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Posteroinferior glenosphere positioning is associated with improved range of motion following reverse shoulder arthroplasty with a 135° inlay humeral component and lateralized glenoid

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Background: Optimal glenosphere positioning in a lateralized reverse shoulder arthroplasty (RSA) to maximize functional outcomes has yet to be clearly defined. Center of rotation (COR) measurements have largely relied on anteroposterior radiographs, which allow assessment of lateralization and inferior position, but ignore scapular Y radiographs, which may provide an assessment of the posterior and inferior position relative to the acromion. The purpose of this study was to evaluate the COR in the sagittal plane and assess the effect of glenosphere positioning with functional outcomes using a 135° inlay stem with a lateralized glenoid.

Methods: A retrospective review was performed on a prospectively maintained multicenter database on patients who underwent primary RSA from 2015 to 2021 with a 135° inlay stem. The COR was measured on minimum 2-year postoperative sagittal plain radiographs using a best-fit circle fit method. A best-fit circle was made on the glenosphere and the center was marked. From there, 4 measurements were made: (1) center to the inner cortex of the coracoid, (2) center to the inner cortex of the anterior acromion, (3) center to the inner cortex of the middle acromion, and (4) center to the inner cortex of the posterior acromion. Regression analysis was performed to evaluate any association between the position of the COR relative to bony landmarks with functional outcomes.

Institutional review board (IRB) approval was received from the Southern Oregon IRB (study protocol version 05-14-2015; approval date: April 30, 2015; continuing review approval dates: May 28, 2016–May 03, 2024).

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Results: A total of 136 RSAs met the study criteria. There was no relation with any of the distances with outcome scores (American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form, visual analog scale). In regard to range of motion (ROM), each distance had an effect on at least 1 parameter. The COR to coracoid distance had the broadest association with ROM, with improvements in forward flexion (FF), external rotation (ER0), and internal rotation with the arm at 90° (IR90) ($P < .001$, $P = .031$, and $P < .001$, respectively). The COR to coracoid distance was also the only distance to affect the final FF and IR90. For every 1-mm increase in this distance, there was a 1.8° increase in FF and 1.5° increase in IR90 ($\beta = 1.78$, 95% confidence interval [CI] 0.85-2.72, $P < .001$, and $\beta = 1.53$, 95% CI 0.65-2.41, $P < .001$; respectively).
Conclusion: Evaluation of the COR following RSA in the sagittal plane suggests that a posteroinferior glenosphere position may improve ROM when using a 135° inlay humeral component and a lateralized glenoid.
Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Center of rotation; reverse shoulder arthroplasty; sagittal radiographs; scapular Y; glenosphere position; outcomes

Reverse shoulder arthroplasty (RSA) has been associated with improvements in function and pain reduction.[15,22,36] However, limitations in range of motion (ROM) persist because of the constrained nature of the design and risk for bony impingement, especially with a medialized center of rotation (COR).[7,30,42] Most notably, internal rotation is often limited after RSA.[1,31,39]

A substantial volume of research has examined factors associated with improvement in ROM after RSA.[10,12,20,26,35] Lateralizing the COR has been shown to decrease bony impingement and thus improve ROM.[18,24,41] However, there are limits to lateralization including soft tissue tension, increased technical difficulty with implantation, and increased postoperative forces on the baseplate that may increase the risk of fixation failure.[17,33] Additionally, clinical assessment of the COR has largely been performed in the coronal plane alone via anterior-posterior radiographs.[2,35] Although this method allows an assessment of superior-inferior glenosphere position and lateralization, it may not capture subacromial impingement depending on acromial morphology and it does not assess subcoracoid bony impingement. Sagittal or scapular Y views may allow visualization of coracoid and acromial geometry and potential sites of bony contact.

Therefore, the purpose of this study was to evaluate the COR in the sagittal plane and assess the effect of glenosphere positioning with functional outcomes using a 135° inlay stem with a lateralized glenoid. The hypothesis was that posterior-inferior positioning, represented as increased COR to coracoid and increased COR to acromial distances, would be associated with improvement in ROM.

Methods

Database and study patients

This was a retrospective cohort study that was performed on a prospectively maintained multicenter database on patients who underwent primary RSA from 2015-2021. Inclusion criteria were as follows: minimum 2-year follow-up, postoperative sagittal plain radiographs, and primary RSA performed with a 135° inlay humeral component. Exclusion criteria were proximal humerus fractures, revision surgery, use of custom implants, presence of coracoid fractures, and postoperative acromial fracture, which could affect the glenosphere to acromion measurements. Institutional review board approval was obtained before study inception as part of the prospective database enrollment.

Surgical technique

RSAs were performed at 12 sites and a deltopectoral approach was used in all instances. A 135° inlay humeral stem (Univers Revers; Arthrex, Inc., Naples, FL, USA) was placed in all cases. On the glenoid side, two designs were used. Prior to 2018, an anatomically shaped baseplate was used (Universal Baseplate; Arthrex, Inc.) and from 2018 to 2021 a modular circular baseplate (Modular Glenoid System; Arthrex, Inc.) was used. The amount of glenoid-sided lateralization varied from 0 to 8 mm in 2-mm increments. This was based on surgeon preference, soft-tissue tension, and patient anatomy. Glenoid-sided lateralization occurred through the baseplate and/or glenosphere. Glenosphere diameters ranging from 33 to 42 mm were implanted based on surgeon preference and patient anatomy. Humeral offset included the polyethylene liner and metallic spacer if used. Subscapularis repair and postoperative rehabilitation were not standardized.

Patient characteristics and outcome measures

Patient characteristics and patient-reported outcomes (PROs) were prospectively collected in a secure database. Baseline demographic data collected were age, sex, body mass index, history of diabetes mellitus, smoking status, surgical side dominance. PROs (American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form [ASES] and visual analog scale [VAS] scores) and ROM were assessed at baseline and at final follow-up. The following ROM measures were assessed by the treating surgeon or their research staff with a goniometer: active forward flexion (FF), active external rotation (ER) in adduction (ER0), active external rotation (ER) with the arm at 90° (ER90), and internal rotation with the arm at 90° (IR90). Internal rotation was also visually estimated to the nearest spinal level (IR spine). Implant characteristics such as glenosphere size, glenoid-sided lateralization, and humeral offset were also recorded.

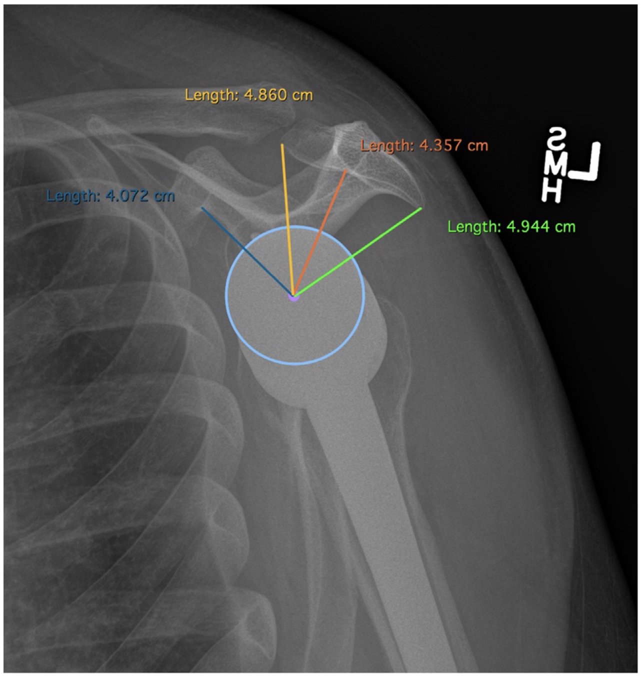

Figure 1 The center of rotation was measured on scapular Y radiographs. A best-fit circle was made on the glenosphere and the center was marked. From there, 4 measurements were made: (1) center to the inner cortex of the coracoid, (2) center to the inner cortex of the anterior acromion, (3) center to the inner cortex of the middle acromion, and (4) center to the inner cortex of the posterior acromion.

Radiographic method

To measure the COR to coracoid and acromial distances, postoperative scapular Y radiographs were reviewed by a fellowship-trained shoulder surgeon not involved in the surgeries (T.P.) in DICOM (digital imaging and communications in medicine) using Horos (Pixmeo, Bernex, Switzerland). The "best-fit circle" concept described on anteroposterior[2,32] and axillary[32] views was applied to scapular Y views. A best-fit circle was made on the glenosphere and the center was marked. From there, 4 measurements were made: (1) center to the inner cortex of the coracoid, (2) center to the inner cortex of the anterior acromion, (3) center to the inner cortex of the middle acromion, and (4) center to the inner cortex of the posterior acromion (Fig. 1). Given that these were novel measurements, an inter-rater reliability analysis was performed prior to assessing all radiographs. Twenty images were randomly selected and measured by both the primary reviewer and a senior author (B.C.W.). On inter-rater reliability testing for the radiographic measurements, all intraclass correlation coefficients were greater than 0.995, indicating excellent reliability.

Radiographic measurements

Measurements for postoperative distalization and lateralization were made according to the distalization shoulder angle and lateralization shoulder angle (LSA) and described by Boutsiadis and Barth.[5] To measure LSA, a line connecting the (1) superior glenoid tubercle and (2) the lateralmost aspect of the acromion is drawn. A second line then is drawn to connect (2) the lateralmost aspect of the acromion to (3) the lateralmost aspect of the greater tuberosity. The LSA was further divided into glenoid (GLA) and humeral (HLA) contributions as described by Schippers and Boileau.[34] To measure the GLA and HLA, the lateralmost point of the glenosphere was used to split the LSA (Fig. 2).

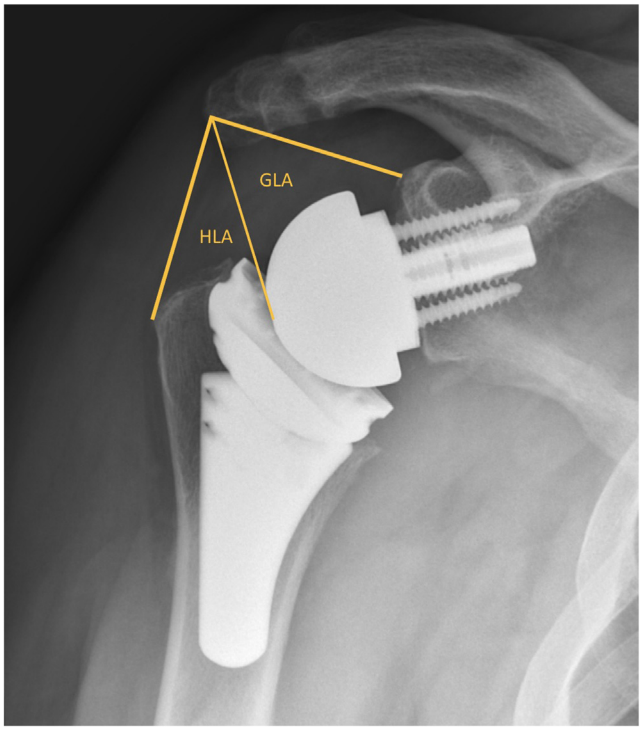

Figure 2 To measure the lateralization shoulder angle (LSA), a line connecting the (1) superior glenoid tubercle and (2) the lateralmost aspect of the acromion was drawn. A second line then was drawn to connect (2) the lateralmost aspect of the acromion to (3) the lateralmost aspect of the greater tuberosity. The LSA was further divided into glenoid (GLA) and humeral (HLA) contributions as described by Schippers and Boileau.[34] To measure the GLA and HLA, the lateralmost point of the glenosphere was used to split the LSA.

Statistical analysis

All measurements were normalized by multiplying the measure by the known glenosphere diameter divided by the measured glenosphere diameter to control for magnification. Descriptive statistics, including means and standard deviations, were provided for baseline cohort characteristics. For each of the 4 measurements, linear regression analyses were performed to assess any relationship between the measurement and the outcome of interest (PRO or ROM), while controlling for patient or implant characteristics. For each outcome measure (PRO or ROM), the baseline of that measure was included in the regression to control for any variability in baseline. The results of the regression analyses are presented as a beta coefficient with 95% confidence interval (CI), with a P value. $P < .05$ was considered statistically significant. All

Table I Baseline patient characteristics

Variable	Mean ± SD or n (%)
Patient characteristics	
Age, yr	70.7 ± 7.3
BMI	30.2 ± 5.4
Sex: male	83/136 (61.0)
Smoker: yes	7/136 (5.1)
Dominant arm	79/136 (58.1)
PRO	
ASES	42.7 ± 17.5
VAS	5.4 ± 2.5
ROM	
FF, degrees	85 ± 37
ER0, degrees	26 ± 21
ER90, degrees	26 ± 27
IR90, degrees	22 ± 25
IR spine	L5 ± 3

BMI, body mass index; *PRO*, patient-reported outcome; *ASES*, American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form; *VAS*, visual analog scale; *ROM*, range of motion; *FF*, forward flexion; *ER0*, external rotation; *ER90*, external rotation with the arm at 90°; *IR90*, internal rotation with the arm at 90°; *IR spine*, internal rotation to spinal level; *SD*, standard deviation.

Table II Regression results: COR to coracoid distance

Variable	β (95% CI)	*P* value
PRO		
ASES	0.50 (−0.19, 1.19)	.153
VAS	−0.06 (−0.13, 0.02)	.145
ROM		
FF	1.78 (0.85, 2.72)	**<.001**
ER0	0.70 (0.06, 1.34)	**.031**
IR spine	−0.10 (−0.22, 0.03)	.131
IR90	1.53 (0.65, 2.41)	**<.001**

COR, center of rotation; *PRO*, patient-reported outcome; *ASES*, American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form; *VAS*, visual analog scale; *ROM*, range of motion; *FF*, forward flexion; *ER0*, external rotation; *IR spine*, internal rotation to spinal level; *IR90*, internal rotation with the arm at 90°; *CI*, confidence interval.
Boldface indicates significance ($P < .05$).

Table III Regression results: COR to anterior acromion distance

Variable	β (95% CI)	*P* value
PRO		
ASES	0.17 (−0.45, 0.78)	.590
VAS	−0.01 (−0.08, 0.06)	.734
ROM		
FF	0.08 (−0.82, 0.97)	.867
ER0	0.27 (−0.31, 0.85)	.355
IR spine	−0.14 (−0.24, 0.03)	**.014**
IR90	0.39 (−0.44, 1.21)	.360

COR, center of rotation; *PRO*, patient-reported outcome; *ASES*, American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form; *VAS*, visual analog scale; *ROM*, range of motion; *FF*, forward flexion; *ER0*, external rotation; *IR spine*, internal rotation to spinal level; *IR90*, internal rotation with the arm at 90°; *CI*, confidence interval.
Boldface indicates significance ($P < .05$).

statistical analyses were performed in SPSS (version 29; IBM, Armonk, NY, USA).

Results

There were a total of 136 RSAs that met study criteria, with baseline characteristics summarized in Table I. The mean distances were as follows: center to coracoid 36.6 ± 4.8 mm, center to anterior acromion 40.2 ± 5.7 mm, center to middle acromion 39.1 ± 4.7 mm, and center to posterior acromion 43.4 ± 5.7 mm.

There was no relationship with any of the distances with patient-reported outcome scores (ASES: $P = .153$, .590, .428, and .353; VAS: $P = .145$, .734, .679, and .378, respectively). In regard to ROM, each distance had an effect on at least 1 parameter. The COR to coracoid distance was associated with statistically better FF, ER0, and IR90 at 2 years postoperatively ($P < .001$, $P = .031$, and $P < .001$, respectively). The COR to the middle acromion distance was associated with statistically better ER0 and IR spine at 2 years postoperatively ($P < .025$ and $P < .001$, respectively). The COR to anterior acromion and COR to posterior acromion distances were associated with statistically better IR spine at 2 years only ($P = .014$ and $P = .033$, respectively) (Tables II-V).

When assessing the magnitude of various distances on ROM, the COR to the middle acromion distance had the greatest effect on IR spine ($\beta = -0.24$, 95% CI −0.37 to −0.10, $P < .001$). ER0 was affected more by the COR to the middle acromion distance than by the COR to coracoid distance ($\beta = 0.84$, 95% CI 0.11-1.57, $P = .025$, vs. $\beta = 0.70$, 95% CI 0.06-1.34, $P = .031$). The COR to coracoid distance was the only distance to affect the final FF and IR90. For every 1-mm increase, there was a 1.8° increase in FF and 1.5° increase in IR90 ($\beta = 1.78$, 95% CI 0.85-2.72, $P < .001$, vs. $\beta = 1.53$, 95% CI 0.65-2.41, $P < .001$, respectively) (Tables II-V).

Discussion

The purpose of this study was to evaluate the COR of RSAs in the sagittal plane and assess the effect of glenosphere positioning with functional outcomes using a 135° inlay stem and a lateralized glenoid. The main findings were that this method was reproducible and associated with changes

Table IV Regression results: COR to middle acromion distance

Variable	β (95% CI)	*P* value
PRO		
ASES	0.32 (−0.47, 1.11)	.428
VAS	−0.02 (−0.11, 0.07)	.679
ROM		
FF	0.86 (−0.28, 2.00)	.138
ER0	0.84 (0.11, 1.57)	**.025**
IR spine	−0.24 (−0.37, −0.10)	**<.001**
IR90	0.61 (−0.45, 1.67)	.253

COR, center of rotation; *PRO*, patient-reported outcome; *ASES*, American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form; *VAS*, visual analog scale; *ROM*, range of motion; *FF*, forward flexion; *ER0*, external rotation; *IR spine*, internal rotation to spinal level; *IR90*, internal rotation with the arm at 90°; *CI*, confidence interval.
Boldface indicates significance ($P < .05$).

Table V Regression results: COR to posterior acromion distance

Variable	β (95% CI)	*P* value
PRO		
ASES	0.30 (−0.33, 0.93)	.353
VAS	−0.03 (−0.10, 0.04)	.378
ROM		
FF	0.27 (−0.63, 1.17)	.555
ER0	0.46 (−0.12, 1.05)	.119
IR spine	−0.12 (−0.23, −0.10)	**.033**
IR90	0.12 (−0.72, 0.97)	.771

COR, center of rotation; *PRO*, patient-reported outcome; *ASES*, American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form; *VAS*, visual analog scale; *ROM*, range of motion; *FF*, forward flexion; *ER0*, external rotation; *IR spine*, internal rotation to spinal level; *IR90*, internal rotation with the arm at 90°; *CI*, confidence interval.
Boldface indicates significance ($P < .05$).

in ROM, of which the COR to coracoid distance had the broadest effect on the sagittal plane ROM. Every sagittal plane measurement had an effect on a ROM parameter, even after adjusting for preoperative ROM. These findings may have implications for surgical technique as well as implant design.

The COR to coracoid distance was the most important in terms of overall ROM with gains in FF, ER0, and IR90. In fact, it was the only distance that affected FF and IR90, demonstrating that coracoid impingement is a potential source of limitation in ROM after RSA. Interestingly, IR to spinal level was not affected by this distance. This may be because the humeral component passes inferiorly to the coracoid. The COR to coracoid distance increases as the glenosphere is shifted posterior and inferior. Although previous work has demonstrated the importance of either lateralization or inferior position in decreasing bony impingement,[4,19,21,23,40] it appears that the posterior shift is also important.[25] Clinically, the extent of desirable inferior position may be limited by the risk of nerve injury and/or acromial stress fracture.[8,13,43] Thus, posterior shift may be an appealing way to decrease coracoid impingement. Possible methods for achieving this position may include adjusting baseplate position or use of an eccentric glenosphere with the offset directed posteriorly. The use of an eccentric glenosphere may be preferable as it is the posteroinferior positioning of the glenosphere in relation to the acromion and coracoid that appears to improve ROM, and adjusting the baseplate position may compromise fixation within the glenoid vault.

Our findings also demonstrated that COR to acromial distances are related to postoperative ROM. All 3 measured distances (COR to anterior, middle, and posterior acromion) were associated with improvements in IR to the spinal level, even after adjusting for distalization. However, the fact that IR to the spinal level was affected by all acromial distances suggests the relationship is not necessarily a reflection of acromion impingement, but rather representative of generalized inferior positioning that decreases glenoid impingement in IR. However, further study may be warranted to evaluate the combined effect of the inferior and lateral position in the 3D plane in order to better define the amount of inferior position required to optimize IR behind the back.

Interestingly, among the acromial distances, the COR to middle acromion had the greatest effect on IR to the spine. Additionally, it was the only acromial distance associated with improvement in ER0. This may indicate that optimal glenosphere positioning may also be affected by its relative position to the acromion in the anteroposterior direction, of which the middle acromion may afford improved ROM.

There was no relation with any of the distances and outcomes scores. This is not surprising as there are many multifactorial factors affecting outcomes following RSA. Outcomes have been shown to be affected by structural (ie, soft tissue) factors[7,9,37] and nonstructural (ie, psychosocial) factors,[3,11,14] which were unable to be completely controlled for in this study.

The findings of this study should be viewed in light of its limitations. First, as this study was based on plain radiographs, computed tomography scans were not used, which could affect the accuracy. With plain radiographs, sagittal views may also have variability in quality, but radiographs were obtained according to standardized protocols across study sites. Additionally, all intraclass correlation coefficients were greater than 0.995, indicating near perfect agreement. The findings of this study and previous work assessing the subcoracoid distance[6,25] suggests this distance is important for improved rotational ROM. Although postoperative computed tomography scans were not used for this study, there is a rationale to investigate the implications of this distance further with preoperative computed tomography–guided planning software and postoperative ROM. Second, all soft tissue factors were unable to controlled for. Specifically posture type, which takes into account scapulothoracic posture, has been shown to affect rotational ROM.[27,28] In an effort to allay these factors, preoperative ROM as well as patient demographics were adjusted for in the analysis. Another limitation was the lack of standardization of humeral retrotorsion, which has been theorized to affect rotational ROM.[16,29,38] In regard to FF and its relationship with the subcoracoid distance (Table II), although the *P* value reached significance ($P < .001$) the β (95% CI) is fairly wide 1.78 (0.85-2.72), and our findings should be interpreted with this in mind. Finally, this study's focus was on COR distances in relation to bony landmarks. Although research on ROM has largely centered on bony impingement, soft tissue factors and muscle tensioning plays an undefined yet likely important role.

Conclusion

Evaluation of the COR following RSA in the sagittal plane suggests that a posteroinferior glenosphere position may improve ROM when using a 135° inlay humeral component and a lateralized glenoid.

Disclaimers:

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Conflicts of interest: Patrick J. Denard is a consultant for and receives royalties from Arthrex, Inc. Benjamin W. Sears is a consultant for United Orthopaedic Corp., Biopoly, and Shoulder Innovations and receives research support from Arthrex, Inc., FX Solutions, and Tornier. Evan Lederman is a consultant for and receives royalties from Arthrex, Inc. Brian C. Werner is a consultant for Arthrex, Inc., and receives research support from Biomet and Flexion Therapeutics. Philipp Moroder is a consultant for and receives royalties from Arthrex, Inc. 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.

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