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Effect of glenosphere lateralization with and without coracoacromial ligament transection on acromial and scapular spine strain in reverse shoulder arthroplasty

Brett D. Haislup, MD[a,*], Roman Ashmyan, MD[a], Peter S. Johnston, MD[b], Melissa A. Wright, MD[a], Pooyan Abbasi, MSME[a], Anand M. Murthi, MD[a]

[a]Department of Orthopaedic Surgery, MedStar Union Memorial Hospital, Baltimore, MD, USA
[b]Georgetown University School of Medicine, Washington, DC, USA

A R T I C L E I N F O

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Background: Small changes in deltoid tension and moment arm due to glenosphere lateralization may be associated with an increase in acromion or scapular spine strain in reverse shoulder arthroplasty (RSA), which can lead to stress fracture. The coracoacromial ligament (CAL) may be protective and lower the strain seen on the acromion or scapular spine. This biomechanical study investigated the impact of glenosphere lateralization and CAL integrity on acromion and scapular spine strain after RSA.

Methods: Ten cadaveric specimens were tested on a custom dynamic shoulder frame. Acromial and scapular spine strain were measured at 0°, 30°, and 60° of abduction using strain rosettes fixed to the acromion (Levy Type 2) and the scapular spine (Levy Type 3). Specimens were first tested with a standard commercially available RSA implant with zero lateralization and then subsequently with the +3 and +6 lateralizing glenospheres for that implant. The CAL was then cut in each specimen and testing was repeated with the 0, +3, and +6 glenospheres. Maximal strain was recorded at both the acromion and scapular spine and analysis of variance compared strain across various abduction angles and glenospheres with and without CAL transection.

Results: In the intact CAL group, maximal strain decreased significantly at the acromion with abduction from 0° to 30° and 0° to 60°, however, at the scapular spine abduction did not significantly impact strain. Maximal strain decreased significantly with increasing abduction from 0 to 30 and 0 to 60 at both the acromion and scapular spine in the cut CAL group. Average strain at the acromion was significantly higher in the cut group (844.7 με) versus the intact group (580.3 με), a difference of 31.3% ($P = .0493$). Average strain at the scapular spine, did not differ in the cut group (725 με) compared with the intact group (787 με) ($P = .3666$). There were no statistically significant differences in acromial or scapular spine strain between various levels of glenosphere lateralization in either the cut or intact state.

Conclusion: In this biomechanical study, arm abduction decreased acromial and scapular spine strain following RSA. Cutting the CAL significantly increased strain at the acromion, and did not significantly alter strain at the scapular spine for all angles of abduction, differing from prior literature. Glenosphere lateralization did not have a significant effect on strain at the levels studied regardless of CAL status. Continued study of the complexion relationship between surgical and implant factors on strain following RSA is needed.

Reverse shoulder arthroplasty (RSA) utilizes a medialized center of rotation to increase the lever arm of the deltoid muscle and allow forward elevation of the arm in the absence of a functional rotator cuff.[4,5] Because of the change in moment arm and increased deltoid tension, there is increased strain on the superior acromion and the base of the acromion at the scapular spine, which may result in fractures at these areas.[6,17] The incidence of acromial and scapular spine fractures after RSA varies in the literature, and has been reported between 3.7% and 10.2%.[11,12,15] Acromial stress fractures are classified based on location relative to the deltoid muscle origin, with type I fractures involving a portion of the anterior and middle deltoid (avulsion of anterior acromion), type II involving the entire middle and a portion of posterior deltoid (fracture posterior to the

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*Corresponding author: Brett D. Haislup, MD, Department of Orthopaedic Surgery, MedStar Union Memorial Hospital, 201 E University Pkwy, Baltimore, MD 21218, USA.
E-mail address: brett.d.haislup@gmail.com (B.D. Haislup).

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acromioclavicular joint), and type III involving the entire middle and posterior deltoid origin (fractures at the scapular spine).[11] Regardless of location, patients with an acromial or scapular spine fracture following RSA have significantly worse outcomes than those seen in an uncomplicated RSA.[5-7,19]

Both patient and surgical factors may contribute to the development of an acromial or scapular spine stress fracture. Because surgical factors are modifiable, understanding what technical decisions decrease the risk of acromial and scapular spine stress fractures is key to optimizing outcomes. Using glenoid baseplates and glenosphere components to lateralize the center of rotation is becoming increasingly popular to improve range of motion, but may increase acromial and scapular strain patterns after RSA.[20] Another surgical variable that has been recently shown to affect the scapular and acromial strain is the handling of the coracoacromial ligament (CAL). Resection of the CAL has been associated with significantly higher scapular spine strain at 0° abduction after RSA.[18] A better understanding of the independent and combined effects of glenoid lateralization and CAL transection on acromial and scapular spine strain may help surgeons improve operative technique and prevent acromial and scapular stress fractures.

The purpose of this biomechanical study was to evaluate the impact of both CAL integrity and glenosphere lateralization on acromial and scapular spine strain in RSA. We hypothesized that transection of the CAL would be associated with significantly higher strain across the acromion and scapular spine, that glenosphere lateralization would also independently increase strain, and that the combination of a lateralized glenosphere and transected CAL would show the highest level of acromial and scapular spine strain.

Materials and methods

Specimen preparation

Ten fresh-frozen cadaveric shoulders (3 female, 7 male; average age 81.6 years) were dissected of all soft tissue except the deltoid musculature and tendon and the CAL. Ligaments of the AC joint were kept intact to stabilize the clavicle and therefore the origin of the anterior deltoid. Careful dissection was performed to avoid transection to the CAL. The deltoid musculature was then sharply split at the posterolateral acromion to separate the anteromedial and posterior deltoid. Two #5 ethibond sutures were used to whip stitch the anteromedial and posterior deltoid to attach the weights supported by the deltoid. A saw was used to cut the humeral shaft 5 cm below the deltoid insertion to allow mounting of the humerus to a custom testing frame with 6 degrees of freedom.

RSA implantation

RSA was performed utilizing a commercially available implant system (Zimmer Biomet Comprehensive Reverse system; Zimmer Biomet, Warsaw, IN, USA). The humeral head was cut in an anatomic fashion along the medial rotator cuff insertion. The glenoid was prepped using the appropriate instrumentation, and a 25-mm baseplate was used for all specimens. A +0 (standard) glenosphere was initially placed on all specimens. Glenospheres were set in the B position for the chosen system to provide 1.5 mm of inferior offset consistently among all specimens. The humerus was then broached, and an appropriately sized short humeral stem was placed. A standard (no offset) humeral tray and standard +0 humeral polyethylene bearing were utilized.

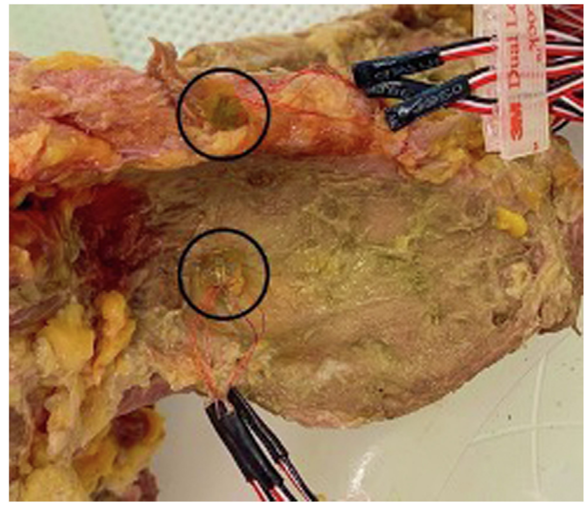

Figure 1 Specimen demonstrating the positions of strain rosettes on the scapular spine and acromion. *Black circles* (○) demonstrate location of rosettes where strain was measured.

Strain gauge placement

Two C2A-06-031WW-120 stacked rosettes per specimen were used (Vishay Measurements Group, Inc, Malvern, PA, USA). Each strain rosette has 3 strain gauges placed at 0°, +45°, and −45° relative to each other. We used Optotrak Data acquisition Unit III (Northern Digital Inc. Waterloo, ON, Canada) to record voltage output of the strain gauges at 300 Hz and then converted voltages to maximum principal strain.

Strain rosettes were placed in locations corresponding to Levy type II and Levy type III acromial and scapular spine fractures (Fig. 1), the origins of the middle of posterior deltoid, respectively. For consistency, the acromial rosettes were placed halfway across the acromion on a line drawn and measured from the posterolateral corner of the acromion to the superior glenoid. The scapular spine rosettes were placed 1 cm medial to the lateral flare of the base of the acromion. A curette was used to clear all soft tissue and periosteum from the scapula. The rosettes were then glued onto the bony surface.

Specimen mounting and testing

The scapula for each specimen was fixed using rigid screws to the shoulder frame. The humeral shaft was placed in a cylindrical metal frame and fixed with rigid screws drilled through the shaft. Established regression equations were utilized to determine the glenohumeral angles needed to account for a fixed scapula and 2:1 scapulothoracic rhythm.[13] (Fig. 2)

Loads were then placed to simulate active glenohumeral abduction and joint compressive forces. Loads were 300-N compression load across the joint, 150-N load to the anteromedial deltoid, and 75-N load to the posterior deltoid.[18] Loads were applied via wear-resistant wires and a pulley system to allow unobstructed movement within the frame construct during range of motion. Maximal principal strain was recorded at both the acromion and scapular spine at 0°, 30°, and 60° of abduction. Once this testing was complete, loads were removed, thereby relieving the compressive forces across the prosthesis. A tuning fork was then used to remove the +0 glenosphere, and the +3 lateralized glenosphere was impacted on to the glenoid with the offset directed inferiorly. Loads were reapplied and strain was again recorded at

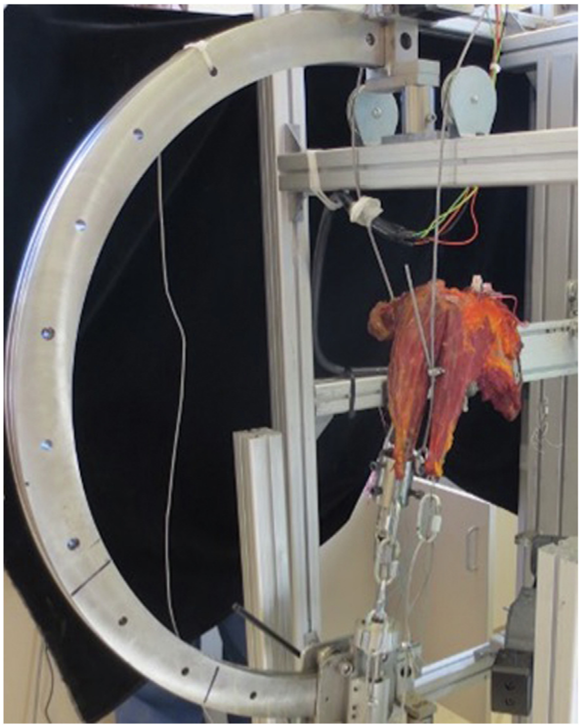

Figure 2 Specimen on the custom dynamic shoulder frame. No. 5 ethibond was passed through two deltoid heads and loops were tied to connect to the pulley system that loaded the deltoid. The specimen was manually abducted to 30° and 60° and the humerus was then held at those angles.

the previously mentioned abduction angles. This process was then repeated for the +6 lateralized glenosphere. The CAL was then cut and the entire loading process was repeated with the +0, +3, and +6 lateralized glenospheres.

Statistical analysis

Analysis of variance was utilized to determine differences between maximal principal strain between the intact and cut CAL group at various abduction angles and with different lateralized glenospheres. Statistical significance was set at 0.05. *P* values were reported using the Tukey-Kramer adjustment for multiple comparisons. A priori power analysis, based upon research performed by Wong et al indicated that a sample size of 10 cadaveric specimens would provide 85% power to reject the null hypothesis of zero effect size (no difference between the four groups).

Results

In the intact CAL group, acromial maximum principal strain decreased from 0° to 30° of abduction by an average of 20.8% (−171.6 με, $P = .0699$) and from 0° to 60° of abduction by an average of 67.7% (−569 ± 99 με, $P = .0009$). At the acromion in the cut CAL group, maximum acromial strain decreased significantly from 0° to 30° (−960.9 ± 620.3; $P = .016$) of abduction by an average of 19.7% (−201 ± 87 με) and from 0° to 60° by 49.9%(−293.7 ± 214; $P = .0009$).

At the scapular spine, in the intact CAL group, strain did not differ significantly from 0 to 30° (−157.7 με ,$P = .0837$) or 0 to 60° (−212.8 με, $P = .37$). In the cut CAL group, scapular spine strain decreased significantly by an average of 12.3% from 0 to 30° of abduction (−108.5 με; $P = .043$) and by 40% from 0 to 60° (−351.4 με, $P = .00023$).

Table I
Strain at the acromion and scapular spine with cut and intact coracoacromial ligaments. Difference between cut and intact ligaments included.

Anatomic site	Ligament status	Strain	*P* value	Percent difference
Acromion	Cut	844.7	–	–
	Intact	580.3	–	–
	Difference cut - intact	264.4	.049*	−31.3
Scapular spine	Cut	725.0	–	–
	Intact	786.7	–	–
	Difference cut - intact	−61.7	.367	7.8

*P < .05 are statistically significant.

Average strain at the acromion was significantly higher in the cut group (844.7) versus the intact group (580.3), a difference of 31.3% ($P = .049$). Average strain at the scapular spine did not differ significantly between the cut group (725 με) compared with the intact group (785 με) ($P = .367$). (Table I)

At both the acromion and scapular spine, there were no significant differences in strain between the +0, +3, and +6 lateralizing glenospheres. No interaction between lateralization and CAL transection was observed. (Tables II and III)

Discussion

This cadaveric biomechanical study evaluated the effects of glenosphere lateralization and CAL transection on acromial and scapular spine strain through a range of motion following RSA. Strain decreased across the scapular spine and acromion when the arm was abducted from a neutral position. Glenosphere lateralization showed no impact on acromial and scapular strains at the levels of lateralization studied, while CAL integrity impacted acromial strain regardless of glenoid lateralization.

Appropriate deltoid tensioning is important in RSA as this influences active abduction at the shoulder. One goal of RSA is to improve the efficiency of the deltoid lever arm by distalizing and medializing implants, compared to the natural center of rotation.[1,2] Higher abduction forces working against the deltoid will reduce its mechanical advantage. In our study, acromial strain was reduced with arm abduction from 0° to 30° and 0° to 60°. This result occurred regardless of glenosphere lateralization and whether the CAL was cut or intact. Taylor et al also found that increasing abduction angle decreased strain at the acromion and scapular spine.[18] After surgery, patients with RSA are commonly braced with a bolster that abducts the shoulder, which is supported by these biomechanical results as the position may help remove strain from the acromion and prevent fracture.

With CAL transection, strain significantly increased at the acromion while strain was not significantly different at the scapular spine, for all abduction angles, regardless of glenosphere lateralization. This contrasts with previous literature, which also showed a significant independent effect of CAL integrity on scapular strain following RSA, but the significant increase in strain was at the scapular spine, with a decrease in strain at the acromion after cutting the CAL.[18] Taylor et al describe a scapular ring model, made up of the scapular spine, acromion and CAL.[18] When the CAL is removed, the stress is redistributed, and in theory, this increases the load on the scapular spine rather than the more anterior acromion or coracoid. In our study, strain was increased at the acromion with CAL transection, which is not consistent with the scapular ring model. The reasons why our results differ from Taylor et al are likely multifactorial and complex. Our model is a truly dynamic powered shoulder model which may have led to varying results.[18] Subtle differences in the location of strain measurement could play a role. Variability in cadaveric anatomic factors and bone quality may also impact strain, and how CAL integrity impacts

Table II
Strain on acromion with cut and intact coracoacromial ligament with varying offsets for glenoid components sized 0, 3, and 6.

Maximum principal strain by glenoid offset at the acromion				
State of CAL	Glenoid component	Mean	Standard deviation	*P* value
Cut	Size 0	711.77	659.5	.293
	Size 3	1105.9	1351.5	
	Size 6	887.6	631.8	
Intact	Size 0	867.4	1072.8	.910
	Size 3	925.9	749.2	
	Size 6	981.1	1038.7	

CAL, coracoacromial ligament.

Table III
Strain on scapular spine with cut and intact coracoacromial ligament with varying offsets for glenoid components sized 0, 3, and 6.

Maximum principal strain by glenoid offset at the scapular spine				
State of CAL	Glenoid component	Mean	Standard deviation	*P* value
Cut	Size 0	918.2	1096.1	.970
	Size 3	839.8	955.5	
	Size 6	884.9	1391.2	
Intact	Size 0	794.9	459.4	.700
	Size 3	933.2	830.9	
	Size 6	918.6	696.9	

CAL, coracoacromial ligament.

strain, leading to such a difference in results. A study by Shah et al[17] demonstrated that deltoid lengthening above 25 mm and a more posteriorly oriented acromion result in higher strain patterns within the scapula. Another study by Sabesan et al[16] found that smaller acromions are at higher risk of stress fracture. Other patient specific risk factors for acromial and scapular spine stress reactions identified in a large multicenter study included chronic dislocations, massive rotator cuff tear without arthritis, rotator cuff arthropathy, self-reported osteoporosis, inflammatory arthritis, female sex, and older age.[12,15,21] Rheumatological disorders such as RA have shown to increase the risk of acromial stress fracture.[14] All these factors which may differ between the specimens used in the present study and that of Taylor et al may affect how the CAL contributes to acromial and scapular spine strain. Additionally, while our methods were modeled on the prior work of Taylor et al,[18] a minor difference in scapulothoracic motion exists between the shoulder model used in our biomechanics lab and the model used in their study. Our model abducts the arm to reach 90 degrees of total scapular abduction with 60 degrees of shoulder abduction, whereas the model in the paper by Taylor et al reaches 90 degrees of scapular motion at 67.5 degrees of shoulder abduction.[13,18] This variation may alter strain through range of motion.[13]

Glenoid lateralization in RSA has become more common to prevent complications seen with earlier medialized implants. However, studies have shown that increased lateralization may increase stress at the acromion during abduction.[8,10,20] Our study showed glenosphere lateralization at the levels studied did not have a significant impact on strain patterns at the acromion or at the scapular spine, regardless of CAL integrity. A prior cadaveric study examining glenosphere lateralization in isolation demonstrated that glenoid lateralization from 0 to 5 mm caused negligible changes in scapular spine strain; however, from 5 to 10 mm, there were significant increases in strain. In our study, we lateralized to a +6 mm glenosphere, for both the cut and intact CAL states, and saw no effect from glenoid lateralization, perhaps because the level of lateralization was not substantial enough.[9] Alternatively, other implant, surgical, and patient factors may actually be more important than glenosphere lateralization for altering acromial and scapular spine strain. In a cadaveric study, Kerrigan et al[9] found humeral lateralization to significantly decrease scapular spine strain. A biomechanical analysis by Wong et al[20] found the glenoid position inferior and medial serves to decrease acromial stress. Finally, the present study found cutting that the CAL independently affected acromial and scapular spine strain regardless of arm position and glenosphere lateralization. Continued study of the patient, implant, and surgical factors that may be impacting acromial and scapular spine strain is needed as these relationships are complex.

There are limitations to this study. A biomechanical model cannot fully reproduce the dynamic loads seen in vivo. Additionally, stress reactions and fractures seen clinically are a result of repetitive loading, not time zero strain. During biomechanical testing, soft tissues may undergo creep after sequential loading, leading to additional variation in values recorded during the earlier tests with ligament intact and the latter values after the CAL was cut. Finally, the various lateralized glenospheres were placed in order and not randomized, which may create bias as the soft tissue changes with sequential testing may confound differences seen or not seen in lateralization.

Conclusion

In this biomechanical study, arm abduction decreased acromial and scapular spine strain following RSA. Sectioning the CAL significantly increased strain at the acromion and did not significantly alter strain at the scapular spine for all angles of abduction, differing from prior literature. Glenosphere lateralization did not have a significant effect on strain at the levels studied regardless of CAL status. Continued study of the complex relationship between surgical and implant factors on strain following RSA is needed.

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