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A method for documenting the change in center of rotation with reverse total shoulder arthroplasty and its application to a consecutive series of 68 shoulders having reconstruction with one of two different reverse prostheses

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Background: Reverse shoulder arthroplasty changes the center of rotation (COR) of the glenohumeral joint and in doing so affects the resting tension in the deltoid and residual cuff muscles, as well as their respective moment arms. The purpose of this study was to assess the change in COR from the preoperative to postoperative state in a group of patients undergoing reverse shoulder arthroplasty.
Materials and methods: The position of the COR in relation to a scapular coordinate system was determined for the anteroposterior and axillary radiographs before and after reverse total shoulder arthroplasty for 68 shoulders (63 patients) receiving either a Delta prosthesis or an Encore Reverse Shoulder Prosthesis.
Results: Preoperatively, the COR was superiorly displaced a mean of 9 ± 7 mm from the origin of the coordinate system. For all shoulders, the postoperative COR was inferiorly displaced by 12 mm to a position 3 ± 3 mm below the coordinate origin ($P < .001$) and medially displaced by 27 ± 4 mm from the coordinate origin ($P < .001$) in the anteroposterior projection. For the shoulders receiving the Delta prosthesis, the COR was inferiorly displaced by 2 ± 3 mm from the coordinate origin, whereas it was inferiorly displaced by 7 ± 3 mm with the Encore prosthesis ($P < .001$). The COR was medially displaced by 28 ± 4 mm with the Delta prosthesis and by 19 ± 3 mm with the Encore prosthesis ($P < .001$).
Conclusions: The position of the COR relative to the scapula is significantly altered by reverse shoulder arthroplasty and is significantly different for 2 different implant designs.
Level of evidence: Basic Science Study, Anatomic/Radiologic Study.

Keywords: Reverse; arthroplasty; glenohumeral; center of rotation

Reverse shoulder arthroplasty is used to treat conditions, such as anterosuperior escape and pseudoparalysis, in which the location of the center of rotation (COR) cannot be stabilized by anatomic arthroplasty.[3,8,9,17,25] In the

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reverse total shoulder, the COR is in the center of a spherical glenoid component fixed to the scapula,[17] whereas before surgery, the COR is in the center of the humeral head.[15] Changes in the COR affect the resting tension in the deltoid and residual cuff muscles as well as their respective moment arms. The position of the COR after a reverse total shoulder arthroplasty is determined by the design of the glenoid prosthesis and the position in which it is placed. Several studies have evaluated the effect of reverse total shoulder prosthesis design on range of motion,[12,13] implant micromotion,[11,14,23] and unwanted contact between the humeral component and the scapula,[12,20,22] but with 1 exception,[6] no studies to date have quantified the actual change in glenohumeral COR after reverse shoulder arthroplasty in patients.

In that the positioning of the COR is a variable under the control of the surgeon and is likely to have an important effect on the biomechanics of the reconstruction, it is desirable to have a method for documenting the preoperative and postoperative position of the COR so that future clinical research can correlate the outcome with this anatomic parameter. In this study we present a method for documenting the position of the COR before and after reverse total shoulder arthroplasty and use it to test the hypotheses that (1) the COR of the glenohumeral joint is changed in a characteristic manner by reverse shoulder arthroplasty and (2) the change in COR is different for different implant designs.

Materials and methods

Radiographic method

The method requires standardized radiographs in the anteroposterior (AP) and axillary projections.[18] For each radiograph, the COR is documented as either the center of the native humeral head or the center of the prosthetic humeral head for preoperative films and the center of the glenosphere for postoperative films (Figure 1). These centers were located by use of picture archiving and communication system tools (Centricity PACS; GE Healthcare Technologies, Waukesha, WI). First, a best-fit circle was drawn on the native humeral head, the prosthetic humeral head, or the glenosphere. Second, perpendicular diameter lines were drawn, and their intersecting point was marked as the COR. Next, transparent templates that define a coordinate system based on the position and orientation of the scapula in each projection were superimposed on the PACS images and fit by eye to the outline of scapula. The relationship of the COR to the origin of the coordinate system was then measured for each projection in each shoulder before and after surgery. Superior-inferior and medial-lateral distances of the head center from the origin of the coordinate system were measured on the AP projection (Figure 1, A). Anterior-posterior and medial-lateral distances of the head center from the origin of the coordinate system were measured on the axillary projection (Figure 1, B).

Study shoulders

Institutional review board approval was obtained before we commenced this investigation. Patients undergoing reverse shoulder arthroplasty at our institution by 1 of 2 surgeons between 2004 and 2009 were included. Two patients were excluded because of poor-quality radiographs, leaving 63 patients (68 shoulders) for evaluation. The indication for surgery was cuff tear arthropathy in 28 shoulders, failed arthroplasty in 25, failed cuff surgery in 14, and post-traumatic deformity in 1. Of the shoulders, 59 received a Delta prosthesis (DePuy, Warsaw, IN) and 9 received an Encore Reverse Shoulder Prosthesis (Encore Medical, Austin, TX). Both surgeons made an effort to place the glenosphere as inferiorly as possible from 2007 to 2009 in an effort to avoid scapular notching.[22] A summary of patient demographics for both groups of patients is shown in Table I.

Statistical analysis

For assessment of the significance of change in COR position between preoperative and postoperative states, a 2-tailed, paired t test was used. For comparison of the 2 prosthesis designs, a 2-tailed, unpaired t test was used, assuming unequal variance. The results were considered significant at $P < .05$.

Results

Preoperatively, the COR was superiorly displaced a mean of 9 ± 7 mm from the coordinate origin and centered in the anterior-posterior and medial-lateral directions. When the results for both types of prostheses were combined, the postoperative COR was inferiorly displaced by 12 mm to a position 3 ± 3 mm below the coordinate origin ($P < .001$) and medially displaced by 27 ± 4 mm from the coordinate origin ($P < .001$) on the AP projection. On the axillary projection, the postoperative COR remained centered in the anterior-posterior direction and was medially displaced by 24 ± 8 mm from the coordinate origin ($P < .001$) (Table II). Our first hypothesis—that the COR of the shoulder is changed in a characteristic manner by reverse shoulder arthroplasty—was therefore supported.

Our second hypothesis—that the change in COR is different for different implant designs—was also supported. The postoperative position of the COR on the AP projection was significantly different for the Delta and Encore shoulders. Postoperatively, on the AP projection, the COR was displaced inferiorly by 2 ± 3 mm from the coordinate origin for the Delta prosthesis and displaced inferiorly by 7 ± 3 mm from the coordinate origin for the Encore prosthesis ($P < .001$). Postoperatively, on the AP projection, the COR was displaced medially by 28 ± 4 mm from the coordinate origin for the Delta prosthesis and displaced medially by 19 ± 3 mm from the coordinate origin for the Encore prosthesis ($P < .001$). Postoperatively, on the axillary projection, the COR remained centered in the anterior-posterior direction for both the Delta prosthesis

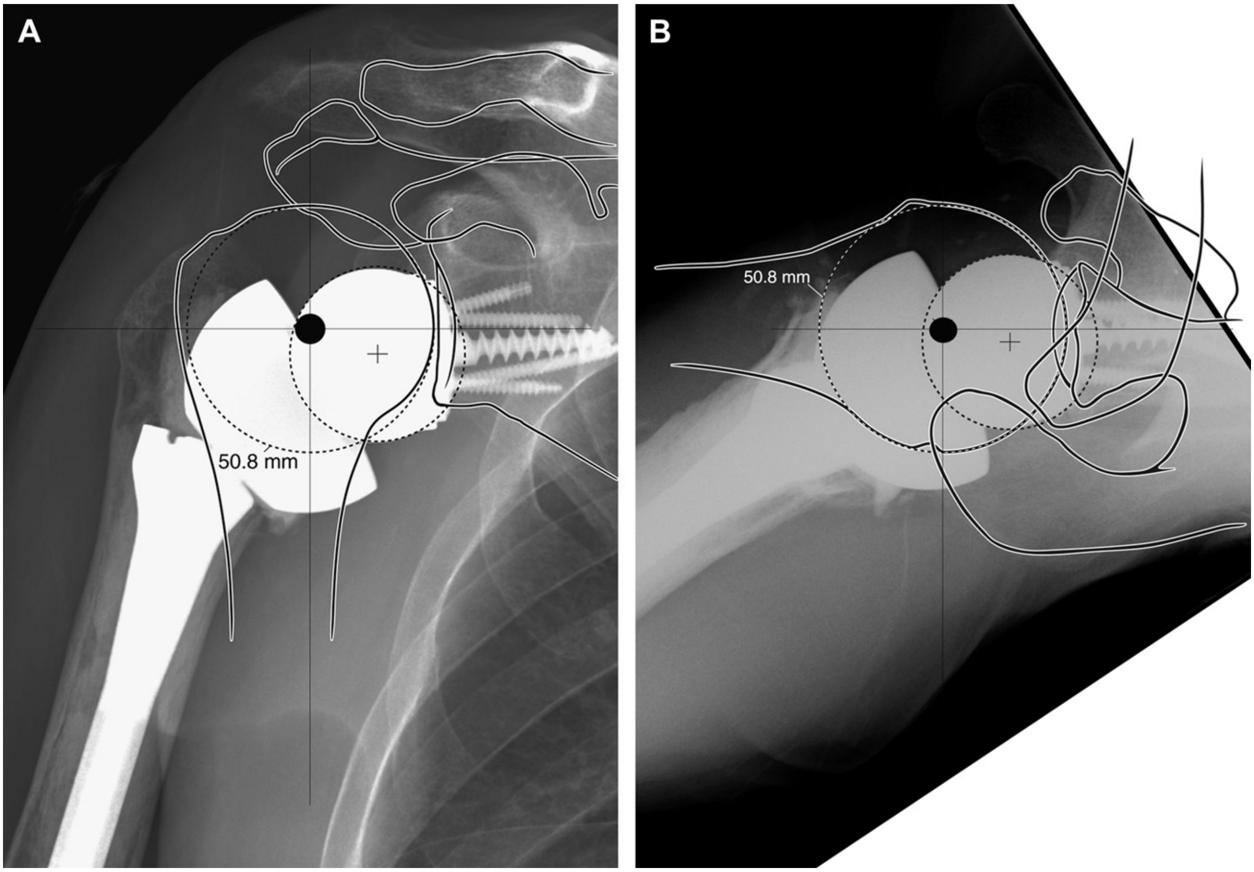

Figure 1 (**A**) AP radiograph and (**B**) axillary radiograph of a patient who underwent reverse shoulder arthroplasty with the superimposed coordinate system. The origin of the coordinate system is indicated by the *black circle*. The COR is the center of the humeral head in anatomic shoulders or conventional arthroplasties and the center of the glenosphere (as shown here with a *plus sign*) for reverse total shoulders. The superior-inferior and lateral-medial distances of the COR from the coordinate origin are measured on the AP radiograph. The anterior-posterior and the lateral-medial distances of the COR from the coordinate origin are measured on the axillary radiograph.

and the Encore prosthesis and was displaced medially by 26 ± 8 mm from the coordinate origin for the Delta prosthesis and 16 ± 4 for the Encore prosthesis ($P < .001$) (Table III) (Figure 2).

Table I Baseline patient demographics

	Delta (n = 59)	Encore (n = 9)
Age (y)	71 ± 10	72 ± 8
Side		
R	34 (58%)	7 (78%)
L	25 (42%)	2 (22%)
Gender		
M	17 (29%)	4 (44%)
F	42 (71%)	5 (56%)
Diagnosis		
Cuff tear arthropathy	22 (37%)	5 (56%)
Failed arthroplasty	24 (41%)	1 (11%)
Failed cuff surgery	13 (22%)	2 (22%)
Post-traumatic	0 (0%)	1 (11%)

Discussion

Reverse shoulder arthroplasty is used to treat shoulders with severe disruption of the normal stabilizing mechanisms of the shoulder. The advantage of this procedure is that it fixes the glenohumeral COR in a new position that defines the moment arms and the resting tension of the scapulohumeral muscles. Re-tensioning of the deltoid is essential to regaining active elevation and has prompted recent investigators to develop a method to preoperatively set the height of implantation for the reverse prosthesis based on contralateral radiographs.[16] The position of the new COR in the center of the glenosphere is determined both by the design of the glenoid implant and by the location in which it is placed by the surgeon. In our study, the COR was moved a mean of 19 mm medially (on the axillary view), 27 mm medially (on the AP view), and 12 mm inferiorly (on the AP view) with the insertion of the reverse prosthesis. In 4 shoulders having reverse total shoulder arthroplasties for tumor

Table II Preoperative and postoperative distances of CORs from coordinate origin for all shoulders

	Axillary		AP	
	M/L position	A/P position	M/L position	S/I position
Preoperatively (mm)				
Mean	3.4 medial	0.1 anterior	0.0 lateral	9.0 superior
SD	6.7	9.3	5.8	7.0
Postoperatively (mm)				
Mean	24.4 medial	0.3 posterior	26.9 medial	2.7 inferior
SD	7.9	1.3	4.4	3.4
P value	< .0001	.64	< .0001	< .0001

M/L, Medial-lateral; *A/P*, anterior-posterior; *S/I*, superior-inferior.

Table III Preoperative and postoperative distances of CORs from coordinate origin for each implant design

	Axillary		AP	
	M/L position	A/P position	M/L position	S/I position
Preoperatively				
Delta				
Mean (mm)	3.4 medial	0.7 anterior	0.3 lateral	9.1 superior
SD (mm)	7.2	9.5	5.2	7.0
Encore				
Mean (mm)	3.3 medial	3.4 posterior	2.1 medial	8.4 superior
SD (mm)	2.6	7.2	8.9	7.6
P value	.90	.16	.44	.81
Postoperatively				
Delta				
Mean (mm)	25.6 medial	−0.4	28.0 medial	−2.0
SD (mm)	7.6	1.3	3.3	3.0
Encore				
Mean (mm)	16.1 medial	0.2	19.3 medial	−6.9
SD (mm)	4.0	1.3	2.5	3.1
P value	< .001	.31	< .001	.001

M/L, Medial-lateral; *A/P*, anterior-posterior; *S/I*, superior-inferior.

reconstruction, De Wilde et al[6] used a digital image manipulation system (Photoshop; Adobe Systems, San Jose, CA) to measure the change in COR, finding that in these 4 shoulders, the COR was medialized 28 mm and moved 5 mm inferiorly. Because the glenoid anatomy in these cases was unaltered by the shoulder pathology, these authors were able to reference the position of the COR to the midpoint of the line between the superior and inferior bony edges of the articular surface. In cases of rotator cuff tear arthropathy or failed conventional total shoulder arthroplasty or after a reverse total shoulder arthroplasty, these landmarks are neither dependable nor reproducible. For this reason, the method presented in this report used as much of the radiographic anatomy of the scapula as is visible on the AP and axillary images to orient the coordinate system, rather than relying on only 2 points on the glenoid.

Previously, investigators have evaluated in vitro how glenosphere position on the scapula, angle of glenosphere insertion, and amount of lateral offset affect parameters such as range of motion, implant micromotion on the scapula, and scapular notching.[4,11-14,19,20,22,23] However, a practical method for documenting the in vivo change in COR resulting from reverse total shoulder arthroplasty in actual patients has not been previously described.

The diagnoses in this series were associated with superior displacement of the humeral head center in relation to the head center of normal shoulders.[7,17,24] By design, the reverse total shoulder moved the COR medially and inferiorly. As indicated by the fact that the SDs for the post—reverse arthroplasty COR were small (3 mm on average), the new COR is determined mostly by the prosthesis design and, to a lesser degree, by the surgical technique in this series.

The inferior and medial displacement of the COR can be expected to affect the tension and moment arms of the 3 components of the deltoid muscle and any rotator cuff muscles that remain intact.[3,11,12,15,17,22] Because of changes in lever arms and resting muscle lengths with reverse prostheses, some authors have recommended concomitant

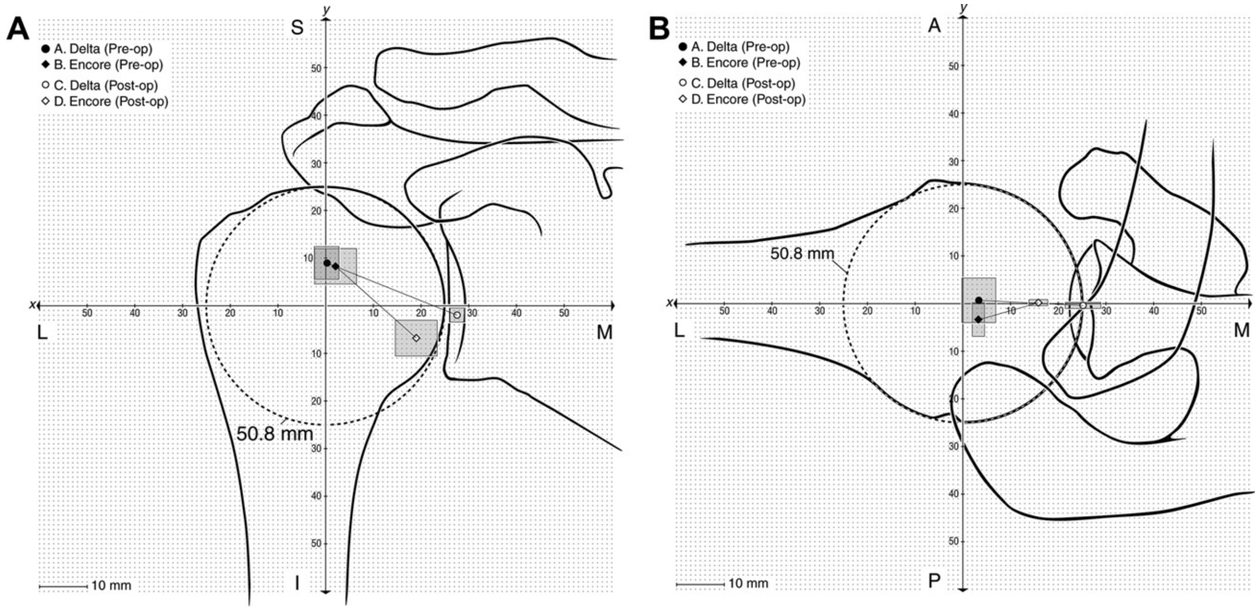

Figure 2 Preoperative (*Pre-op*) to postoperative (*Post-op*) change in COR for the 2 prosthesis designs in the (**A**) AP projection and (**B**) axillary projection. *Circles* and *diamonds* represent the average COR position for the Delta and Encore designs, respectively. *Solid symbols* and *open symbols* represent the preoperative and postoperative average COR positions, respectively. *Gray boxes* indicate the SDs for these positions. *S*, Superior; *I*, inferior; *L*, lateral; *M*, medial; *A*, anterior; *P*, posterior.

latissimus dorsi and teres major transfers to optimize external rotation strength.[1,2,10,21] Others have suggested modifications in reverse shoulder design, such as increased lateral offset, that change the tension in the remaining infraspinatus and teres minor.[5,9]

Although we observed differences in COR placement between 2 prosthesis designs, we did not correlate these differences with the outcome of surgery and make no conclusions regarding the superiority of one design over another. However, our observations do suggest that there may be opportunities to modify the COR location, by either prosthesis design or surgical technique, to suit the specific needs of specific shoulders. Furthermore, the method of documentation of the changes in COR provides a way to correlate outcomes with the COR position in future clinical research.

The results of this study need to be viewed in light of certain limitations. First, the series represents the practice of 2 surgeons who work at the same institution; the changes in COR may be different for other surgeons. Second, the study only evaluated 2 of the several reverse shoulder designs that are currently available; our findings only relate to the designs studied. Third, as mentioned previously, we did not evaluate functional outcome measures such as range of motion, strength, and stability and cannot comment on the clinical significance of the differences in position of the COR. Fourth, the technique for implantation of the reverse prosthesis evolved over the time period of the study, with a preference for inferior placement of the glenosphere later in the study. However, it is noted that the SDs in superior-inferior position were quite small (Table III); thus, the variability in surgical technique does not seem to be as influential on the position of the COR as the prosthesis design. Fifth, this study does not address the many other factors a surgeon must consider in the selection and conduct of a reverse total shoulder arthroplasty, including optimizing the durability of scapular fixation, minimizing the lever arms that may contribute to glenoid component loosening and stability, avoiding unwanted contact between the medial aspect of the humeral prosthesis and the scapular neck, and optimizing the diameter of curvature or the glenosphere.

Despite these limitations, the data support our 2 hypotheses: the COR of the glenohumeral joint is characteristically shifted in an inferior and medial direction after reverse shoulder arthroplasty, and the change in the COR varies depending on implant design. We have described a practical method for documenting the head center position before and after reverse arthroplasty and suggest that this parameter may be useful in future clinical outcomes studies of reverse shoulder arthroplasty.

Conclusion

A reverse total shoulder arthroplasty is performed specifically to change the COR to a position that will enhance shoulder function. We have presented a clinically practical method for documenting the presurgical and postsurgical position of the COR in each case of reverse total shoulder arthroplasty. In a series of shoulders having reverse arthroplasty, the method shows the significant change in COR and the statistically significant differences in head center position with 2 different designs of reverse total shoulder components.

Disclaimer

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