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Mid-term outcomes of reverse shoulder arthroplasty using the alternative center line for glenoid baseplate fixation: a case-controlled study

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Background: A critical step in reverse shoulder arthroplasty (RSA) is glenoid baseplate fixation. In cases of glenoid bone loss, use of the anatomic glenoid center line may not provide sufficient bone support for fixation. Anteversion along the alternative center line is a described method for achieving baseplate fixation in these cases. However, concern remains regarding negative consequences in functional outcomes and complications. The purpose of this study was to compare the outcomes of RSA using the anatomic or alternative center line.

Methods: We performed a retrospective case-controlled study of patients who underwent RSA between November 2006 and August 2017, performed by a single surgeon, with a minimum of 2 years' follow-up. Patients treated with the anatomic center-line technique for baseplate fixation were matched 3:1 based on sex, indication for surgery, and age with patients treated with the alternative center-line technique. Patient-reported outcome measures (PROMs), active range of motion, and the ability to perform functional tasks of internal rotation were compared. Evaluations of the most recently obtained radiographs focused on acromial fractures, scapular notching, and glenoid loosening.

Results: A total of 88 patients (66 in anatomic center-line group and 22 in alternative group) participated in the matched analysis, with a mean age of 74.2 years (range, 58-89 years) and mean follow-up period of 53 months (range, 24-130 months). At the final follow-up, we found no significant differences in PROMs, including the Simple Shoulder Test score ($P = .829$), American Shoulder and Elbow Surgeons score ($P = .601$), visual analog scale pain score ($P = .068$), and Single Assessment Numeric Evaluation score ($P = .674$). Moreover, both the overall improvements in these PROMs and all active motions and functional tasks of internal rotation were not different. No radiographic evidence of glenoid loosening was found in either group, and 2 patients in each cohort (3% of the anatomic group and 9% of the alternative group) experienced an acromial fracture. Low-grade scapular notching developed in 15.2% of the anatomic group and 18.2% of the alternative center line group ($P = .736$).

Conclusion: The alternative center line can be used for baseplate fixation in the setting of glenoid bone loss and leads to similar patient outcomes and functional tasks of internal rotation, as well as a low rate of complications, compared with the anatomic center line following RSA.

Level of evidence: Level III; Retrospective Cohort Design; Treatment Study

Keywords: Reverse shoulder arthroplasty; alternative center line; outcomes; glenoid bone loss; baseplate fixation; notching; loosening; glenoid component placement

Performed at Holy Cross Hospital and Holy Cross Orthopedic Institute, Fort Lauderdale, FL, USA.

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The use of reverse shoulder arthroplasty (RSA) has seen exponential growth with expanding indications.[8,25] Critical to the success of RSA has been improvement in glenoid fixation, with glenoid-sided failures becoming more of a rare complication.[7] Traditionally, the glenoid baseplate can be implanted along the anatomic center line matching the normal glenoid version. However, glenoid bone loss can be quite severe in complex primary and revision RSA cases, and the remaining bone along the anatomic center line may not be sufficient to support fixation of the glenoid baseplate.[23,24] Bone grafting, placement of the baseplate along the alternative center line, and custom prostheses, as well as a combination of techniques, have all been used to manage bone loss at the time of RSA.[9,10,13,15,34] Each technique has advantages and disadvantages, and few studies have reported the outcomes of each technique.[4,20,9,13,15,18,34]

The alternative center line was first described as a method of achieving glenoid baseplate fixation in the setting of severe glenoid bone loss (Fig. 1).[9] This surgical technique requires anteversion and inferior tilting of the central baseplate axis into the column of bone central to the glenoid vault, where the base of the scapular spine and the base of the coracoid meet (Fig. 2), prioritizing glenoid baseplate fixation over what is traditionally considered anatomic placement in the glenoid. Klein et al[15] initially reported no difference in American Shoulder and Elbow Surgeons (ASES) scores between patients treated with the anatomic center line and those treated with the alternative center line. With an alteration in glenoid version, concern remains that functional outcomes, especially tasks of internal rotation, may be negatively impacted. Furthermore, with fixation directed in proximity to the scapular spine, concern remains that use of the alternative center line may result in higher rates of scapular spine fractures or additional complications.

The purpose of this study was to compare the outcomes of RSA when the glenoid baseplate is placed in the traditional center line vs. when placed in the alternative center line, with a focus on multiple patient-reported outcome measures (PROMs), functional tasks of internal rotation, and radiographic and clinical complications. We hypothesized that patients with baseplate fixation using the alternative center line would show noninferior outcomes and low rates of complications, despite worse presurgical glenoid pathology, compared with patients with standard glenoid baseplate fixation.

Methods

Patient selection

A retrospective case-controlled study was performed using our institutional shoulder and elbow repository, identifying all patients undergoing primary RSA between November 2006 and August 2017. The inclusion criteria identified patients with complete preoperative data and a minimum of 2 years' follow-up. Two cohorts were created based on the surgical technique used for glenoid baseplate placement, and a matched-cohort analysis was performed to compare the standard and alternative center-line groups. The standard center-line cohort was matched in the largest possible ratio (3:1) to the alternative center-line cohort (Table I) based on sex, primary indication for surgery, and age (±8 years).

Surgical technique

All procedures were performed by a single shoulder and elbow fellowship–trained surgeon who performs high-volume shoulder arthroplasty annually at a single institution. The same monoblock central-screw glenoid baseplate was used in all cases (Reverse Shoulder Prosthesis; DJO Surgical, Austin, TX, USA). In cases in which the anatomic center line was used, the baseplate was inserted along the standard glenoid center line as described by Matsen and Lippitt[21] and Bicos et al.[3] Alternative center-line placement of the baseplate was used to achieve primary baseplate fixation as described by Klein et al[15] in cases in which it was determined preoperatively or intraoperatively that there was inadequate bone to support fixation of the center screw. If <80% coverage of the baseplate could be obtained on host bone, structural grafting with either humeral head autograft or femoral head allograft was used to augment baseplate support. Attempts were made to achieve secondary fixation by resting the peripheral rim of the glenosphere on the host glenoid bone or bone graft to distribute the load observed through the baseplate fixation.[27] Often, a glenosphere with a lip extension was used to achieve this goal (glenosphere sizes of 36 mm – 4, 40 mm neutral, and 40 mm – 4). Postoperatively, all patients were managed with the same rehabilitation protocol consisting of wearing a shoulder immobilizer with a self-directed therapy protocol focused on only pendulum exercises for the first 6 weeks, followed by an active-assisted stretching program. Strengthening and lifting were delayed for 3 months.

Clinical and radiographic evaluation

PROMs analyzed preoperatively and at most recent postoperative follow-up included the Simple Shoulder Test (SST) score, ASES score, visual analog scale (VAS) score for pain, and Single Assessment Numeric Evaluation (SANE) score. Active range of motion also was reported through goniometer-based measurements of external rotation and forward elevation. Internal rotation was measured based on the highest vertebral level reached behind the back. Functional tasks of internal rotation were compared by noting the patient's reported ability to reach the back, wash the back, and perform toileting. Sequential postoperative anteroposterior, scapular-Y, and axillary lateral radiographs were reviewed for evidence of acromial fractures,[16] scapular notching,[32] or gross glenoid loosening.[30] All imaging reviews were performed by a shoulder and elbow fellow (R.C.) independently from the primary surgeon.

Data were compared by either an independent-samples t test or the Mann-Whitney U test for continuous variables and by the Fisher exact test for categorical variables. These significance tests were 2-tailed, and $P < .05$ was deemed statistically significant.

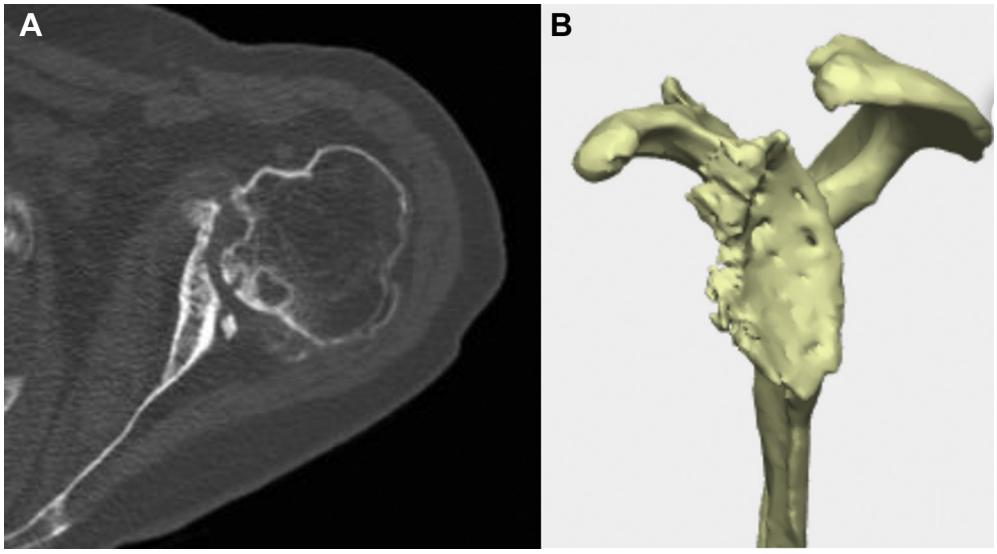

Figure 1 (**A**) Axial computed tomography scan showing severe glenoid bone loss, medialization, and small window of bone in glenoid vault available for baseplate fixation. (**B**) Three-dimensional reconstruction of same glenoid with severe bone loss.

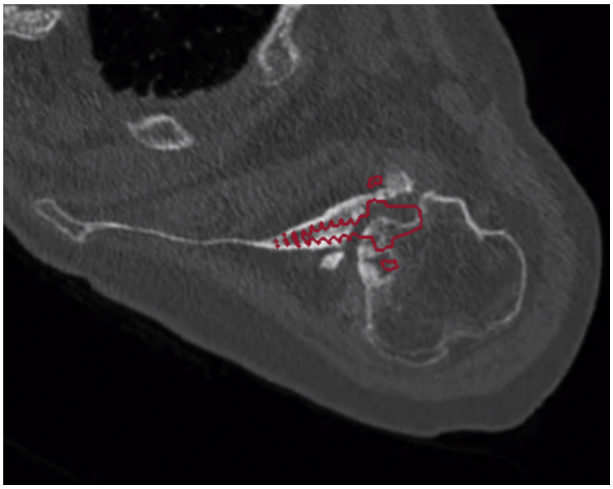

Figure 2 Virtual planning software showing planned anteversion of baseplate into remaining column of glenoid bone.

Results

The query of our institutional repository identified 748 patients treated using standard center-line placement (standard group) and 35 treated using alternative center-line placement (alt center group). Of these patients, 532 in the standard group (61%) and 22 in the alt center group (63%) had complete preoperative data with a minimum of 2 years' follow-up. We matched 66 standard patients 3:1 to the 22 alt center patients. The groups were well matched (Table I) with an equal sex distribution (27% male and 73% female patients; $P > .999$), similar age ($P = .812$), and similar indications ($P > .999$). The underlying indications for RSA in both cohorts included failed total shoulder arthroplasty or failed hemiarthroplasty (45.5%), cuff tear arthropathy (22.7%), osteoarthritis (18.2%), locked anterior dislocation (9.1%), and fracture sequelae (4.5%) (Table I). The mean follow-up periods for the standard and alt center groups were 54 months (range, 24-130 months) and 50 months (range, 25-97 months), respectively.

Because the alternative center line was used in cases of severe glenoid bone loss, larger glenosphere sizes were more commonly used in these patients ($P = .0003$). These larger glenospheres with more medialized centers of rotation helped to limit stress on the primary fixation, more adequately cover glenoid bone deficiency, provide a lip extension to compress bone graft, and provide secondary fixation through load-sharing contact with the native glenoid and/or bone graft. In addition, these larger glenospheres were typically used to protect glenoid bone grafts, which were applied in 41% of patients treated using the alternative center line and 9% of those with standard placement ($P = .0002$). In most patients in the alt center group, a glenosphere size of either 36-mm neutral (6-mm lateralized center of rotation) (41%) or 36 mm – 4 (2-mm lateralized center of rotation) (41%) was implanted. On the other hand, patients with standard baseplate fixation underwent implantation of a glenosphere size of 32 mm – 4 (6-mm lateralized center of rotation) in 45.4% of cases and 36 mm neutral (6-mm lateralized center of rotation) in 31.8%. The mean glenosphere lateralized center-of-rotation offset was 6 mm (±1 mm) in the standard group vs. 4 mm (±2 mm) in the alt center group ($P = .002$) (Fig. 3).

A summary of the clinical and radiographic comparison of PROM improvement, PROM scores at most recent follow-up, active motion, functional internal rotation tasks, and radiographic outcomes is presented in Table II. All of the most recent postoperative PROMs, including the SST

Table I Demographic data for reverse shoulder arthroplasty patients, matched 3:1 for glenoid baseplate placement in standard and alternative center line

	Standard (n = 66)	Alternative (n = 22)	*P* value
Mean follow-up (range), mo	54 (24-130)	50 (25-97)	.476
Sex distribution, n (%)			>.999
Male	18 (27)	6 (27)	
Female	48 (73)	16 (73)	
Mean age (range), yr	73.9 (58-88)	74.4 (61-89)	.812
Indication, n (%)			>.999
Cuff tear arthropathy	15 (22.7)	5 (22.7)	
Locked anterior dislocation	6 (9.1)	2 (9.1)	
Failed hemiarthroplasty or TSA	30 (45.5)	10 (45.5)	
Fracture sequelae	3 (4.5)	1 (4.5)	
Osteoarthritis	12 (18.2)	4 (18.2)	
Glenosphere size, n (%)	4 (6.1)	1 (4.5)	.003*
32 mm neutral	30 (45.4)	2 (9.0)	
32 mm – 4	21 (31.8)	9 (41)	
36 mm neutral	7 (10.6)	9 (41)	
36 mm – 4	4 (6.1)	1 (4.5)	
40 mm neutral	0	0	
40 mm – 4			
Glenoid bone grafting, n (%)	6 (9.1)	9 (40.9)	.002*

TSA, total shoulder arthroplasty.
* Statistically significant ($P < .05$).

score, ASES score, VAS pain score, and SANE score, showed no differences between the 2 cohorts. Moreover, the mean improvements in outcomes from preoperatively to the most recent postoperative follow-up remained the same between the cohorts. Active range of motion, including internal rotation, external rotation, and forward elevation, as well as the ability to perform functional tasks of internal rotation (performing toileting, washing the back, and reaching the back), was also not different.

With an average radiographic follow-up period of 48 months for both cohorts, there was no evidence of glenoid loosening, and no differences were observed in the incidence of acromial fractures and scapular notching (Table II). Two shoulders in each cohort had an acromial fracture, characterized using the Levy classification[16] as type 3 in the alt center group and types 2 and 3 in the standard group. Notching developed in 4 alt center shoulders (18.2%) and 10 standard shoulders (15.2%, $P = .736$). All notching of the scapular neck was classified as grade 1 according to the Nerot grading system,[32] with the exception of 2 patients in the standard cohort with grade 2 notching.

Discussion

Use of the alternative center line for glenoid baseplate fixation in the setting of severe glenoid bone loss demonstrated no differences in pain, function, or complications and remains a useful surgical technique for optimizing glenoid component fixation in RSA. The results of our study support the use of this surgical technique, which prioritizes glenoid fixation over restoration of the anatomic axis of the scapular plane without compromising overall shoulder function or specific functional tasks of internal rotation and without an increased risk of acromial fractures.

Management of glenoid bone loss during RSA can be challenging. Several surgical techniques have been described and specific implants have been developed to assist in glenoid baseplate placement. When priority is placed on restoring the anatomic glenoid version based on the axis of the scapular plane, the use of bone graft to reconstruct glenoid defects or the use of augmented or patient-specific implants has become popularized. When priority is instead placed on maximizing baseplate fixation, identifying the largest column of bone remaining in the scapula directs the central axis of the baseplate fixation toward the alternative center line. In all cases, survivability of the glenoid component rests on achieving osseous integration to the baseplate. Without such osseous integration, baseplate failure or gross loosening is inevitable.

Use of bone graft to restore glenoid bone deficiency is common in RSA, as the fixation used for the glenoid baseplate provides for stability of both the bone graft and glenosphere. Numerous studies have reported successful results using autograft in the setting of RSA, with high rates of graft incorporation.[5,19,26,30] Although bone graft techniques have been effective, multiple studies have demonstrated shortcomings. Specific to cases that used the

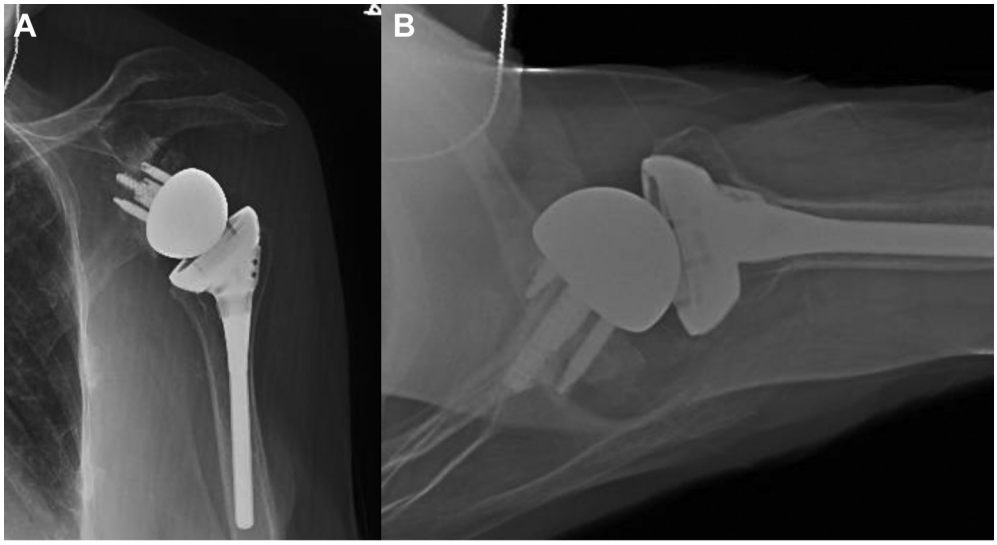

Figure 3 Postoperative radiographs showing alternative center-line placement of glenoid baseplate. (**A**) Anteroposterior radiograph showing placement with inferior tilt. (**B**) Axillary radiograph showing anteversion of baseplate and large posterior structural autograft.

anatomic center line, Wagner et al[34] found that patients who required bone grafting had a lower rate of survival free of revision than those who did not require grafting. Jones et al[13] noted that patients requiring bone grafting had worse outcomes and range of motion than a control group. Furthermore, bone grafting and RSA performed in the revision setting have been shown to be independent risk factors for aseptic baseplate loosening.[4] Recently, Ho et al[11] found a 25% rate of structural graft resorption and gross baseplate loosening. In contrast, Klein et al[15] reported that managing glenoid bone defects with the selective use of the alternative center line, bone grafting, and larger glenospheres enabled patients to obtain the same outcomes as those with normal glenoid morphology. Similarly, our study demonstrated no difference in complications, PROMs, functional tasks of internal rotation, or radiographic complications when using the alternative center line, in which bone grafting was more commonly used.

There are limited reports on the outcomes of augmented glenoid baseplates and custom glenoid components, and the body of evidence supporting the use of these implants is lacking. Early results have been encouraging, with low rates of notching, complications, and aseptic glenoid loosening.[33] Roche et al[29] compared augmented baseplates with bone grafting and found no difference in clinical outcomes. The augmented baseplate cohort had a lower complication rate and less scapular notching. Although augmented baseplates may increase the amount of backside baseplate coverage in mild to moderate defects, the current designs may not be adequate for the most severe defects. Augmented baseplates attempt to improve baseplate stability by increasing the host bone contact, minimizing glenoid bone removal during preparation, and preserving the goal of restoration of more anatomic glenoid version. This differs from alternative center-line placement that prioritizes primary fixation along the central baseplate axis to maximize bone support, irrespective of the goal of restoration of normal anatomic glenoid version or inclination.

The use of virtual planning software, patient-specific instrumentation, and intraoperative navigation has been shown to improve the accuracy of implementing a surgical plan.[2,12,17] With virtual planning software, it is possible to anticipate the degree of glenoid bone loss and the challenges of maximizing baseplate fixation. Integration of 2-dimensional computed tomography scans helps to identify areas of increased bone density, which may provide increased fixation opportunities.[31] When virtual planning software anticipates that primary fixation along the anatomic center line could be insufficient, modifying the surgical plan to use the alternative center line will help guide the surgeon as to the starting point on the glenoid face, as well as the modifications required in glenoid version and inclination (Fig. 4). Furthermore, the use of a patient-specific guide can be quite useful in optimizing the central drill path based on the surgical plan. Using 3-dimensional models during surgery can further assist in confirming the appropriate path and may facilitate glenoid bone graft preparation.

In cases in which primary glenoid baseplate fixation is compromised, secondary fixation from glenosphere load sharing can be used to help minimize micromotion of the glenoid baseplate. Load sharing occurs when additional implant-bone contact is created between the glenosphere and the host glenoid. A Sawbones testing model (Sawbones, Vashon Island, WA, USA) using the implant system from this study showed that a glenosphere with a 10-mm lateralized center of rotation successfully managed glenoid bone loss $\leq$50% with standard techniques and

Table II Comparison of PROMs, range of motion, functional internal rotation tasks, and radiographic outcomes based on glenoid placement

	Standard	Alternative	*P* value
Mean PROM improvement			
SST score	5.1 ± 3.4	4.0 ± 3.3	.209
ASES score	40.7 ± 31.3	41.7 ± 20.6	.885
VAS pain score	3.5 ± 4.2	5.5 ± 2.9	.052
SANE score	41.1 ± 30.2*	33.2 ± 26.3	.350
PROM at most recent follow-up			
SST score	6.9 ± 3.4	6.8 ± 3.4	.829
ASES score	68.0 ± 27.1	71.3 ± 19.1	.601
VAS pain score	2.4 ± 3.0	1.1 ± 1.9	.068
SANE score	68.4 ± 28.8*	71.7 ± 22.5	.674
Active motion at most recent follow-up			
Forward elevation, °	117 ± 34	119 ± 31	.817
External rotation, °	35 ± 22	34 ± 16	.942
Internal rotation,† points	4.8 ± 2.6	5.5 ± 2.9	.269
Functional internal rotation task			
Reach small of back (0, no; 1, yes)	0.48 ± 0.51	0.45 ± 0.51	.857
Wash back‡	1.0 ± 1.1	0.74 ± 0.87	.260
Perform toileting‡	2.2 ± 1.1	2.2 ± 0.96	.759
Radiographic outcome, n (%)			
Acromial fracture	2 (3.0)	2 (9.1)	.242
Any scapular notching	10 (15.2)	4 (18.2)	.736
Any glenoid loosening	0	0	—

PROM, patient-reported outcome measure; *SST*, Simple Shoulder Test; *ASES*, American Shoulder and Elbow Surgeons; *VAS*, visual analog scale; *SANE*, Single Assessment Numeric Evaluation.

Data are presented as mean ± standard deviation unless otherwise indicated.

* Data missing for 10 patients.

† Internal rotation conversion scale: buttock to greater trochanter, 2 points; sacrum to L4, 4 points; L1-L3, 6 points; T8-T12, 8 points; and T1-T7, 10 points.

‡ Functional score scale: unable to do, 0 points; very difficult, 1 point; somewhat difficult, 2 points; and not difficult, 3 points.

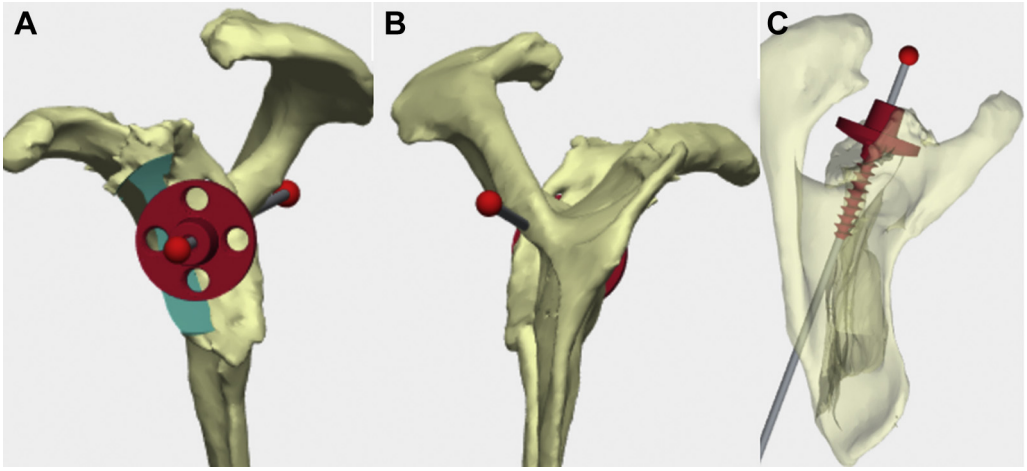

Figure 4 (**A**) Virtual planning representation of alternative center line showing glenoid-face view with baseplate coverage. (**B**) Medial scapular view showing baseplate trajectory into remaining column of bone. (**C**) Superior view showing anteversion of baseplate.

without increasing the micromotion above the 150-μm threshold standard for osseous integration. Nigro et al[27] performed a finite element analysis of micromotion and stress between the glenoid baseplate and host bone, evaluating the impact of glenosphere contact with the native glenoid. Both stress and micromotion were reduced

significantly when the glenosphere contacted the native glenoid. One must be cautious in using this glenosphere load-sharing technique, as optimizing glenosphere contact on the host glenoid can limit the ability to properly engage the Morse taper between the glenosphere and the baseplate. Incomplete seating of the glenosphere can subsequently result in glenosphere dissociation. In our series, larger glenospheres with more medialized centers of rotation were used for the alternative center line patients with severe glenoid bone loss to maximize fixation using the remaining host glenoid, minimize micromotion with less lateralization of the center of rotation, and provide the opportunity for secondary fixation through load-sharing contact with the larger glenosphere.

Although glenoid baseplate fixation in the alternative center line group yielded similar, low rates of scapular notching and no early signs of loosening, 2 patients (9%) sustained a type III acromial stress fracture. Use of the alternative center line necessitates anteverting the glenoid baseplate and directing the fixation toward the scapular spine. Although this may theoretically increase the risk of type III fractures, no statistical difference was observed in our cohort comparison. With a small sample size and a low overall incidence of type III fractures, this study is underpowered to make conclusions regarding acromial fracture risk. However, previous studies have investigated the influence of surgical technique on acromial or scapular fractures after RSA.[1,6,16,22,28] Although Otto et al[28] noted that 14 of 16 scapular spine fractures observed after RSA were associated with a glenoid baseplate screw, anteverting the baseplate (using the alternative center line) was not shown to increase the risk of fracture. Crosby et al[6] hypothesized that the superior metaglene screws used with the Equinoxe Reverse Total Shoulder Arthroplasty system (Exactech, Gainesville, FL, USA) act as stress risers and lead to propagation of scapular fractures, and they later demonstrated a lower fracture risk and incidence by avoiding superior screws altogether.[14] Use of short superior locked screws or nonlocked screws directed away from the scapular spine is a strategy that can be used to avoid these fractures. Because fixation opportunities in severe glenoid bone loss are often limited, the superior screw is often used in these cases. Further investigation of the impact of baseplate version on acromial fractures is needed, as our study did not observe differences in the incidence between the 2 cohorts.

The strengths of this study relate to the study design with well-matched cohorts, as well as the use of the same implant system in all patients. This study is not without limitations. First, virtual planning and patient-specific instruments were available only for the more recent patient cases. The use of this technology helps surgeons study an individual's glenoid defects and direct placement and fixation of the central screw and baseplate into sufficient bone. In addition, postoperative computed tomography scans were not available to confirm the placement and fixation of the glenoid baseplate as intended. Finally, as this study was a single-surgeon series using a single type of prosthesis, the results may not be extrapolated to practitioners who either use other reverse shoulder devices or have less experience. The implant design in this study consisted of a monobloc central compression-screw baseplate and glenospheres with centers of rotation lateral to the glenoid. Surgical techniques may need to be altered based on varying baseplate and glenosphere designs. Nonetheless, with low rates of acromial fractures and scapular notching, the study may suffer from a lack of power to detect significant differences in complications. Finally, although the results are encouraging for these techniques in the 2-year period assessed, longer follow-up is necessary to evaluate radiographic changes, bone graft absorption, and whether the clinical outcomes can be maintained.

Conclusion

The use of the alternative center line for glenoid baseplate fixation appears to have the same clinical improvement and functional results as those in patients treated with the standard anatomic center line. With low rates of complications, alternative center-line placement does not diminish clinical outcomes and can be effectively used in patients with severe bone loss to achieve stable baseplate fixation.

Disclaimer

Jonathan C. Levy is a paid consultant for DJO Orthopaedics and Globus Medical and receives royalties from DJO Orthopaedics, Globus Medical, and Innomed.

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