess for any fracture gapping. This increased torque was cycled to 10 times in both IR and ER, and the fracture gap markers were digitized.

Lastly, the humerus was cycled 10 times internally and externally to twice the amount of torque required to achieve the same IR and ERs. Humeral points were collected to measure fracture gaps. (Fig. 4)

*Data analysis*

All measurements were performed twice, and the means was used for data analysis. Data are reported as the mean and the standard deviation. ROM and muscle length data passed the Shapiro-Wilk test for normality; however, majority of the gap data were not normally distributed. Therefore, a paired t-test was used to compare the normally distributed data and a Wilcoxon signed rank tested for paired samples was used to compare non-normally distributed data. $P < .05$ was considered significant.

## Results

*Humeral ROM*

For the native glenohumeral joint, the average IR was $44.6 \pm 3.0°$ and the average ER was $44.5 \pm 2.3°$. For the 2-mm lateralized RSA condition, the average IR was $66.5 \pm 18.3°$ and the average ER was $31.2 \pm 16.4°$. For the 6-mm lateralized RSA condition, the average IR was $60.9 \pm 20.7°$ and the average ER was $31.8 \pm 14.6°$. The IR and total range of motion demonstrated a significant decrease in the 6-mm RSA when compared to the 2-mm RSA ($P < .05$) (Table I).

*Muscle lengths*

Anterior, middle, and posterior deltoid lengthened for both RSA compared to native by an average of $14.2 \pm 5.4$ mm. The 6-mm lateralized RSA condition saw a significant increase in all rotator cuff muscle lengths when compared to the 2-mm lateralized RSA condition except for infraspinatus by an average of $2.7 \pm 1.9$ mm ($P < .05$) (Table II).

*Tuberosity fracture gap*

There was no significant gapping of the proximal fracture gap in any of the following scenarios: (1) 2-mm vs. 6-mm RSA after cyclic loading of 1.1 Nm in IR and ER; (2) 6-mm RSA after cycling loading of 1.1 Nm vs. 1 cycle of increased torque; or (3) 6 mm RSA after cycling loading of 1.1 Nm vs. 10 cycles of increased torque. After doubling the torque, the proximal fracture gap increased by

**Figure 3** RSA for 4-part proximal humerus fracture with Arthrex Revers System. *RSA*, reverse shoulder arthroplasty.

1.2 ± 1.3 mm compared to the initial gap with the 6-mm RSA; however, this was not statistically significant ($P = .438$) (Table III).

The gap after converting the 2-mm RSA to 6-mm RSA and applying 1.1-Nm torque in internal and ER was 1.7 ± 2.4 mm proximally and 1.7 ± 1.3 mm distally which was not statistically significant ($P = .059$). The only gapping that occurred which achieved statistical significance was the gapping of the distal fracture gap in 6-mm lateralized component which was 3.7 ± 1.5 mm ($P = .031$) after doubling the torque and 10 cycles of loading (Table III).

## Discussion

The primary finding of the current study was that only a minimal amount of fracture gapping occurs with glenoid lateralization of 6 mm compared to 2 mm when a stem-based tuberosity repair technique is utilized in a 135° RSA. The gapping that occurred in the distal segment of the fracture repair was not noted until the torque was increased to double its initial testing amount. The average gapping at the distal fragment following lateralization measured only 0.7 ± 0.7 mm for normal torque loading. This amount of gapping is unlikely to inhibit fracture healing in an *in-vivo* setting.[5] These findings may have implications in tuberosity repair in RSA for fracture as the surgeon now has biomechanical evidence that supports employing similar lateralization states that he or she uses in elective shoulder arthroplasty.

Although originally intended for rotator cuff arthropathy, the role of RSA has continued to expand and is now regularly utilized in the setting of displaced 4-part proximal humerus fractures. While many proximal humerus fractures in geriatric patients can be treated nonoperatively, when surgical management is indicated RSA perform better than previous methods. For example, Fraser et al demonstrated superiority of RSA when compared to plate fixation in displaced proximal humerus fractures in the elderly in a multicenter randomized controlled trial.[7] Namdari et al similarly found in their systematic review that the outcomes of RSA were superior to those of hemiarthroplasty.[10] As surgeon comfort with RSA and the incidence of proximal humerus fractures rise, the use of RSA in this setting will continue to grow.[16] Consequently, it is of paramount importance to determine the ideal methods by which to implant a reverse for fracture and the optimal amount of lateralization in this setting remains unknown.

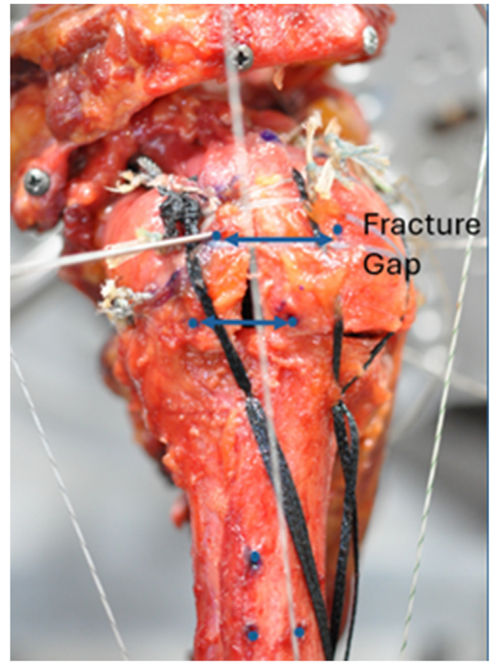


**Figure 4** Photograph of a left specimen after testing showing the placement of digitizing markers for fracture gap measurement.

Given the importance of tuberosity healing, it is imperative to optimize modifiable factors that support tuberosity healing. Multiple tuberosity repair techniques have been reported in the literature and through various implant company technique guides. These can generally be broken down into 2 categories: soft tissue and stem-based. Boileau et al described a well-known soft tissue technique in which the sutures are placed around the prosthesis and through the bone–tendon junction; the sutures are not linked to the implanted stem.[3] In their biomechanical study, Erickson et al demonstrated that stem-based repairs provide greater strength with higher load to failure and less cyclic displacement. This study specifically examined the FxBridge repair used in this study for its stem-based repair. Strength testing of it revealed a load to failure of 668 +/− 164 N vs. that of 483 +/− N for the nonstem-based repair.[6] Other factors important to the rate of tuberosity healing include the humeral inclination angle. O'Sullivan et al demonstrated greater healing rates with a 135° implant when compared to 145° of 155° prosthesis.[12]

To create a realistic comparison of the muscle tension effects for the medialized and lateralized RSA, we predetermined the muscle lengths from the intact specimen at 45° of IR and 45° of ER. For IR, stoppers were then placed on the cables attached to the infraspinatus and the teres minor to prevent further muscle excursion. For ER, stoppers were placed on the 2 lines of pull for the subscapularis. Following placing the stoppers, the amount of torque in internal and ER was measured with a torque wrench using 1.1 Nm and the degrees of rotation and fracture gapping of the tuberosities were measured. The torque was then increased such that the lateralized construct was rotated to the same IR and ERs achieved by the neutral construct and the points on the humerus were redigitized to assess for any fracture gapping. In this manner, the realistic differences in the muscle tension arising from the medialized and the lateralized RSA was effectively simulated.

Achieving an optimal outcome with RSA for fracture is dependent on several factors but healing of the tuberosities is paramount. Multiple studies have demonstrated that outcomes after RSA are

**Table I**
Humeral rotational range of motion for each condition.

| Humeral rotation | Native glenohumeral joint | 2-mm lateralized reverse | 6-mm lateralized reverse |
|---|---|---|---|
| Internal rotation | 44.6 ± 3.0° | 66.5 ± 18.3°* | 60.9 ± 20.7°*+ |
| External rotation | 44.5 ± 2.3° | 31.2 ± 16.4°* | 31.8 ± 14.6°* |
| Total range of motion | 89.2 ± 3.0° | 105.2 ± 20.9° | 103.3 ± 23.9°+ |

Data are presented as mean ± standard deviation.
$P < .05$ * vs. Intact; + vs. 2-mm lateralized reverse.

**Table II**
Muscle length from tendon insertion to origin loading plate for each condition.

| Muscle | Native glenohumeral joint | 2-mm lateralized reverse | 6-mm lateralized reverse |
|---|---|---|---|
| Inferior subscapularis | 140.1 ± 13.3 mm | 135.9 ± 7.8 mm | 138.7 ± 8.6 mm+ |
| Superior subscapularis | 128.4 ± 15.4 mm | 129.2 ± 11.9 mm | 131.7 ± 11.7 mm+ |
| Anterior supraspinatus | 104.0 ± 8.6 mm | 105.0 ± 8.5 mm | 108.0 ± 9.7 mm+ |
| Posterior supraspinatus | 102.4 ± 11.0 mm | 102.4 ± 4.4 mm | 105.1 ± 5.4 mm+ |
| Infraspinatus | 114.3 ± 17.6 mm | 107.8 ± 11.7 mm | 109.4 ± 10.3 mm |
| Teres minor | 131.7 ± 16.8 mm | 119.7 ± 7.3 mm | 122.0 ± 6.5 mm+ |
| Anterior deltoid | 128.5 ± 15.7 mm | 141.0 ± 13.8 mm* | 142.8 ± 15.2 mm* |
| Middle deltoid | 132.9 ± 16.5 mm | 150.0 ± 13.2 mm* | 150.7 ± 14.0 mm* |
| Posterior deltoid | 144.5 ± 11.7 mm | 155.7 ± 10.0 mm* | 157.2 ± 11.0 mm* |

Data are presented as mean ± standard deviation.
$P < .05$ * vs. Intact; + vs. 2-mm lateralized reverse.

**Table III**
Proximal and distal fracture gap following cyclic loading in internal and external rotation.

| Testing condition | Proximal gap | Distal gap |
|---|---|---|
| 2-mm lateralized reverse after 1.1 Nm | 1.4 ± 1.6 mm | 1.0 ± 0.7 mm |
| 6-mm lateralized reverse after 1.1 Nm | 1.7 ± 2.4 mm | 1.7 ± 1.3 mm |
| 6-mm lateralized reverse after 1 cycle increased torque | 1.8 ± 2.4 mm | 1.8 ± 1.1 mm |
| 6-mm lateralized reverse after 10 cycles increased torque | 2.3 ± 2.1 mm | 2.3 ± 1.4 mm |
| 6-mm lateralized reverse after 10 cycles double increased torque | 3.2 ± 1.8 mm | 3.7 ± 1.5 mm+ |

Data are presented as mean ± standard deviation.
$P < .05$ + vs. 2-mm lateralized reverse.

improved when the tuberosities heal.[1,2] Boileau et al found in their retrospective cohort study that successful tuberosity repair improved forward flexion, ER, and patient satisfaction.[2] Ohl et al found that tuberosity healing improved clinical outcomes and also decreased the risk of postoperative instability.[13] Other studies have demonstrated similar results, reinforcing the importance of tuberosity reconstruction.[4,9] This study demonstrated that significant fracture gapping did not occur with lateralization from 2 mm to 6 mm.

The ability to reliably procure tuberosity reconstruction in the setting of a 135° implant with lateralization is paramount given the increasing trend toward these implants. Although there remains a paucity of clinical data supporting the use of 135° implants, multiple biomechanical studies have demonstrated benefits of this design when compared to the original 155° Grammont-style.[14,15,18]

There are several limitations to this study. First, as a cadaveric biomechanical study, aspects may not translate to *in-vivo* performance. The 1.1-Nm load is not physiologically large. As noted above, the relatively low muscle loads and IR and ER torques were based on preliminary studies to maximize the quantitative information without compromising the specimen construct. Furthermore, with each humerus and scapula only the critical skeletal components were included in this cadaveric study to quantify and compare the effects of RSA lateralization on fracture gapping in 4-part proximal humerus fracture with a stem-based tuberosity repair. If higher IR and ER torques were used, internal control experimental design with repeated measures would not be possible as the specimens would be destroyed during testing. The specimens also had their forearms removed. However, this was necessary as the presence of the forearms would represent additional variables that needed to be controlled and would exacerbate individual specimen variation. Also, a tensioner device was not utilized to standardize the amount of tension provided to each repair. This however recreates the clinical scenario whereby the technique is to tighten the FxBridge repair by hand. The biomechanical study set up did not take into account various amounts of abduction, which can be a deforming force in the *in-vivo* setting. This choice was made to minimize the amount of dependent variables introduced into the study design. This biomechanical study employed a novel technique to assess fracture gapping. Various methodologies could have been employed but ultimately the decisions made in this study were chosen to minimize the possible number of dependent variables. Lastly, the tuberosity repair was not reperformed between the 2-mm and the 6-mm lateralized conditions. This added more stress to the repair in the lateralized condition and would bias toward demonstrating increased gapping. The strengths of the study are its focus on the isolated effect of muscle lateralization on fracture gapping when a stem-based repair is used in a 135° reverse construct. To the authors' knowledge, no other study to date has focused on the effect of lateralization on tuberosity fixation.

## Conclusion

This current study demonstrated that no significant amount of fracture gapping occurs with glenoid lateralization of 6 mm compared to 2 mm when a stem-based tuberosity repair technique is utilized in a 135° reverse arthroplasty. This may have implications on the choice of glenoid components when performing a RSA for fracture.

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Conflicts of interest: Dr. Michael J. Bercik discloses board or committee membership for American Shoulder and Elbow Surgeons and being a paid consultant for Arthrex, Inc and Novus Surgical (Arthrex distributor). Dr. Patrick Denard discloses board or committee membership for American Shoulder and Elbow Surgeons and Arthroscopy Association of North America; receives research support and IP royalties and is a paid consultant and paid presenter or speaker Arthrex, Inc; editorial or governing board membership in Orthopedics Today; stock or stock options in Kaliber Labs, PT Genie, Right mechanics, and Stryker; and publishing royalties, financial or material support from Wolters Kluwer Health—Lippincott Williams & Wilkins. Dr. Thay Q. Lee discloses board or committee membership for American Orthopaedic Society for Sports Medicine and American Shoulder and Elbow Surgeons; receives IP royalties and research support and is a paid consultant at Arthrex Inc; editorial or governing board membership in Clinics in Orthopaedic Surgery; IP royalties from CONMED Linvatec; paid consultant at DJ Orthopaedics; editorial or governing board membership, publishing royalties, financial or material support Journal of Shoulder and Elbow Surgery; IP royalties from Smith & Nephew; and stock or stock options in Coracoid Solutions, GLABS X, and Subchondral Solutions. The other authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

## References


1. Anakwenze O, Zoller S, Ahmad C, Levine W. Reverse shoulder arthroplasty for acute proximal humerus fractures: a systematic review. J Shoulder Elbow Surg 2014;23:E73-80. https://doi.org/10.1016/j.jse.2013.09.012.
2. Boileau P, Alta T, Decroocq L, Clavert P, Favard L, Chelli M. Reverse shoulder arthroplasty for acute fractures in the elderly: is it worth reattaching the tuberosities. J Shoulder Elbow Surg 2019;28:437-44. https://doi.org/10.1016/j.jse.2018.08/025.
3. Boileau P, Walch G, Krishnan S. Tuberosity osteosynthesis and hemi-arthroplasty for four-part fractures of the proximal humerus. Tech Shoulder Elbow Surg 2000;1:96-109.
4. Chun Y, Kim D, Lee D, Shin S. Reverse shoulder arthroplasty for four-part proximal humerus fracture in elderly patients: can a healed tuberosity improve the functional outcomes? J Shoulder Elbow Surg 2017;26:1216-21. https://doi.org/10.1016/j.jse.2016.11.034.
5. Claes L, Augat P, Suger G, Wilke HJ. Influence of size and stability of the osteotomy gap on the success of fracture healing. J Orthop Res 2005;15:577-84. https://doi.org/10.1002/jor.1100150414.
6. Erickson B, Shishani Y, Bishop M, Romeo A, Lederman E, Gobezie R. Tuberosity repair in reverse total shoulder arthroplasty for fracture using a stem based double-row repair: a cadaveric biomechanical study. JAAOS 2020;28:e1059-65. https://doi.org/10.5435/JAAOS-D-19-00667.
7. Fraser A, Bjordal J, Wagle T, Karlberg A, Lien O, Eilertsen L, et al. Reverse shoulder arthroplasty is superior to plate fixation at 2 years for displaced proximal humeral fracture in the elderly. J Bone Joint Surg Am 2020;102:477-85. https://doi.org/10.2106/JBJS.19.01071.
8. Imiolczyk JP, Audige L, Harzbecker V, Moroder P, Scheibel M. Metallic humeral and glenoid lateralized implants in reverse shoulder arthroplasty for cuff tear arthropathy and primary osteoarthritis. JSES Int 2022;6:221-8. https://doi.org/10.1016/j.jseint.2021.10.009.
9. Jain N, Mannan S, Dharmarajan R, Rangan A. Tuberosity healing after reverse shoulder arthroplasty for complex proximal humeral fractures in elderly patients-does it improve outcomes? A systematic review and meta-analysis. J Shoulder Elbow Surg 2019;28:e78-91. https://doi.org/10.1016/j.jse.2018.09.006.
10. Namdari S, Horneff J, Baldwin K. Comparison of hemiarthroplasty and reverse arthroplasty for Treatment of proximal humeral fractures: a systematic review. J Bone Joint Surg Am 2013;95:1701-8. https://doi.org/10.2106/JBJS.L.01115.
11. Nunes B, Linhares D, Costa F, Neves N, Claro R, Silva M. Lateralized versus nonlateralized glenospheres in reverse shoulder arthroplasty: a systemic review with meta-analysis. J Shoulder Elbow Surg 2021;30:1700-13. https://doi.org/10.1016/j.jse.2020.09.041.
12. O'Sullivan J, Ladermann A, Parsons B, Steinbeck J, Tokish J, Denard P. A systematic review of tuberosity healing and outcomes following reverse shoulder arthroplasty for fracture according to humeral inclination of the prosthesis. J Shoulder Elbow Surg 2020;29:1938-49. https://doi.org/10.1016/j.jse.2020.03.032.
13. Ohl X, Bonnevialle N, Gallinet D, Decroocq L, Boileau P. How the greater tuberosity affects clinical outcomes after reverse shoulder arthroplasty for proximal humeral fractures. J Shoulder Elbow Surg 2018;27:2139-44. https://doi.org/10.1016/j.jse.2018.05.030.
14. Pak T, Menendez M, Gobezie R, Sears B, Lederman E. "Rates of Subacromial notching are low following reverse shoulder arthroplasty with a 135° Inlay humeral component and a lateralized glenoid. JSES Int 2024;8:522-7. https://doi.org/10.1016/j.jseint.2024.01.009.
15. Parry S, Stachler S, Mahylis J. Lateralization in reverse shoulder arthroplasty: a review. J Orthopaedics 2020;22:64-7. https://doi.org/10.1016/j.jor.2020.03.027.
16. Patel A, Wilder J, Ofa S, Lee O, Savoie F, O'Brien M, et al. Trending a decade of proximal humerus fracture management in older adults. JSES Int 2022;6:137-43. https://doi.org/10.1016/j.jseint.2021.08.006.
17. Schamlzl J, Jesson M, HOlschen M, Cohen BC, Steinbeck J, Lehmann J, et al. Tuberosity healing improves functional outcome following primary reverse shoulder arthroplasty for proximal humeral fractures with a 135° prosthesis. Eur J Orthop Surg Traumatol 2020;30:909-16. https://doi.org/10.1007/s00590-020-02649-8.
18. Scolaro JA, Chalmers CE, Wright DJ, Patel N, McGarry M, Lee TQ. Suture Augmentation Neutralizes deforming Muscular forces in a simulated 2-Part Osteoporotic proximal humeral fracture model. J Orthop Trauma 2022;36:312-7. https://doi.org/10.1097/BOT.0000000000002351.
19. Werner BC, Lederman E, Gobezie R, Denard PJ. Glenoid lateralization influences active internal rotation after reverse shoulder arthroplasty. J Shoulder Elbow Surg 2021;30:2498-505. https://doi.org/10.1016/j.jse.2021.02.021.